NOORUL ISLAM COLLEGE OF ENGINEERING, KUMARACOIL

BRANCH NAME: - AERONAUTICAL ENGINEERING

AE 1301- FLIGHT DYNAMICS

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PART-A

Short questions and answers (Module-I & II)

1) What is the need to define ISA and give its values at standard sea level condition?

Ans: Since atmospheric conditions like pressure, temperature and density are constantly varying with altitude and location of the earth surface, there is a need for a normal atmosphere to use it as standard for the design and flight evaluation of aircraft all over the world. Its standard sea level values are, pressure = 1.013 $\times 10^5$ N/m2, temperature =288K, and density =1.225 kg/m3.

2) Distinguish between Troposphere & Stratosphere.

	Troposphere	Stratosphere
(a)	It extends from earth surface to around 11km altitude.	It extends from troposphere to about 50 km altitude.
(b)	It is a turbulent region and its temperature decrease linearly at the rate of 6.5^{o}C/km (288K to 216K at 11km)	Its temperature remain constant upto about 25km and then increases upto 47km at the rate of 3^{o}C/km. At 47km to 53km, temperature remains constant at 282K.

3) Define Geometric and Geopotential altitudes. Give the relation between 'g' at the Absolute altitude (h_a) in terms of earth's surface gravity (g_o) and geometric altitude (h_g) and radius of earth (r).

Ans: Geometric altitude (hg) is the physical altitude above the sea level .Geopotential altitude (h) is the fictious altitude and differs from geometric altitude (hg) and is physically compatible with the assumption of constant acceleration due to gravity (g_o), ie; $h = (g/go)^{0.5}$ hg.

The ratio of acceleration due to gravity at an altitude ha, to that on the earth surface (go) is : $g/go = (r/ha)^2$, ie, $g = go\,(r / (r+hg\,))^2$

4) Derive from 1st principle the variation of pressure (dp) in ISA with respect to the variation of Geometric altitude (dh_g) .

Ans: Assume an air column of height dh_g and unit base area as shown in fig. The 3 forces acting on the tiny air column are,

$(p+dp)\,1 + \rho g dh_g = p.1$, ie , $dp = -\rho g dh_g$

5) Define the terms (a) Pressure altitude (b) Temperature altitude (c) Density altitude.

Ans: If an aircraft senses the actual outside air pressure which corresponds to some standard altitude ,then that altitude is called pressure altitude .Similarly if an aircraft senses the actual outside temperature and density which corresponds to some standard altitude , those are called temperature altitude and density altitude respectively.

6) What are the factors which decide the flying path of an airplane as a rigid body?

Ans: Airplane as a rigid body its flying path is decided by ,

a) Its inertia characteristic.
b) Earth's acceleration due to gravity
c) Propulsive force generated by power plant
d) Aerodynamic forces (L&D) and moments created on it due to the reaction between airplane and air.

7) Why the airplane is considered as a dynamic system in six degrees of freedom? What are the conditions to be satisfied for equilibrium along a straight unaccelerated flight path?

Ans: Airplane motion in air can be completely defined only if six velocity components (linear velocities u,v,w along X,Y,Z axes and angular velocities p,q,r about X,Y,Z) are given . Hence airplane is considered as a dynamic system in six degrees of freedom. For equilibrium along a straight unaccelerated flight path, the equation of static applied to each degree of freedom must be satisfied:

ie; $\sum Fx = 0$, $\sum Fy = 0$, $\sum Fz = 0$

$\sum L = 0$, $\sum M = 0$, $\sum N = 0$

8) What is plane of symmetry of airplane and define symmetric and asymmetric degrees of freedom?

Ans: Plane of symmetry of airplane is the X-Z plane that divides it into two symmetric halves. Symmetric degrees of freedom are those components of motion related to airplane's longitudinal motion .They are motions along X and Z axes and about Y-axis . Asymmetric degrees of freedom are those components of motion related to airplane's lateral motion. They are motions along Y- axis and about X and Z axes .

9) What will decide the lateral (asymmetric) degrees of freedom and define directional stability and dihedral effect.

Ans: Lateral degrees of freedom of an airplane is decided by the direction of relative wind to the plane of symmetry . This angle is called sideslip (β) and the airplane is designed to resist the development of sideslip during all normal flight maneuvers .The ability of the airplane to create yawing moments that tend to eliminate any sideslip is called directional stability (sometimes called **weathercock stability**). The rolling moment created because of sideslip is referred to as dihedral effect . The second type of static lateral stability is associated with the dihedral effect .

10) Define compressibility of fluids and what decides the speed of propagation of small pressure waves in fluids ?

Ans: Compressibility of fluids (K) is defined as the reciprocal of bulk modulus of fluids ;or it is the volumetric strain (dv/v) developed per unit change in pressure. ($K = -(dv/v)/dp$) .Speed of propagation of small pressure waves (sound waves) is dependent on the elastic property (bulk modulus) of the fluids . Speed of propagation of sound wave is $a = \sqrt{(dp/d\rho)}$, where dp &$d\rho$ are change in pressure and density .

11) How the sound waves travel in gases and give the expression for the speed of sound in gases?

Ans: Sound waves travel in gases as a series of adiabatic compressions and rare fractions and hence the expression for the speed of sound waves is $a = (\gamma(dp/d\rho))^{0.5} = (\gamma p/\rho)^{0.5} = (\gamma gRT)^{0.5}$.

12) What are the different power plants used in airplanes? Which power plant is most efficient for subsonic airplanes .

Ans: Latest power plants used in airplanes include; propeller driven by reciprocating engines as well as turbines , turbojets ,ramjet and rockets .Here other than rockets all other power plants are using air-breathing engines. Turbojet power plants are most efficient for subsonic airplanes compared to Turboprop, ramjet and rockets. Ramjet and rockets are efficient for short duration supersonic flights whereas turbo propellers are less efficient and can be used only at low speed.

13) Write down the major differences between the turboprop and turbojet engines in generating the propulsive power

Ans: In airplanes using turbo propeller system, out of total useful work done to propel the airplane , 80-95% is derived from the propeller and the reminder only from the exhaust jet reaction . In typical turboprop system, power($P= TV$) is nearly constant and hence thrust (T) decreases as speed (V) increases. In turbojet propulsion system, the total useful work done to propel the airplane is produced by the expansion of the combustion gases through exhaust nozzle. Thrust is made nearly constant by increasing the mass flow rate (kg/s) at high speed (V) .

14) What are the conditions for minimum drag and minimum power required for an airplane? Mention them in drag coefficients also.

Ans: Minimum drag (D) occurs when L/D or C_L/C_D is a maximum .It occurs when parasite drag = induced drag or when $C_{Df} = C_L{**2}/\pi Ae$.

Minimum power (P_{min}) occurs when the parasite power is 1/3 of Induced power .In the drag coefficient form $C_{Df} = 1/3(C_L{**2}/\pi Ae)$.

15) What causes induced drag?

Ans: Induced drag is an unavoidable by-product of lift and it increases as the angle of attack (∞) increases . Up to a critical angle of attack (∞_c at which C_{Lmax} occurs) both lift and induced drag increases . Since there are two types of lift (dynamic & induced lift) , there are two types of drag also ; dynamic drag and induced drag . Above ∞_{cr} ,lift will decrease and drag will overcome the thrust causing reduction of speed and altitude.

16) Define skin friction drag and pressure drag.

Ans: Drag caused by the shear force (viscous flow) in the boundary layer is called skin friction drag . The drag caused by the pressure variation over and below the surface of the wing is called pressure drag. It is caused by flow of high pressure air from under the wing to over the wing .Sum of the above two drags are called profile drag. All drags other than induced drag is called parasite drag.

17) What are the conditions required for maximum drag and minimum power?

Ans: Maximum drag occurs when the angle of attack exceeds the critical angle of attack and the speed approaches the stalling speed . The left hand limit of P_R versus Vcurve shows the stalling speed corresponding to maximum lift (C_{Lmax}) and maximum drag.

Minimum power occurs at the speed at which total power(P_R) is minimum .This occurs when parasite drag is 1/3 of induced drag .In drag coefficient form, $C_{Df} = 1/3(C_L{**}2/\pi Ae)$.

18) Explain the significance of load factor.

Ans: Load factor (n) is defined as the lift (L) divided by the weight (W) at the stalling speed corresponding to C_{Lmax} . Any attempt to increase the lift by further increasing the angle of attack will result in the reduction of C_L and increase of C_D . This will result in increase of thrust required to maintain the flight at lower speed . Hence a load factor of 1, at C_{Lmax}, only feasible provided enough power is available.

19) Plot the variation of power available (P_A) with flight speed (V) for a propeller powered airplane and indicate the effect of altitude on the curve.

Ans: Firm line (P_{AO}) on the P_A versus V graph shows the power available at sea level for a propeller powered airplane .The dotted line $P_A\sigma$ shows the power available at an altitude where the density ratio, $\sigma = \rho$ of air at altitude/ ρ of air at sea level ,

$P_A\sigma = P_{A0} * \sqrt{\sigma}$.

20) How load factor (L/W) is related to bank angle?

Ans: During turning, the bank angle (φ) is related to Lift (L) and weight (W) as follows:

$$L \, Sin\varphi = C.F = \frac{W}{g}\frac{v^2}{R}.$$

$$\text{i.e, } Sin\,\varphi = \frac{v^2}{gR}\frac{W}{L} = \left(\frac{v^2}{gR}\right)\frac{1}{Loadfactor}$$

Hence bank angle (φ) decreases when load factor (L/W) increases.

21) Define service and absolute ceiling.

Ans: The system of P_R and P_A versus V curves, both at sea level (o) and altitude (σ) are fundamental in determining climb and decent performance of airplane. Minimum and maximum speeds (absolute ceilings) are determined by the intersection of the two curves (P_R and P_A) taken for the same altitude . Any speed between the maximum and minimum ceiling speeds can be the service speed . Sometimes in altitude flight, the minimum speed will be higher than the stalling speed and hence the stalling speed cannot be achieved in level continuous flight.

22) What is the compressibility speed correction of airplane and how Vcorr is related to true speed V?

Ans: At or near the critical mach number (Mcr) of the air plane , the drag increases at a greater rate than the parabolic variation . Speed correction curves (thrust constant) at different altitudes are available . A correction speed Vcorr is obtained from the chart for any incompressible speed ,V. By the assumption of constant thrust for turbojet between V and Vcorr ,the V can be related to Vcorr as follows:

T = D ie; C_D. q. S = C_{Dcorr}.q_{corr}.S. Hence V = Vcorr $\sqrt{(C_{Dcorr}/CD)}$.

23) How the speed correction (Vcorr) due to compressibility effect is related to incompressible speed (V) when speed, altitude, t/c ratio and C_L increases.

Ans: For a specific V, Vcorr will be lesser than V and the deviation increases with the speed , increase in t/c ratio and C_L . For each case Mcr is the upper limit. Above specified deviations between V and Vcorr are further enhanced in higher altitude .

From constant power curves , Vcorr is related to V as follows :

$V = V_{corr}(C_{Dcorr}/C_D)^{0.333}$.

24) Define range and endurance of an airplane.

Ans: For an airplane-engine combination, the range (R- km) may be determined By multiplying the total fuel (F-kg) available by the average km traveled per kg of fuel consumed .

ie; R (km) = F(kg) * (km/kg)

Similarly for an airplane –engine combination, the endurance (E-hrs) may be computed by dividing the total fuel (kg) available by the average consumption of fuel in kg/hr .

ie ; E (hrs) = F (kg) /(kg/hr)

25) For turbojet driven airplane at what $V/V_{L/Dmax}$ β_{min} or Ψ_{max} occurs . Also for the turbo-propeller driven airplane at what $V/V_{L/Dmax}$, R/C_{max} or R/S_{min} occurs.

Ans: For turbojet driven airplane , from the $T_A/T_{L/Dmax}$ versus $V/V_{L/Dmax}$ curve , it is found that at β_{min} or Ψ_{max}, the value of $V/V_{L/D_{MAX}} = 1$.

Similarly for the turbo-propeller driven airplane from the $P_A/P_{L/Dmax}$ versus $V/V_{L/Dmax}$ curve, it is found that at R/C_{max} or R/S_{min} , the value of $V/V_{L/Dmax}$ is equal to 0.76 .

26) Draw T_R versus V graph of turbojet airplane and indicate V_{maxE} and V_{maxR}.init.

Ans: V_{maxE} is the minimum TR point on the graph.

V_{maxR} is the tangent point on the graph.

27) Draw P_R versus V graph of turbo propeller airplane and indicate V_{maxE} and V_{maxR}. in it .

Ans: V_{maxE} is the minimum P_R point on the graph .

V_{maxR} is the tangent point on the graph.

28) What are the conditions for maximum endurance of a jet powered airplane?

Ans: Equation for maximum endurance (Emax) for jet powered airplane is:

Emax = (1/c)*(L/D)max * ln (Wo/W1)

For maximum endurance: 1) c(1/hr) should be small

2) $(L/D)_{max}$ should be high .

3) (Wo/W1) mass ratio should be high.

29) What is the condition for R_{min} for turning an airplane in level flight? Also give the time (t) for 360^0 turn in terms of V and tanø (ø-turning or yawing angle).

Ans: Considering the turning banking angle as ø, tan ø= V^2/R.g ,

ie ; R = V^2/g tan ø . For Rmin ; 1) V should be small, approaching to V_{stall}.

2) tan ø should be high .

Time for 360^0 turn (t) = 2πR/V =2ΠV/g tan ø.

30) What is the impact of acceleration in R/C as compared to non-accelerating climb?

Ans: Angle of climb (γ) is related to R/C as Sin γ = (R/C) /V.

Also Sin γ =(T-D-F1)/W (where T is thrust , D- drag and F1 –inertia for acceleration), then R/C (m/s) = V(T-D-F1)/W --(1)

And R/C without acceleration =V(T-D)/W --(2)

If acceleration is not considered (2), the R/C will be higher than R/C with acceleration (1). That is the time to climb to a particular altitude will be higher by 25 – 30% than that of without acceleration .

31) Show by graphical solution of range (R), what is the additional fuel(dF) required to get the same range when empty weight is increased by (ΔW).

Ans: For keeping the range (R) same, the additional fuel (dF) required when empty weight of airplane is increased by ΔW , can be find out by equating area

A1= A2 , ie; C1.dF =C2. ΔW

(where C1 and C2 are the range per kg at the start and end of flight .C2 will be higher than C1.

Then dF = ΔW* C2/C1 , ie; dF is greater than ΔW .

<u>Short questions and answers(Module-III)</u>

32) What is meant by control of an airplane, how longitudinal, roll and directional controls are provided in airplane.

Ans: When an airplane is stable, it is necessary for the pilot to be able to control it, so that he can maneuver it into any desired position.

Longitudinal control is provided by the elevator, ie; flaps hinged behind the tail plane. Roll control is provided by the ailerons, ie; flaps hinged at the rear of the Aero foils near each wing tip. Directional control is provided by the rudder, ie; a vertical tail hinged to the stern post .

33) What is meant by stability of an airplane and what way it is different from Balance?

Ans: The stability of an airplane means its ability to return to some particular condition of flight , after having disturbed from that condition ,without any effort by the pilot. The stability is often confused with the balance or equilibrium of an aircraft .For eg: when an airplane flies with one wing lower than the other may often ,when disturbed from that attitude ,return to it . Such an airplane is out of its balance or trim, but it is stable . Stability is sometimes called inherent stability .

34) Define the three conditions of stability.

Ans: There is a half-way condition between stability and instability. If the airplane on disturbance tends to move father away from its original position, it is unstable. If it comes back to its original position, then it is in stable condition. But sometimes the airplane may tend to do neither of the two and prefer to remain in its new position. This condition of airplane is called neutral stability.

35) With the help of C_m vs C_L curve of an airplane, state the stable, neutral and unstable conditions of it.

Ans: Draw a graph with Cm on Y axis and C_L on X axis . In Y axis, represent Cm =0 above origin to indicate both positive and negative Cm values.

Line (1)&(2) in which $dCm/dC_L \geq 0$ shows unstability or neutral stability

Line (3) in which $dCm/dC_L \leq 0$ stability .

When Cm = 0, the airplane is in equilibrium.

36) What are the two methods for predicting fuselage contribution to longitudinal stability of airplane? Write down the formulae for simpler method and explain the terms in it.

Ans: Methods for predicting fuselage contribution to longitudinal stability are

(a) Computational method by dividing the fuselage ito many sections (b) A

Shorter method for which the following formulae is used.

$(dCm/d\,C_L)_{fus} = (K_f\ W_f^{**}2\ L_f)/S_w\ c\ a_w$

(where Lf is the over all fuselage length ,Wf is its maximum width and Kf is an empirical factor developed from experimental evidence . It depends entirely on the wing root chord's position on the fuselage.

37) Define neutral point.

Ans: It is the limit of the centre of gravity of the airplane at which the static longitudinal stability becomes neutral $(dCm/dC_L) = 0$. This stability criterion of the airplane (ie; neutral point) will be different at different operating conditions like, stick-fixed with and without power ,stick free with power. Also there is aft c.g limit as well as forward c.g limit . Between these limits of neutral points only the airplane c.g can be allowed to shift during all maneuvering conditions of airplane in order to maintain longitudinal stability.

38) What is the criterion for static longitudinal stability?

Ans: For static longitudinal stability of the airplane (AP) the over all value of $(dCm/dC_L)_{AP} \leq 0$. This rate of change of coefficient of moment about Yaxis (dCm) with respect to the change in lift coefficient (dC_L) is the summation of similar values contributed by different parts of airplane , like ,wing ,fuselage , engine power, tail/elevator etc. Some of them are positive and others are negative. The cumulative effect should be such that over all value should be negative (ie; $(dCm/dC_L)_{total} \leq 0$) .

39) State two contributions for static longitudinal stability and indicate them with a plot .

Ans: In Cm versus C_L plot indicate the longitudinal stability contributions of wing And fuselage, tail alone and the total for airplane. If the total longitudinal stability which is the sum of individual contributions is negative $(dCm/dC_L) \leq 0$ then the airplane will be stable .

40) Briefly define wing`s vortex system with figure.

Ans: Wing`s vortex system can be represented as shown in figure, consisting of `bound vortex ` located at the wing quarter chord (0.25 c) and a vortex sheet streaming from the wing trailing edge, which will roll up to form the familiar two trailing vortices . The wing wake center line which is in the vortex sheet is displaced downward and deformed by the influence of the bound vortex and the powerful trailing vortices . The strength of the vortex system is proportional to the C_L therefore the downwash (€) at any particular point will be proportional to C_L . ie; € = f(C_L) .

41) What is Neutral point (N_0) of an airplane at stick fixed and power-off condition. Show the new position of 'N_0' at power-on condition relative to the earlier N_0.

Ans: The aft position of c.g of the airplane obtained by equating the static longitudinal stability equation $(dCm/dC_L)_{total}$ to zero , with the contribution for stability at stick-fixed and power –off condition added to it. This c.g limit at aft end with stick-fixed and power-off gives the limit for the stability . The new position of the airplane neutral point No` at power-on condition will be towards the forward side of the No, since the contribution to stability by the power effect is slightly destabilizing .

42) What are the two major effects of the running propeller that contribute to the Longitudinal stability and define them .

Ans: Two major effects are (1) Direct propeller contribution arising as a result of the forces created by the propeller itself . (2) Indirect effects which arises as the result of the slip stream from the propeller and its interaction with the wing and tail surfaces .Propeller forces ,both thrust (T) and normal force(Np) create moments about c.g of the airplane and hence they have stability contribution $(dCmp/dC_L)$ which influence the over all static longitudinal stability.

43) What are the major contributions of the indirect effects of the running propellers on the static longitudinal stability ?

Ans: There are 4 major contributions making up the indirect effects of the running propellers on static longitudinal stability . They are the effects of slip stream created by propeller on the following :

a. effect of slipstream on wing-fuselage moments
b. effect of slipstream on wing lift coefficient (C_L)
c. effect of slipstream downwash at the horizontal tail
d. effect of increased slipstream dynamic pressure (q) on the tail.

44) Define elevator power and write down the elevator power criterion equation

Ans: The magnitude of pitching moment coefficient, Cm, obtained per degree deflection of the elevator is termed as the elevator power .It is the derivative of Cm w.r.t elevator deflection ($dCm/d\delta e = Cm_\delta$)

The elevator power criterion is mentioned below $dCm/d\delta e = Cm\delta$

45) What are the direct propeller contributions to S.L.S arising due to the forces created by propeller and write their simple forms in terms of (h/c) and (lp/c).

Ans: Direct propeller contribution to S.L.S arising due to forces (T and Np) created by propeller are thrust (T) contribution $(dCmp/dC_L)_T$ and the normal Force (Np) contribution $(dCmp/dC_L)_{NP}$.

$(dCmp/dC_L)_T = 0.25\ h/c$

if c.g of airplane is above thrust line (h/c is +ve), ($dCmp/dC_L$) is positive and hence destabilizing . If thrust line is above c.g (h/c is –ve),($dCmp/dC_L$) is negative and hence stabilizing .Simlarly $(dCmp/dC_L)_{NP} = 0.02 l_p/c$.

46) Briefly explain the c.g limits with the help of a figure and what decides the anticipated c.g travel of the airplane.

Ans: Between stick-fixed power-on condition neutral point (No) and forward c.g limit at $C_L max$ landing condition ,the c.g of airplane can travel. More c.g range required , the more powerful will be the elevator. It can be seen that anticipated c.g travel of the airplane is decided by the elevator and the horizontal tail .

47) How the most forward c.g limit of the airplane is fixed?

Ans: An indication of the most forward c.g permissible comes from the elevator theory. That is from the requirement that the elevator must always be capable of bringing the airplane into equilibrium at $C_L max$ attainable by it. As the c.g moves forward ,the airplane becomes more stable and more up-elevator is required to trimout C_{Lmax} . Obviously some forward c.g , the elevator will be just powerful enough to attain equilibrium at C_{Lmax}.

48) Write down the expression for the maximum stability attainable by the elevator using its maximum up-elevation .

Ans: The expression for the limiting stability can be obtained by substituting δ_{emax}

and C_{Lmax} in the eqation given below :

Elevator up- deflection $\delta_e = \delta_{eo} - (dCm/dC_L) C_L/C_{m\delta}$ and solving for

$(dCm/dC_L)_{max} = (\delta_{eo} - \delta_{emax}) C_{m\delta} / C_{Lmax}$.

(where δ_{eo} is the elevator angle at zero lift and $C_{m\delta}$ is the elevator power .)

49) How the forward c.g limit is restricted by the ground effect or for landing maneuvers .

Ans: The forward c.g location is limited by the influence of the ground on the downwash during landing. The variables that will be altered by the ground effect are wing`s angle of attack (α_w) ,elevator power ($C_{m\delta}$) due to increase in $a_t = dC_{Lt}/d\alpha_t$ and $d\epsilon/ d\alpha_t = \tau$, the elevator effectiveness .

50) Write the total elevator hinge moment coefficient equation and define the components it .

Ans: Elevator total hinge moment coefficient (Ch) equation can be written as:

$Ch = \ \ +Ch_\alpha \alpha + Ch_\delta \delta$

Ch_o –is the hinge moment coefficient term at zero angle of attack.

Ch_α – the partial derivative of hinge moment coefficient w.r.t angle of attack of the tail $= \partial Ch/\partial\alpha$

Ch_δ - the partial derivative of hinge moment coefficient w.r.t control surface (elevator) deflection $= \partial Ch_\delta/\partial\delta$

Since most control surfaces (elevator) are symmetric airfoil sections the Term Ch_o will not be included unless specifically asked for.

51) What is meant by aerodynamic balancing control surface and how it is most frequently done?

Ans: Methods for controlling the parameters Chα and Chδ (partial derivatives of hinge moment coefficients with respect to α and δ) are called aerodynamic balancing control surfaces . One of the most frequently used methods is the set-back hinge. In this ,by suitable mechanism the hinge line is moved aft such that the sum of moments about the hinge line will become smaller .

52) What is a tab and how it is effective?

Ans: Tab is a control surface and is an auxillary flap usually built into the trailing edge of the main control surface . Because of its location, it can create very powerful moments about the control surface hinge line. It is used as a trimming device,a balancing device and in some cases as a primary control surface.

53) Get a relation for the control surface floating angle of an elevator fitted with tab also .

Ans: Assuming linearity for the hinge moment coefficients, the total control surface hinge moment coefficient (Ch) can be written :

$Ch = Ch_{\alpha}\, \alpha + Ch_{\delta e}\, \delta e + Ch_{\delta t}\, \delta t$

At the floating balanced condition, Ch = 0, and $\delta e = \delta_{float}$

Ie; $\delta_{float} = -\ (Ch_{\alpha} / Ch_{\delta e})\, \alpha - \ (Ch_{\delta t} / Ch_{\delta e})\, \delta t$

which indicates that deflecting the tab can change the control surface floating angle .

54) How the effect of freeing the elevator changes the tail contribution to the longitudinal stability ?

Ans: The effect of freeing the elevator enters the tail term of the longitudinal stability as a multiplying factor ($1- \tau\, (Ch\alpha/ Ch\delta e)$). If an elevator has a large floating angle , $(Ch\alpha/ Ch\delta e)$ will be large and positive .Then the stability contribution of the horizontal tail can be reduced sufficiently . For eg: if $(Ch\alpha/ Ch\delta e) = 2$ and $\tau = 0.5$, the floating of the elevator can make the whole tail contribution of stability zero. This shows the importance of careful elevator balance design to ensure proper hinge moment characteristics and thereby good stick-free stability can be readily appreciated .

55) What is the effect of gradient of stick-force with velocity on the stability of the airplane ?

Ans: The gradient of stick-force (Fs) with velocity is extremely important, as it plays a major role in determining the pilot`s feel of airplane stability . A large gradient (dFs/dV) will tend to keep the airplane flying at constant V and will resist the influence of disturbance towards changing V. It also enable the pilot to bring the airplane to trim easily and will not require a lot of pilot attention to hold the given Vtrim .

56) What are the two methods in determining the stick-free neutral point (No`) and

define them .

Ans: Both methods are through flight test data evaluation .In 1st method , the non-dimensional stick force equation (Fs/q) is differentiated w.r.t to C_L and equate to zero. The c.g position for $d(Fs/q)/dC_L = 0$ will give the neutral point. It can be seen that (No`) will decrease with increase of $C_L$ .In the second for getting neutral point (No`) is to obtain flight curves of tab angle (δe) to trim (Fs=0) versus speed for different c.g positions. The slope of α_t vs C_L is a function of stick-free longitudinal stability criterion and the neutral point (No`) is the c.g position when $d\delta_t /dC_L =0$.

57) What are the commonly used gadgetries for improving stick force gradient?

Ans: There are a few new devices now available for giving constant pull force on the stick . The most common of them are the down spring and bob weight, vee tab or spring tab. The down spring and bob weight are not very effective in ground operation where as the spring tabs are more efficient in giving a constant torque about the hinge line of the elevator.

58) What is the restriction on the aft c.g imposed by the stick-free neutral point (No`) ?

Ans: The concept of stick-free neutral point (No`) is that c.g location where $(dCm/dC_L)_{free} = 0$ or where $dFs/dV = 0$ through trim speed where Fs=0. This brings a new restriction on the aft limit of the allowable c.g range . At present the Army and Navy call only for the most aft c.g to be ahead Of the stick-free neutral point (No`).
(Show the new aft limit of c.g (No`) and usable c.g range in a figure usually used .)

59) What are the two important maneuvering flights and their essential requirements?

Ans: Flight in curved paths are called maneuvering flight . Two important maneuvering flights (a) that taking place in vertical plane passing through the plane symmetry of air plane called pull-up maneuvering (b) that taking place in horizontal plane called normal turn. In (a) , the net upward force (L-W) act as the pull-up force perpendicular to the curved path .In (b) the resultant of lift vector in the horizontal plane perpendicular to the flight path act as the centripetal force .

60) Define stick-fixed maneuvering point (Nm) and stick- free maneuvering point (Nm`) .

Ans: If the c.g is moved aft behind (No) and (No`), the stability in accelerated flight will be reduced until at some c.g position the change in elevator angle ($d\delta_e$ ) and the stick force (Fs) required to accelerate flight will be zero. These c.g`s are termed as the maneuvering points .The c.g where the elevator angle (δ_e) required to accelerate the airplane vanishes is the stick-fixed maneuvering point (Nm) and the c.g where Fs required to accelerate the airplane vanishes is the stick- free maneuvering point (Nm`) .

61) What is the criterion for longitudinal stability and control in maneuvering flight?

Ans: The increment of elevator angle ($\Delta\delta_e$) and stick force (ΔFs) to produce an increment in normal acceleration equal to 1g at constant speed ,both in pull-ups and in steady turn is the criterion for longitudinal stability and control in maneuvering flight . That is ($d\delta_e/dn$) and (dFs/dn) are criterion .

62) Define stick- fixed maneuvering point (Nm) and where it is located with reference to neutral point at stick-fixed (No) .

Ans:As the airplane c.g is moved aft of (No) , the gradient ($d\delta_e/dn$) continues to reduce until at some c.g position it vanishes. This c.g position at which $d\delta_e/dn = 0$ is termed as the stick- fixed maneuver point (Nm). Since Nm – No= $(dCm/dC_L)_{fix}$, the Nm is aft of No . The difference between Nm and No is the greatest at sea level and for light wing loads $(W/S)_{min}$.

63) Define stick- free maneuver point (Nm`) and where it is located with reference to neutral point at stick –free (No`) .

Ans: The gradient of the stick force (dFs /dn) do not vanish at stick –free neutral point (at $(dCm/dC_L)_{free} = 0$) but shows that , if c.g is moved sufficiently aft of No` , a position will reach where dFs/dn =0 . This c.g position is termed as stick-free maneuver point (Nm`) .

64) What are the restrictions on the c.g travel imposed by the gradient of stick force

per g in modern airplane ?

Ans: The upper limit or lower limit of stick-force per g (dFs/dn) required for modern airplanes imposed further restriction on the c.g travel of the airplane for maintaining S,L,S .The forward c.g is limited to max: gradient dFs/dn and the aft c.g is limited by the min: gradient of the same. However it is found that the stick-free neutral point (No`) comes between these two .

65) What is the final c.g travel limit of the airplane for S.L.S considering the flight upto stick-free conditions ?

Ans: The critical limits on airplane`s c.g are :

1) On the forward c.g,
   (a) Maximum gradient ,stick force per g $(dFs/dn)_{max}$
   (b) Elevator required to land at C_{Lmax}

2) On the aft c,g :
   (a) Power –on stick-free neutral point (No`)
   (b) Minimum gradient, stick force per g $(dFs/dn)_{min}$

The usable c.g range is between $(dFs/dn)_{max}$ point and power-on stick-free Neutral point (No`)

Short questions and answers(M4 & M5)

66) What is meant by dihedral effect?

Ans: The angle that the relative wind makes with longitudinal axis of airplane is called sideslip . This sideslip (β) alters the wing's span wise lift distribution to create a net rolling moment . This rolling moment due to sideslip is termed as dihedral effect . It is the measure of change in rolling moment coefficient (dCl) per degree change in sideslip ($\beta = -\psi$ for straight flight path).

ie; dihedral effect = $dCl/d\psi$ or $Cl\psi$ (+ve for stable)

67) Define power of lateral or aileron control.

Ans: The power of lateral or aileron control will be expressed as the change in rolling moment coefficient per degree deflection of the ailerons . It is expressed as $dCl/d\delta_a$ and it acts in such a way that to counter balance the dihedral effect so that the wings can be held level from straight flight or maintained at some equilibrium angle of bank (Φ) during turn .

68) What are the basic requirements that are to be fulfilled by the lateral control system?

Ans: The basic requirements that determine the size of the control and amount of aerodynamic balance are (a) it should be large enough to provide sufficient rolling moment at low speeds to counteract the unbalance tending to roll the airplane ;(b) the second requirement is that it roll the airplane at a sufficiently high rate at high-speed for a given stick force .

69) What is meant by aileron reversal speed?

Ans: The deflection of the aileron will create a pitching moment tending to twist the wing . When the wing twists it rotates in a direction tending to reduce the rolling moment created by the aileron. When the speed is high enough, a point can be reached where the wing twist will just counter the aileron rolling moment and lateral control will be lost. This speed is known as the aileron reversal speed. Hence designer should ensure that wings are sufficiently rigid in torsion so that the aileron reversal speed is higher than the maximum speed anticipated by the airplane.

70) What are the advantages of sideslip?

Ans: Sideslip can be used (a) to increase the airplane drag and thereby its flight path angle during an approach for landing, (b) useful in getting smooth aerobatics such as slow rolls and (c) finally it can help during flight with asymmetric power.

71) How the total directional stability contributions of parts of airplane is made more stabilizing ?

Ans: Sum of the directional stability contributions of wings, fuselage and propeller and that of their interference effects will usually give an unstable effect . Hence an additional stabilizing surface must be incorporated not only to overcome the instability but also to give the desired level of directional stability. This stabilizing surface is the normal vertical tail placed as far aft of the c.g of airplane as practicable.

72) What is the requirement of directional control – rudder?

Ans: Although the airplane will normally be in equilibrium at zero sideslip (β=0), there are many maneuvers that introduce yawing moments which are to be opposed by some yawing moment control (directional control) to achieve zero sideslip . This yawing moment control is supplied by pilot by means of a rudder, normally a plane flap attached to the aft portion of the vertical tail.

73) What are the flight conditions or maneuvers that produce unbalance yawing moments those are to be overcome by rudder?

Ans: One is (a) the adverse yaw moment, which happens due to turn during normal flight (b) slipstream rotation ; the slip stream behind the propeller has rotational components which changes the angle of attack on the vertical tail (α_v) and create sideslip .This is critical at high power – low speed flight. © Cross wind during take-off and landing. (d) spinning recovery by rudder (e) antisymmetric power flight ,when one of the multi-engines of airplane fails.

74) Define rudder power and how it is related to directional stability of airplane.

Ans: The rate of change of yawing moment coefficient (dCn) per degree change in rudder angle ($d\delta_r$) is called the rudder power. That is equal to dCn/ $d\delta_r$ or $C_{n\delta r}$. The directional stability of airplane is dCn/dψ = $C_{n\psi}$. If $C_{n\delta r}$ = -0.001 and $C_{n\psi}$ = - 0.001, it can be seen that 1^0 of rudder will produce 1^0 of yaw.

75) What is adverse yaw effects and how it is controlled by rudder?

Ans: Rudder power required to overcome the adverse yaw during rolling maneuver is usually not very high and not usually used for rudder design .Adverse yaw is created by the normal action of the aileron together with the yawing moment created by the twisting of wing itself. These adverse moments are always critical at low speeds and rudder must be capable of overcoming them at speeds very close to stall .

76) How rudder power is estimated?

Ans: Rudder power to overcome the adverse yawing moment $(Cn)_{tail}$ is estimated using wind-tunnel model test data .The adverse yawing moment coefficient due to rolling of the wing $(Cn)_{roll}$ can be estimated theoretically . So the rudder power required to overcome adverse yaw can be expressed as follows:

$dCn/d\delta_r = Cn_{\delta r} = ((Cn)_{roll} + (Cn)_{tail})$/ rudder throw ($=30^0$) .

77) Why the rudder is designed to suit one-engine inoperative condition?

Ans: The yawing moment coefficient due to the asymmetric thrust (Cn_{th}) is proportional to $1/V^3$. The rudder at full deflection gives a constant corrective yaw moment coefficient (Cnr) . The intersection of these two Cn_{th} and Cnr gives the critical speed of airplane below which Cn_{th} is more than Cnr . Hence below the critical speed (near stalling at full power) the full rudder will not balance out the moment due to antisymmetric power . Since other types of yawing moments are not critical , most rudder are designed only to fulfill the antisymmetric power flight condition.

78) How the floating rudder (stick-free) affects the directional stability?

Ans: When rudder is left free to float in response to its hinge moment, it can have large effects on the directional stability. It is in the similar way, the floating elevator affects the longitudinal stability. When the airplane sideslips, the restoring moment due to the tail will be decreased if the rudder floats with the wind and will be increased if it floats against the wind . The floating rudder changes the effective angle of attack of the total vertical tail .

79) What is the criterion to keep the directional stability with stick-free above certain limit or not to lose much?

Ans: For high speed airplanes which require close aerodynamic balance of rudder and hence the rudder pedal force to be applied by the pilot should be within practicable limit. So it is essential that the ratio of derivative of H.M coefficient with tail angle of attack (α_v)and rudder power ($Ch_{\delta r}$) should be kept low so as not to lose too much directional stability with stick-free .

80) What is the relation for the greatest of pedal force (PF) with respect to sideslip (ψ) and give its accepted value .

Ans: The greatest of pedal force (PF) w.r.t to sideslip (ψ) can be derived as $dPF/d\psi = (G\, q\, \eta_v\, S_r C_r Ch_{\delta r} / Cn_{\delta r}) * (Cn_\psi)_{free}$,where $(Cn_\psi)_{free} = (Cn_\psi)_{fix} - (Ch_{\alpha v} . Cn_{\delta r}) / Ch_{\delta r}$. It shows that $dPF/d\psi$ varies with V^2 for normal aerodynamic balance . A criterion of 2.25 kgf/deg of sideslip at 240 km/hr speed has been taken as the minimum for this gradient .

81) What is meant by rudder lock?

Ans: A typical curve of floating angle (δ_{float}) vs sideslip (ψ) can be made for a closely balanced rudder . The rudder angle (δ_r) required to produce the sideslip varies some what linearly upto high (ψ). The pedal force required is a function of the difference between δ_{rreqd} and δ_{float} . At high ψ, the δ_{float} may catch up to $\delta_{rreqd,}$ at which point the PF becomes zero .This point of intersection is called rudder lock. Considerable force is required afterwards, to break the lock and restore the airplane to zero sideslip .

82) How to avoid rudder lock?

Ans: Rudder lock can be avoided by two ways; 1) To cut down the rudder effectiveness ($d\alpha_v / d\delta_r$) , thereby increasing the δ_{rreqd} at a given sideslip (ψ). (2)Another way is to provide a dorsal fin which increases the fuselage stability at high (ψ) as well as reduces the tendency of the vertical tail to stall .

83) What is the concern of the designer to keep the pedal force required within suitable practicable values?

Ans: A fighter airplane climbing at full throttle (power) at 288 km/hr may push over to a dive up to 720 km/hr speed . If the airplane is trimmed out directionally at climb, the pilot may have to exert a PF as high as 92 kgf to maintain zero sideslip in the dive. Hence it is essential for the designer to keep the pedal force changes with speed as low as possible by suitable aerodynamic balance.

84) Why the study on dynamic characteristics of the airplane is necessary ?

Ans: In order to understand the requirements for static stability and control, it is necessary to study the dynamic characteristics of the airplane . It is done by investigating the types of motions of the airplane in response to a disturbance from some equilibrium flight condition and the nature of transient motions of the airplane in response to the movement of its controls .

85) What way the dynamic stability analysis of the airplane help the design of control systems and the pilot who operates it ?

Ans: If the motion of the airplane in response to some disturbance is very slow divergence, the control requirements are different from those needed if the divergence is extremely rapid. The ability of the pilot to react and apply the controls is a factor which must be kept in mind for all studies of airplane dynamics. The design of controls and the ability of the pilot to apply controls in time , requires some knowledge of the transient response of the airplane to a disturbance or to controls .

86) What are the 4- different modes of motion of a dynamic system when responding to a disturbance from an equilibrium position?

Ans: Dynamic system in general have 4- different modes of motion when responding to a disturbance from its equilibrium position. They are aperiodic and oscillatory modes with and without damping . That is aperiodic can be pure convergence if the motion is damped (stable) and divergence if undamped (unstable) .Similarly oscillatory motions (periodic) can be damped oscillation (stable) or undamped oscillation (unstable) .

87) What are the six degrees of motion of a dynamic system and how it is formed for the airplane ?

Ans: According to the Newtonian laws of motion which states that (a) the sum of all external forces in any direction must be equal to the time rate of change of momentum, and (b) the sum of all external moments of forces must be equal to the time rate of change of moment of momentum, all measured w,r,t axes fixed in space . The six equations of motion are: $\sum Fx = m\, a_x$, $\sum Fy = m\, a_y$, $\sum Fz = m\, a_z$, $\sum L = dHx /dt$, $\sum M = dHy/dt$, $\sum N = dHz /dt$. (where `m` is the mass , a_x ,a_y ,a_z are linear accelerations and Fx , Fy , Fz are external forces and L, M, N are external moments of forces and Hx ,Hy , Hz are moments of momentum about X, Y, Z axes respectively .)

88) How the true acceleration and moment of momentum of airplane w. r. t fixed axes in space are generated ?

Ans: Accelerations w. r. t moving axes (X, Y, Z) as well as moments of momentum are generated 1st w. r. t moving axes . But they will not be the true values because as per Newtonian laws they are to be worked with reference to fixed axes in space . To overcome this difficulty use is made of moving axes which coincide in some particular manner from instant to instant with a definite set of axes fixed in the airplane .

89) What are the different ways the moving airplane axis system can be fixed with reference to the airplane?

Ans: The moving airplane axis system can be fixed with reference to the airplane in two different ways : (1) One is to consider the axes fixed to airplane under all conditions ,and are called body axes in which X -axis is along the thrust axis. (2) Other possibility is to consider the X- axis always pointing to the direction of motion or into the relative wind , called wind axes .The wind axes are usually convenient .

90) What are the equations of longitudinal motion with free control ?

Ans: It involves 3 symmetric equations in the plane of symmetry of airplane (X-Z plane) and equation of motion of the elevator control about its own hinge. They are: $\sum Fx = m \acute{u}$, $\sum Fz = -mV\acute{r}$, $\sum M = I_Y q`$ and $\sum HM_e = Ie\ \delta_e``$.Major variables to be considered for dynamic analysis are the change in forward speed ΔV, $\Delta\alpha$,change in altitude($\Delta\theta$) and change in elevator angle $\Delta\delta_e$.

91) What are the different modes and stability criterion of dynamic longitudinal motion whose governing equation is a 4^{th} degree quartic ?

Ans: If all the 4 roots (λ`s) come out as real numbers , the dynamic motion is aperiodic , damped or convergent if the real root is negative and undamped or divergent if the real root is positive .

If any of the roots (λ`s) form a complex pair , the motion is oscillatory ; it will be damped oscillation if the real part of the complex root is negative and undamped oscillation if the real part is positive .

92) How the stability of dynamic motion can be judged using the coefficients of the 4^{th} order quartic which govern the motion ?

Ans: If all coefficients (A to E) are positive , there can be no positive real root and no possibility of pure divergence . If the Routh`s discriminant(RD)= ($BCD-AD^2-B^2E$) is positive , then there is no possibility of complex root with positive real part and hence no undamped oscillation. If RD is zero, there will be neutrally damped oscillation and if RD is negative, one root will be complex pair with positive real part, representing undamped oscillation etc.

93) Briefly explain the stability derivatives, Cl_p and Cn_r .

Ans: The derivatives Cl_p and Cn_r are the damping derivatives in roll and yaw respectively; where as the derivatives Clr and Cnp are usually referred to as the rotary or cross derivative . They are the rolling moment (Cl) due to yawing velocity (r) and yawing moment (Cn) due to rolling velocity (p) .

94) What are the characteristic modes of stick-fixed longitudinal motion of airplane?

Ans: Characteristic modes of stick-fixed longitudinal motion for nearly all airplanes are two oscillations (1) Long period with poor damping called **phugoid mode** (2) Short period with heavy damping is referred to as the short period mode or second mode (Note: give figures also.) The damping of the phugoid motion is therefore a direct function of C_D . The cleaner the designer makes the airplane, the more difficult will be to ensure damping of phugoid mode .

95) What is proposing mode of dynamic motion?

Ans: The damping of long period mode (phugoid mode) can become very weak under certain design conditions and can become neutrally damped or even unstable. This mode when neutrally damped is usually called proposing. Such modes have occurred in high speed airplanes, in which the oscillations of normal acceleration become so severe that the pilot was injured seriously and airplane damaged before the pilot could stop the oscillation by slowing down.

96) How many degrees of freedom are there for lateral dynamic motion and what are they ?

Ans: There are 5- degrees of freedom for the lateral dynamic motion, because there are two lateral controls ; the rudder and aileron. The five degrees of freedom are : a) Velocity along the Y –axis (b) rotation about X- axis (c) rotation about Z-axis (d) rotation of rudder about its hinge (e) rotation of aileron about its hinge.

97) Define spiral divergence in dynamic stability?

Ans: This is a characteristics associated with lateral dynamic stability of modern airplane .The divergent mode (undamped) motion is known as spiral divergence .It can be easily demonstrated in equilibrium flight by giving a kick to rudder or aileron and watching the response . If it is uncontrolled, steep high-speed spiral divergence develops. Inspection of lateral dynamic stability quartic equation gives an idea about spiral divergence. If E in quartic is zero, it is spiral boundary and when E is negative it is unstable and positive, stable. Usually with C_L more than 0.213, the airplane will be spirally unstable.

98) Define Dutch roll and its effects.

Ans: Lateral short period oscillation with weak damping are objectionable and such oscillations are called Dutch roll .In most airplane designs the short period oscillation with control locked is not objectionable as the damping is normally heavy .But with control free the Dutch roll can have very weak damping which is quite objectionable. Neutrally damped Dutch roll can be investigated by equating the Routh`s discriminant to zero ,ie;$(BCD-AD^2-B^2E) = 0$, which is oscillation boundary between stable and unstable.

99) What is meant by snaking?

Ans: In most cases with inadequate damping of lateral oscillation, it is tied in with the floating characteristic of the rudder (δ_{rfloat}) . This characteristic under certain conditions of aerodynamic balance can introduce a poorly damped lateral oscillation known as snaking.

100) Briefly explain autorotation. (Note: give figure, α vs C_L and show the cause of autorotation).

Ans: When the wing's are stalled; ie; beyond the critical angle of attack (α_{cr}) , the rising wing will have higher C_L than the falling wing .This creates an unbalanced couple about X-axis to rotate (roll) further which is called autorotation. Rolling occurring in the almost horizontal plane is also a form of autorotation .

101) Briefly explain the spinning of an aircraft.

Ans: Spinning is caused by the autorotation developed by the unequal lift in the wings .In a spin the airplane follows a steep spiral path which is composed of varying degrees of yaw, pitch and roll. A flat spin is chiefly yaw and spinning nose-dive is chiefly roll. The amount of pitch depends on how much the wings are banked from the horizontal . Area and disposition of the fin , rudder and tail plane exert considerable influence on the airplane to spinning .

102)How to get out of the spin smoothly ?

Ans: In order to get out of a spin we must get out of the stalled (C_{Lmax}) state by putting the nose down (reduce α) and also we must stop rotation by applying `opposite rudder `. In practice the roll is stopped first, because it is found the elevators are not effective (to change α) until the rotation is stopped .

103) State two basic requirements of aircraft control surface.

Ans: AP control surfaces are mainly ailerons, canard(forward tail), elevator, rudder and spoilers(special ailerons). Most of the control surfaces are used to produce additional forces when it is required at different locations of AP. Also they produce counter-balancing about three major axes of the AP to improve stability. It aids the pilot to produce control forces to come out of maneuring flights.

104) Distinguish between stability and controllability.

Ans: Stability and control characteristics of an AP are called flying qualities. Stability is the property of an equilibrium state and it is divided into static and dynamic stability. Static stability is the tendency of the AP to return to its equilibrium after a disturbance. In dynamic stability, the vehicle's motion with the time after it is disturbed from its equilibrium point is considered. Controllability of a system is related to its ability to transfer control requirements. A system is controllable if it transfers any initial state Xi(t) to any final state Xf(t) in finite time.

105) What is the need for aerodynamic balancing?

Ans: Control surfaces like elevators, ailerons and rudders are used for generating forces and moments in different directions for controlling the AP. When using, the methods of controlling parameters(H.M coefficients) $Ch\alpha$ and $Ch\delta$ are of prime interest and are referred to as methods of aerodynamic balancing. If these coefficients are not suitably controlled, the stability and control will be in danger and it will do harm. (eg, In $(dC_m / dC_L)_{free}$ eqn, the effect of elevator freeing comes as $1-\tau\, Ch\alpha / Ch\delta$ and if $\tau\, Ch\alpha / Ch\delta = 1$, the whole tail contribution to S.L.S will become zero.

106) What is meant by weather cocking effect?

Ans: See Ans to the short question-9 above.

107) Explain the term stability derivatives.

Ans:- For the analysis of dynamic characteristics(Modes of motion) of AP either in longitudinal or lateral direction, respective simultaneous homogenous differential equations are to be developed. The constant coefficients of these equations are made up of AP mass and inert parameters and so called stability derivatives, like $CL\alpha$, $CD\alpha$ and $Cm\alpha$. $CL\alpha = dCL / d\alpha$ which is the slope of the lift curve with respect to angle of attack. $Cm\alpha = (dCm / dCL)(dCL / d\alpha) = (dCL / d\alpha)$ (S.L.S) criteria.

PART –B (QUESTIONS& HINTS /ANS)

1) (i) Briefly explain with the temperature-altitude plot , the structure of the standard atmosphere upto a 105 km altitude. (10)

Hint: Draw the graph, temperature (K) VS altitude (km) up to 105 km and explain different temp: gradient as well as isothermal layers upto 105 km.(see p2&3 of ISA notes in module-1)

(ii) Find out the geopotential altitude corresponding to 25km geometric altitude (Take radius of earth = 6300km) . (6)

Hint: (See p-5 of ISA Note given in Module-1). Relation between geopotential altitude(h) and geometric altitude (hg) is ; $h = (r/(r+ hg))hg$,where `r` is the radius of earth.
ie; $h = (6300/6325) * 25 = \ldots\ldots$ km.

2) (i) Derive the relation for the pressure variation in the gradient layers of the ISA . (10)

Hint: Use the relation $dp/p = -(go/Ra)\ (dT/T)$ and integrate between the base of the gradient layer (p1) and to some point in it (p&T) and get the result , $p/p1= (T/T1)^{**}(- go/Ra)$ (where `a` is the lapse rate.)

(ii) Find the density at 9km altitude from earth's surface which is on a gradient layer having lapse rate equal -6.5K/km. Take standard sea level as the base and R of air = $287 m^2/s^2 K$. (6)

Hint: Density variation in the gradient layer ($\rho/\rho1$) is obtained from the relation

$\rho/\rho 1 = (p/p1)*(T1/T) = (T/T1)**_{((-go/Ra) -1)}$
$\rho/\rho 1 = (229.5/288)**_{((-9.81/2\ 87*0.\ 65)-1)}$ = rp , hence ρ at 9 km = ρ1* rp
(ρ1 at std.sea level = 1.226 kg/m**3)

3) (i) Derive the relation for pressure variation in the isothermal layers of the ISA. Find out the pressure in the isothermal layer of 165K and at a height of 5km from the base, given the base pressure as $30N/m^2$. (R of air = $287m^2/s^2K$) (10)

Hint: For derivation use dp/p = - (go/RT)dh . Give the base value at h1 as p1, T1&ρ1 and at altitude (h) above base as p, T& ρ . Then integrate dp/p between p1&p and right-hand-side between h1& h , the derivation is obtained as p/p1 =e **(-go/RT)(h-h1)
and ρ/ρ1 = p/p1 , since T=T1 (for isothermal layer)

Problem :T=T1 = 165K , (h-h1) = 5 km , p1 = 30 N/m**2, R= 287 m**2/s*2 K
(-go/RT) (h-h1) = (-9.81/287*165)*5000 = -rp
p = p1(e**(-rp)) = 30 e**(-rp))

(ii) Find out the density at the isothermal layers of 165K at a height 10km from the base, given the base density as $1.2x10^{-4}Kg/m^3$
(R of air = $287m^2/s^2K$) (6)

Hint: ρ/ρ1 = p/p1 = e**(-rp), then ρ = ρ1 e**(-rp) ,
where ρ1 =$1.2*10^{-4}$ kg/m**3

4) (i) Derive the relations for maximum L/D as well as $V_{L/Dmax}$ and V_{minPR}. (8)

Hint: For max: L/D , C_D/C_L should be minimum .
get $C_D = C_{Df} + C_L^2/\pi Ae$. Differentiate (C_D/C_L) function w.r.t C_L and equate to zero. Then $(C_D/C_L)_{min}$ or $(C_L/C_D)_{max}$ at $C_{Df} = C_{Di} = C_L^2/\pi Ae$
Then get $(C_L/C_D)_{max} = (L/D)_{max} = 0.886\ (Ae/\ C_{Df})^{0.5}$.
From L= W , get $V_{(L/D)max} = (2W/\rho\ S\ C_L)^{0.5}$ = Vo .
For $V_{(L/D)max}$ at altitude use ρ at altitude or = $Vo/(\sigma)^{0.5}$.
$V_{min\ PR}$ occurs when $C_{Df} = C_{Di}/3$ or $C_D = 4\ C_{Di}/3$.
This can be obtained by differentiating $(C_D/C_L^{3/2})$ function w.r.t C_L and equate to zero. Then repeating the above process (from L=W) get $V_{min\ PR}$ = $0.76*V_{(L/D)max}$ at sea level . $V_{min\ PR}$ at altitude = $0.76\ Vo/(\sigma)^{0.5}$

(ii) Find out $(L/D)_{max}$, $V_{L/D\ max}$, $T_{L/D\ max}$ and $V_{min\ PR}$ of an airplane with the following features:

$W = 1200kgf$, $S = 20m^2$, $A = 5$, $e = 0.8$, $f = 4m^2$ and $\sigma = 0.5kg/m^3$ (8)

Hint: $C_{Df} = f/S = 4m^2/20\ m^2 = 0.2$
$(L/D)_{max}$ at sea level = $0.886(Ae/\ C_{Df})^{0.5} = 0.886*\sqrt{20}$

$V_{(L/D)max} = \sqrt{(W/\sigma S\, C_L)}$,at $(L/D)_{max}$, $C_{Df} = C_L{**2}/\pi Ae$, $C_L = (0.8\ \pi)^{**0.5}$.
$T_{(L/D)max} = D_{(L/D)max} = W/(L/D)_{max} = 1200*9.81/((L/D)_{max}$
$V_{min\ PR} = 0.76 * V_{(L/D)max}$

5) (i) Explain with the help of a simple pendulum, the characteristics of static and dynamic equilibrium and how its stability can be evaluated. (8)

Hint: Draw the figure given in the note and at position A (top) it is statically unstable and at position B (bottom) it is statically stable . Dynamic stability at bottom (position B) can be analyzed by response analysis . In dynamic sense it will be neutrally stable at B .

(ii) Derive the equilibrium equations for the longitudinal degrees of freedom along a straight path and get the expressions for uniform flight velocity and velocity of climb. (8)

Hint: For longitudinal degrees of freedom along a straight line
$L = W \cos r = 0.5\ \rho\ C_L V^2\ S$
Uniform velocity $V = (2W\cos r / \rho\ C_L\ S)^{0.5}$
Rate of climb $= Vc = R/C = (T-D)V/W$

6) (i) Derive from the fundamental equation for R/C, the non dimensional form of thrust available (T_A) vs velocity relation and plot $T_A/T_{L/Dmax}$ vs $V/V_{L/Dmax}$ curves. Also prove that angle of climb is a maximum (γ_{max}) at $V/V_{L/Dmax} = 1$. (8)

Hint: $R/C = (T_A - T_R)V/W$. Multiply & divide R/C equation by $T_{L/D\ max}\ V_{L/Dmax}$

and put $2\ T_A/T_{L/Dmax} = y1$, $2T_R/T_{L/Dmax} = Y$ and $V/V_{L/Dmax} = x$

also we know that $T_R = AV^2 + B/V^2$

and $T_{L/Dmax} = A\ V^2_{L/Dmax} + B / V^2_{L/Dmax}$

$2\ T_R / T_{L/Dmax} = (V/V_{L/Dmax})^2 + 1/(V/V_{L/Dmax})^2$ ie; $y = x^2 + 1/x^2$

The max: R/C or R/S occurs at maximum $\Delta T\ .V$ or maximum

$x\ \Delta y = x\ (y1 - y) = x(y1 - x^2 - 1/x^2)$

$d(x\ \Delta y)/dx = 0 = y1 - 3x^2 + 1/x^2 = 3x^4 - y1\ x^2 - 1 = 0$

$x^2 = (y1 +/- \sqrt{(y1^2+12)})/6$ or $x = ((y1 +/- \sqrt{(y1^2+12)})/6)^{0.5}$

Also $\sin r = (R/C)/V = (T-D)/W$ ie; $r = \sin^{-1}(T-D)/W =$

Constant $(T_A - T_R)/ T_{L/Dmax}$, ie; r = constant $(y1-y)$ = constant $(y1 - x^2 - 1/x^2)$

For max: r , $dr/dx = 0 = -2x + 2/x^3$, $-2x^4 + 2 = 0$,

ie; $x = 1 = V/V_{L/Dmax}$

(ii) Find out the velocity ratio (x) for max: R/C, when $y_1 = (2T_A/T_{L/Dmax})$ is 2 and 4and also obtain the flight velocity of air plane if its $V_{L/Dmax} = 500$km/hr. (8)

Hint: x= ?, $2\ T_A/\ T_{L/Dmax} = Y1 = 2\ \&\ 4$,

(a) $x = \sqrt{(2+/-(4+12)^{0.5})/6} = 1$, ie; $V = x\ .V_{L/Dmax} = 500$ km/hr

(b) $x = ((4+/-(16+12)^{0.5})/6)^{0.5} = a$, ie; $V = a.\ V_{L/Dmax}$

7) (i) Derive the expression for drag polar and explain it with a neat plot . (6)

Hint: See page 12-13 of Note of Module-1 (after ISA note)

(ii) Draw the thrust / power required (T_R / P_R) and thrust / power available (T_A / P_A) curve for a jet engine and piston engine and state your observations.

Hint: Page- 21 for jet engine & p-23 for turbo-propeller engine .Show both sea level and altitude curves . (10)

8) (i) Derive the two equations given below and represent it graphically .

$D = A\ V^2 + B/V^2$; $P = A\ V^3 + B\ /\ V$, (6)

Hint : $D = D_{Pf} + D_i$ or $C_D = C_{Df} + C_{Di}\ (=C_L^2\ /\pi Ae)$

$= \sigma\ f\ V^2 + (W/b)^2/(\sigma\ e\ V^2)$ ie ; $D = A\ V2 + B\ /V^2$ …..(1)

$P = D.V = A\ V^3 + B/\ V$ ……(2)

(ii) An aircraft weighing 25 k N has a wing area 100m^2 and its drag coefficient is $C_D = 0{,}016 + 0.04\ C_L^2$, calculate the minimum thrust required for straight and level flight ,and the corresponding true air speed at sea level and at 10km ($\sqrt{\sigma} = 0.58$).Calculate also the minimum power required and the corresponding true air speeds at the above conditions . (10)

Hint: Given $C_D = 0.016 + 0.04C_L^2$ ie; $C_{Df} = 0.016$, For min: drag $C_{Df} = C_{Di}$

ie; $0.016 = C_L^2/\pi Ae$,or $1/\ \pi Ae = 0.04$ or $Ae = 25/\pi$,

$(L/D)_{max} = (C_L/C_D)_{max} = (\sqrt{0.4})/2C_{Df} = 20.8$

$V_{L/Dmax} = \sqrt{(W/\sigma\ S\ C_L)} = (2500/3.33)^{0.5} = V_O$, Then $V\sigma = Vo/\sqrt{\sigma} = V_O/0.58$

$T_{min} = W/(L/D)_{max} = 25000/20.8$, $P_{min} = T_{min}\ V_{minPR}$; But $V_{minPR} = 0.76\ V_{L/Dmax}$

$V_{minPR} = 0.76 * V_O$, And V_{minPR} at altitude $= V_{minPR}/\sqrt{\sigma}$

9) (i) Assuming parabolic polar variation for C_D vs C_L, write down the thrust required (T_R) and power required (P_R) equations of an airplane. Give the conditions of speed for minimum P_R and minimum T_R in terms of drag coefficients also. (8)

Hint : Use $T_R = T_{RP} + T_{Ri} = \sigma f V^2 + (W/b)^2/(\sigma e V^2)$

Also $P_R = P_{RP} + P_{Ri} = \sigma f V^3 + (W/b)^2/(\sigma e V)$

Speed at minimum T_R is when $(L/D)_{max}$ or $(C_D/C_L)_{min}$

Form $C_D = C_{Df} + C_L^2/\pi Ae$; To get the $(C_D/C_L)_{min}$, differentiate the equation C_D / C_L , w.r.t C_L and equate to zero .

Then , the condition $C_{Df} = C_L^2/\pi Ae$ is obtained .

Then $(L/D)_{max} = (C_L/C_D)_{max} = C_L/2\ C_{Df} = 0.886\ \sqrt{(Ae/C_{Df})}$

Next using relation , $L = W$, $V = (W/\sigma\ S\ C_L)^{0.5} = V_{L/Dmax}$

For $P_{Rmin} = T_{min}\ V_{minPR}$, But $V_{minPR} = 0{,}76\ V_{L/Dmax}$, $T_{min} = W/(L/D)_{max}$

(ii) For the maximum L/D as well as minimum P_R conditions of an airplane, find out $(L/D)_{max}$, $V_{L/Dmax}$, $T_{L/Dmax}$ and $V_{min\ PR}$ with the following features:

$$W = 1500kgf,\ S = 20m^2,\ A = 5,\ e = 0.8,\ f = 4m2,\ \sigma = 0.5kg/m^3 \qquad (8)$$

Hint: Use the above method given for (i) and solve problem.

10) (i) Derive from the fundamental equation for R/C, the generalized form of thrust vs velocity curves and show that $T_R/T_{L/Dmax} = 1$ when $V/V_{L/Dmax} = 1$.Also indicate in the $T_A/T_{L/Dmax}$ vs $V/V_{L/Dmax}$ graph, the regions of max R/C and min R/S and speed for β_{min} or γ_{max} (8)

Hint: (See page 11 of Note of Module -2) . Also draw fig 6 given in page 11 .

(ii) Find out the velocity ratio (x) for max: R/C, when $y_1 = (2T_A/T_{L/Dmax})$ is 2 and 5 and also obtain the flight velocity of air plane if its $V_{L/Dmax}$ = 600km/hr. (8)

Hint: x for maximum R/C = $((y_1+/-(y_1^2+12)^{0.5})/6)^{0.5}$

When y1 = 2 , x = $((2+/-(4+12)^{0.5})/6)^{0.5}$ = 1 ,hence $V = V_{L/Dmax}$

When y1 = 5 , find out x by the above equation , let it be equal to \`a\`

Then $V = a.\ V_{L/Dmax}$

11) (i) Derive the relation for the maximum range of a turbojet airplane. (10)

Hint: (See Page 23 of Note of Module – 2)

$R_{max} = (2/c\text{`})(CL^{1/2}/C_D)_{max}(W_O/\sigma\ S)^{0.5}\ (1-(W_1/W_O)^{0.5})$

(ii) Calculate the maximum endurance of a turbojet airplane having the following flying characteristic.

$c' = 2.5hr^{-1}$, $W_0/W_1 = 1.2$, A= 10,
$S = 40m^2$, e=0.8 and $f = 2m^2$ (6)

Hint: For maximum endurance, flight $V = V_{L/Dmax}$

$E_{max} = (1/c\text{`})(L/D)_{max}\ \ln(W_O/W_I)$; where $L/D_{max} = 0.886\ b(e/f)^{0.5}$
and $b = (A\ S)^{0.5}$ =20 m, then get L/D_{max} and E_{max} by substitution

12) (i) Derive the relation for the maximum range of a turbo-propeller airplane. 10)

Hint: See page 16-17 of Note of Module -2, $R_{max} = k1(L/D)_{max}(\eta/c)\ \ln(Wo/W1)$

(ii) Calculate the maximum endurance of a turbo-propeller airplane having the following flying characteristic.

$\eta = 0.85$, $C' = 0.45hr^{-1}$, $W_0/W_1 = 1.2$, k=1.5m/s,
$C_L = 1.2$, $C_D = 0.083$, $Wo/\sigma S = 100m^2/s^2$ (6)

Hint: $E_{max} = k\ (\eta/c)\ (C_L^{1..5}/C_D)\ (\sigma S/W_O)^{0.5}((W_0/W_1)^{0.5}-1)$

13) (i)Derive the relation for the take-off ground run distance (S) for an airplane in terms of weight (W), take-off velocity (V_{TO}), effective thrust (Te) @0.7 V_{TO} (8)

Hint: See page 31-32 of Note of Module -2

$Sg = W\ V^2_{TO}/(2gTe\ @0.7\ V_{TO})$

(ii) Find out the take-off ground run distance for an airplane having W=1500kgf,

V_{TO}=360km/hr and T_E at 0.7V_{TO}=3kN and then find the horizontal distance to climb an vertical obstacle of 15m, if the ground run distance is 0.8 times of total distance. (8)

Hint: Sg = 1500*9.81*10^4/(2*9.81*3000) = 2500 m

Sg = 0.8* S_{tot} , ie; S_{tot} = Sg / 0.8 = 3125 m ; S_c =625 m

14)(i) Derive the relation for the total landing distance from over a 15m height obstacle considering V_{15}=1.3V_S and V_L=1.15V_S, where V_S is stalling speed (10)

Hint: S_A = (W/F)((V^2_{15} – V^2_L)/2g +15 ; V_S =100 m/s

Sg = V^2_L/ 2(-a) , S_{tot} =S_A + Sg

(ii) Find out the total landing distance required for an airplane having W/F (average resistance coefficient) 10, and stalling speed 360km/hr. Take average deceleration during ground run as 2.3m/s (6)

Hint: Use the above method given in Hint 14(i) and solve .

15) Derive from fundamentals that the relation for the maximum rate of climb,

$$(R/C)_{\max} = \frac{\eta P}{W} - \sqrt{\frac{K}{C_{Df}}}\left(\frac{W}{\sigma s}\right)^{0.5} \frac{1.155}{(L/D)_{\max}}$$

and give discussion on it.

Ans: Refer page 12a of Module-2 Note.

16) For a straight and level flight, velocity for minimum power is 0.76 times velocity for minimum drag.

Ans: Give the derivations for the velocity ($V_{(L/D)max}$) for minimum drag(D=TR) and minimum power required(V_{minPR}).

(Details given in page 4 & 4b of Module-2 Note)

Descriptive Questions and hints(M3)

17)(a)With the help of a figure, write down the moment equation about the c.g of an airplane flying in power-off and stick fixed condition. Then show the conditions for equilibrium and longitudinal stability. (16)

Hint: See page 4-6 of Note of Module -3

18)(i) Derive the relation for Neutral point (N_0) of an airplane at stick-fixed Power-off condition. (10)

Hint: See the page 19-20 of Note of Module -3

(ii) Find out the type of stability of an airplane at the stick-fixed, power-off condition which is having neutral point at 55% of chord and c.g located at 45 cm aft of a.c . Also state the stability condition if c.g is at 65cm aft of a.c. (Take ‘c’ of airfoil = 1m). (6)

Hint : Neutral point at the stick-fixed power-off condition (No)= 55% of `c` (c =1m), which is aft of aero-dynamic centre (a.c) of the wing .

(1) Stability when c.g is at 45 cm aft of a.c = 45% of `c`,

Ie; $dC_m/Dc_L = x_{c.g} - No = -10\%$ of `c` , (stable)

(2) Stability when c.g is at 65 cm aft of a.c = 65% of `c`,

Ie; $dC_m/Dc_L = x_{c.g} - No = +10\%$ of `c` , (unstable)

19) (a) From fundamental, write down the equation for the Wing contribution to Static Longitudinal Stability (S.L.S) and from the simplified form explain how the location of c.g of airplane with respect to a.c of wing decides the S.L.S of the airplane. (16)

Hint:See page 7-9 of Note of Module -3

20)(i) Derive the equilibrium and S.L.S equation of a turbo-propeller airplane taking the direct thrust alone of the propeller. (8)

Hint: See page 22-23 of Note of Module- 3

(ii) Using the simplified terms of $(dC_{mp}/dC_L)_T$ show graphically (in C_m vs C_L graph), the positions of, a) dC_m/dC_L for h/c=0.2,

b) dC_m/dC_L for h/c= -0.2,

c) if $dC_m/dC_{L\ =-0.1}$ for h/c= 0

Hint: $dCm/dC_L = -0.1$ for $h/c = 0$

And $(dCmp/dC_L)_T = 0.25\ h/c$

dCm/dC_L for h/c = 0.2 , $(dCmp/dC_L)_T = 0.05$, $dCm/dC_L = -0.1+0.05$

$= -0.05$ (stable)

dCm/dC_L for h/c = -0.2 , $(dCmp/dC_L)_T = -0.05$, dCm/dC_L

$= -0.1 - 0.05 = -0.15$ (more stable)

21)(a)Discuss in detail the power effects on static longitudinal stability for a jet powered airplane . (16)

Hint: Details given in pages 32- 34 of Note of Module – 3

22 (a) (i) How most forward c.g. for free flight of an AP is fixed and write the relation for $(dC_m/dC_L)_{max}$ in terms of elevator deflection, its power($Cm\delta$) and C_{Lmax}. (6)

Hint: Details given in page 41 of Note of Module – 3

(ii) Derive the relation for $x_{cg\ forward}$ from fundamental C_{mcg} equation at power-off equilibrium with elevator deflection. (10)

Hint:- Details given in page 44 of Note of Module – 3

22 (b) Write short notes on:

(i) One engine in-operative condition

(ii) Aileron reversal and adverse yaw.

Hint:- Refer note-Module-IV.

23(a) (i) Show that elevator angle for trim is given by

$\delta e_{trim} = - (Cmo\ C_{Lo} + Cm_\alpha\ CL_{trim}) / (Cm_{\delta e}\ CL\alpha - Cm_\alpha\ CL_{\delta e})$

Ans:- An AP is said to be trimmed if the forces and moments acting on the AP are in equilibrium. Setting the pitching moment equation equal to zero, we can solve for the elevator angle required to trim as follows.

$Cm = 0 = Cmo + Cm_\alpha\ \alpha + Cm_{\delta e}\ \delta e$------------------------eqn(1)

Or, $\delta e_{trim} = - (Cmo + Cm_\alpha\ \alpha_{trim}) / Cm_{\delta e}$------------------eqn(2)

The lift coefficient to trim is $CL_{trim} = CL\alpha\ \ \alpha_{trim} + CL_{\delta e}\ \delta e_{trim}$ -----eqn(3)

We can use this equation to obtain the trim angle of attack(α_{trim}).

$\alpha_{trim} = CL_{trim} - CL_{\delta e}\ \delta e_{trim} / CL\alpha$---------------eqn(4)

If we substitute this eqn(4) back into eqn(2) we get the following eqn for elevator angle to trim:

$\delta e_{trim} = - (Cmo\ C_{Lo} + Cm_\alpha\ CL_{trim}) / (Cm_{\delta e}\ CL\alpha - Cm_\alpha\ CL_{\delta e})$

(ii) Discuss the advantages and disadvantages of CANARD configuration.

Ans:- A canard is a tail surface located ahead of the wing. It has several attractive features. The canard, if properly positioned, can be relatively free from wing or propulsive flow interference. Canard control is more attractive for trimming the large nose-down moments produced by high lift devices. To counteract the nose-down pitching moment, canard must produce lift that will add to the lift produced by the wing. An aft tail must produce a download to counteract the pitching moment and thus reduce the airplane's overall lift. The major disadvantages of the canard is destabilizing contribution to the aircraft's static stability. However, it is not a severe limitation. By the proper location of the C.g, one can ensure the AP is statically stable.

24(a) Using the floating angle of elevator (δe) and its H.M coefficient, derive the relation for the stability criteria at stick-free condition. Also get the relation for No-No'(difference between stick-fixed(No) and stick free(No') neutral points). (16)

Hint:- Details given in pages 62-65 of Note of Module – 3.

25 (a) (i) Define stick-fixed maneuver point (Nm) and stick-free maneuver point(Nm'). Write down the expression for Nm and Nm' in terms of No and No' respectively. (8)

Hint:- Details given in page 81 and pages 83 & 85 of Note of Module – 3.

(ii) Briefly explain the limits on AP's c.g with the help of a figure. (8)

Hint:- Details given in page 87 of Note of Module – 3.

26) (a) Discuss in detail the contribution of various components of the airplane on its static directional stability . (16)

Hint: See pages 10-13 -briefly of Note of Module -4)

27) (a) Discuss briefly the following :

(1) Directional control and the basic requirements of the rudder . (8)

Hint: See page 16-17 of Note of Module – 4

(2) Rudder lock and how to avoid it. (8)

Hint: See page 24- 25 of Note of Module -4

28) Discuss briefly the following :

(1) Basic requirements of the rudder (6)

Hint: See page 16-17 of Note of Module -4

(2) Aileron reversal ; (Hint: See page 7 of Note of Module -4) (5)

(3) Adverse yaw ; (Hint: See page 18-19 of Note of Module-4) (5)

29) (a)(i) A statically stable aircraft can be dynamically stable or unstable .
Give the dynamic conditions under which it happens (6)

Hint:A statically stable aircraft can be dynamically stable if its dynamic modes of motion are damped (Both aperiodic and periodic motions. Total 4 types of modes can be possible). Similarly a statically stable aircraft can be dynamically unstable if its dynamic modes of motion are undamped (Both aperiodic and periodic motions. Total 4 types of modes can be possible) .

(ii)Discuss various stability derivatives relevant to longitudinal dynamics . (10)

Hint: See page 16-17 of Note of Module -5

(Explain aerodynamic coefficients like , C_D ,C_L , $C_{D\alpha}$, $C_{L\alpha}$ etc; given in above pages).

30)(a) Write short notes on the following :

(1)Autorotation (Hint: page 48-49 of Module- 5) (6)

(2) Dutch roll (Hint: page 43 of Module- 5) (5)

(3) Spiral divergence (Hint: page 43 & 45 of Module-5) (5)

31) Discuss briefly the following:

(i) Phugoid motion (8)

(Hint: Page 23-24 of Note of Module- 5)

(ii) Stability derivatives in longitudinal dynamic (8)

Hint: See page 17 of Note of Module – 5.

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