FLIGHT MECHANICS –II PPT

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UNIT-I

AIRCRAFT IN EQUILIBRIUM FLIGHT, ELEVAOR ANGLE TO TRIM, LONGITUDINAL AND MANEUVER STABILIY

CONTENTS

- DEGREES OF FREEDOM OF A SYSTEM
- STATIC STABILITY
- DYNAMIC STABILITY
- NEED FOR STABILITY IN AIRPLANES
- PURPOSE OF CONTROLS
- INHERENTLY AND MARGINALLY STABLE AIRPLANES

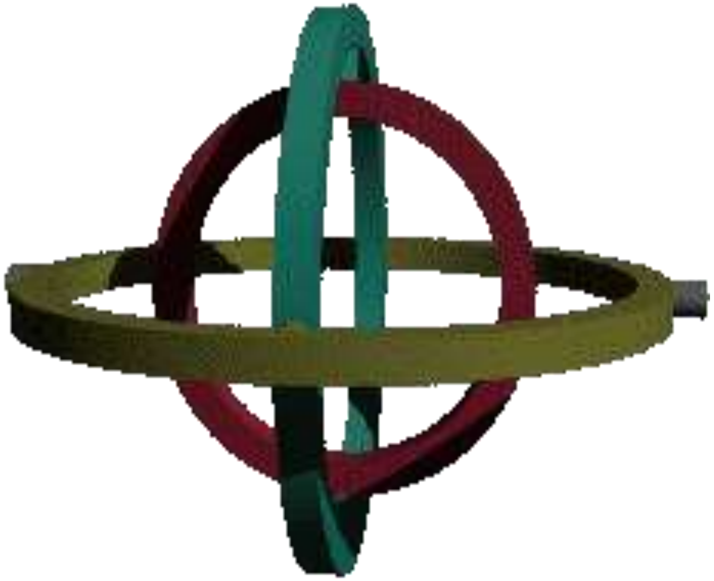
1.DEGREES OF FREEDOM

- The In mechanics, **degrees of freedom** (DOF) are the set of independent displacements and/or rotations that specify completely the displaced or deformed position and orientation of the body or system.
- A rigid body moving in 3–D space system has six degrees of freedom – 3 translational and 3 rotational.
- In general, a rigid body in d dimension space system has $d(d + 1)/2$ degrees of freedom (d translations and $d(d - 1)/2$ rotations).

Degrees of freedom – EXAMPLE

GIMBAL LOCK-contd

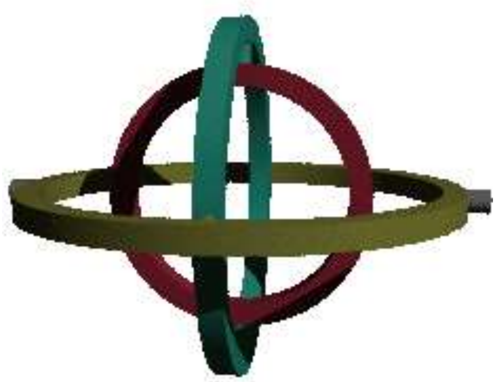
ROTATING GIMBAL



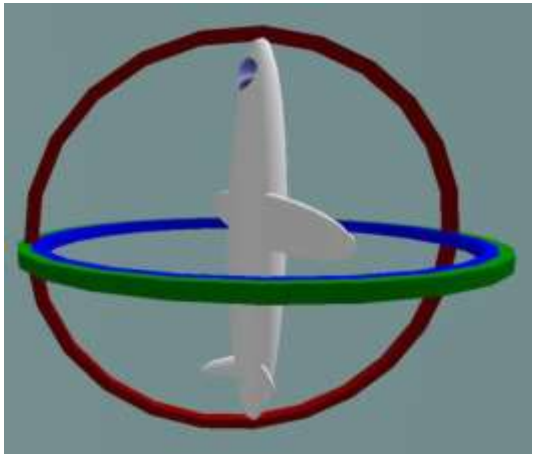
Degrees of freedom – EXAMPLE
GIMBAL LOCK-contd

- **Gimbal lock** is the loss of one degree of freedom that occurs when the axes of two of the three gimbals are driven into the same place and cannot compensate for rotations around one axis in three dimensional space.

GIMBAL NO LOCK



GIMBAL LOCK – LOSS OF ONE D O F



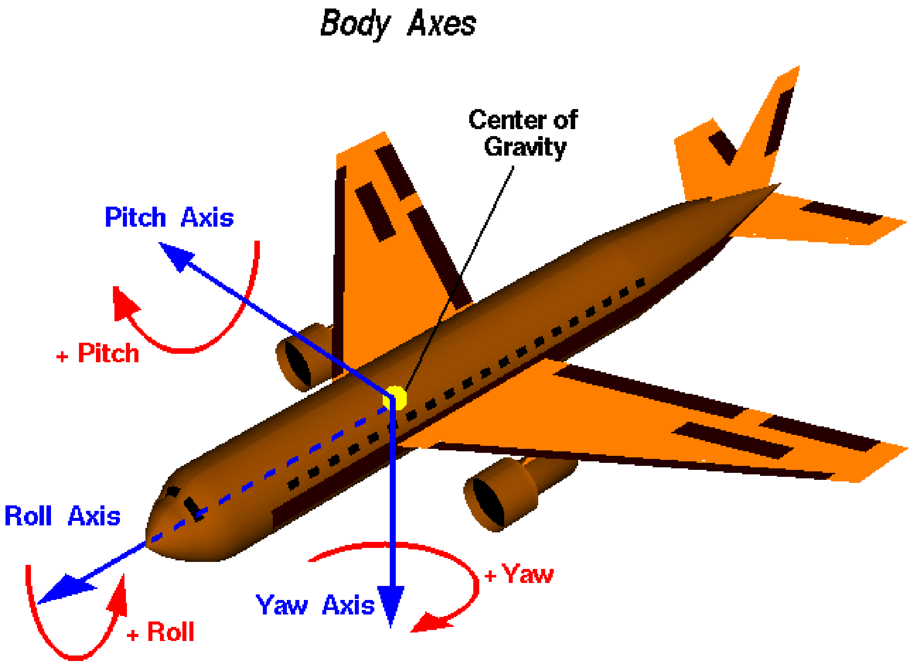
Degrees of freedom – EXAMPLE
GIMBAL LOCK-contd

Note – In a gimbal lock no gimbal is restrained. All three gimbals can still rotate freely about their respective axes of suspension. Nevertheless, because of the parallel orientation of two of the gimbal axes there is no axis available to accommodate rotation along one axis. This results in loss of one degree of freedom.

Degrees of freedom – EXAMPLE
AIRPLANE

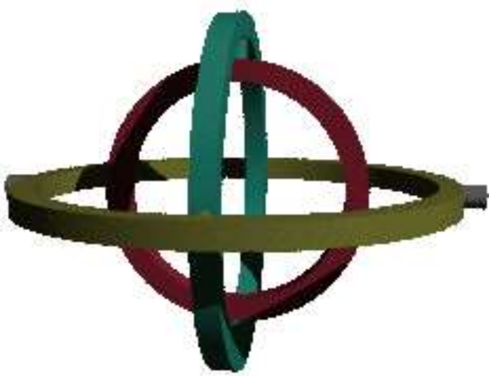
- The airplane axis system is shown below.
- It is a right hand axes system with the positive X and Z axes in the plane of symmetry and Y axis perpendicular to the

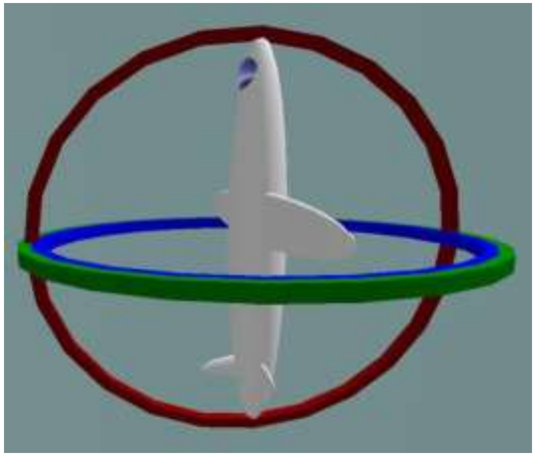
  plane of symmetry



Degrees of freedom – EXAMPLE AIRPLANE-contd

- The airplane is in a kind of gimbal lock when it is in the plane of symmetry when two planes coincide with each other.





Degrees of freedom – EXAMPLE AIRPLANE-contd

- The components of forces and moments acting on the airplane and the components of airplane motion reffered to this axis system are as follows

AXIS	FORCE	MOMENT	LINEAR VELOCITY	ANGULAR DISPLACEMENT	ANGULAR VELOCITY	INERTIA
X	F_x	L	u	ϕ	p	I_x
Y	F_y	M	v	Θ	q	I_y
Z	F_z	N	w	Ψ	r	I_z

Degrees of freedom – EXAMPLE
AIRPLANE

- The motion of an airplane can be completely defined only if the six velocity components are given, the airplane is considered to be a dynamic system in six degrees of freedom
- The equation of statics must be applied to each degree of freedom to check the equilibrium conditions viz.,
- $\Sigma F_X = 0$; $\Sigma F_Y = 0$; $\Sigma F_Z = 0$; &
  $\Sigma L = 0$; $\Sigma M = 0$; $\Sigma N = 0$

Degrees of freedom – EXAMPLE
AIRPLANE-contd

- In three dimensions, the six DOFs of a rigid body (airplane) are described using the following nautical names:
  - Moving up and down (heaving);
  - Moving left and right (swaying);
  - Moving forward and backward (surging);
  - Tilting forward and backward (pitching);
  - Turning left and right (yawing);
  - Tilting side to side (rolling).

2. STATIC STABILITY

- As any vehicle moves it will be subjected to minor changes in the forces that act on it, and in its speed.
- If the change causes further changes that tend to restore the vehicle to its original speed and orientation, without human or machine input, the vehicle is said to be statically stable. The aircraft has positive stability.
- If the change causes further changes that tend to drive the vehicle away from its original speed and orientation, the vehicle is said to be statically unstable. The aircraft has negative stability.
- If the change causes no tendency for the vehicle to be restored to its original speed and orientation, and no tendency for the vehicle to be driven away from its original speed and orientation, the vehicle is said to be neutrally stable. The aircraft has zero stability.

STATIC STABILITY - contd

- LONGITUDINAL STABILITY – It is the stability of an aircraft in the longitudinal, or pitching, plane during static (established) conditions.
  - This characteristic is important in determining whether an aircraft will be able to fly as intended.
- The longitudinal stability of an aircraft refers to the aircraft's stability in the pitching plane – i.e., the plane which describes the position of the aircraft's nose in relation to its tail and the horizon.

STATIC STABILTY – contd

LONGITUDINAL STATIC STABILITY

- If an aircraft is longitudinally stable, a small increase in angle of attack will cause the pitching moment on the aircraft to change so that the angle of attack decreases. Similarly, a small decrease in angle of attack will cause the pitching moment to change so that the angle of attack increases.

STATIC STABILITY - contd

- DIRECTIONAL STABILITY – It is the stability of a moving body or vehicle about a vertical axis.
- If a vehicle is directionally stable, a yawing moment is produced which is in a direction *opposite* to the rotational disturbance. This "pushes" the vehicle (in rotation) so as to return it to the original orientation, thus tending to keep the vehicle oriented in the original direction.

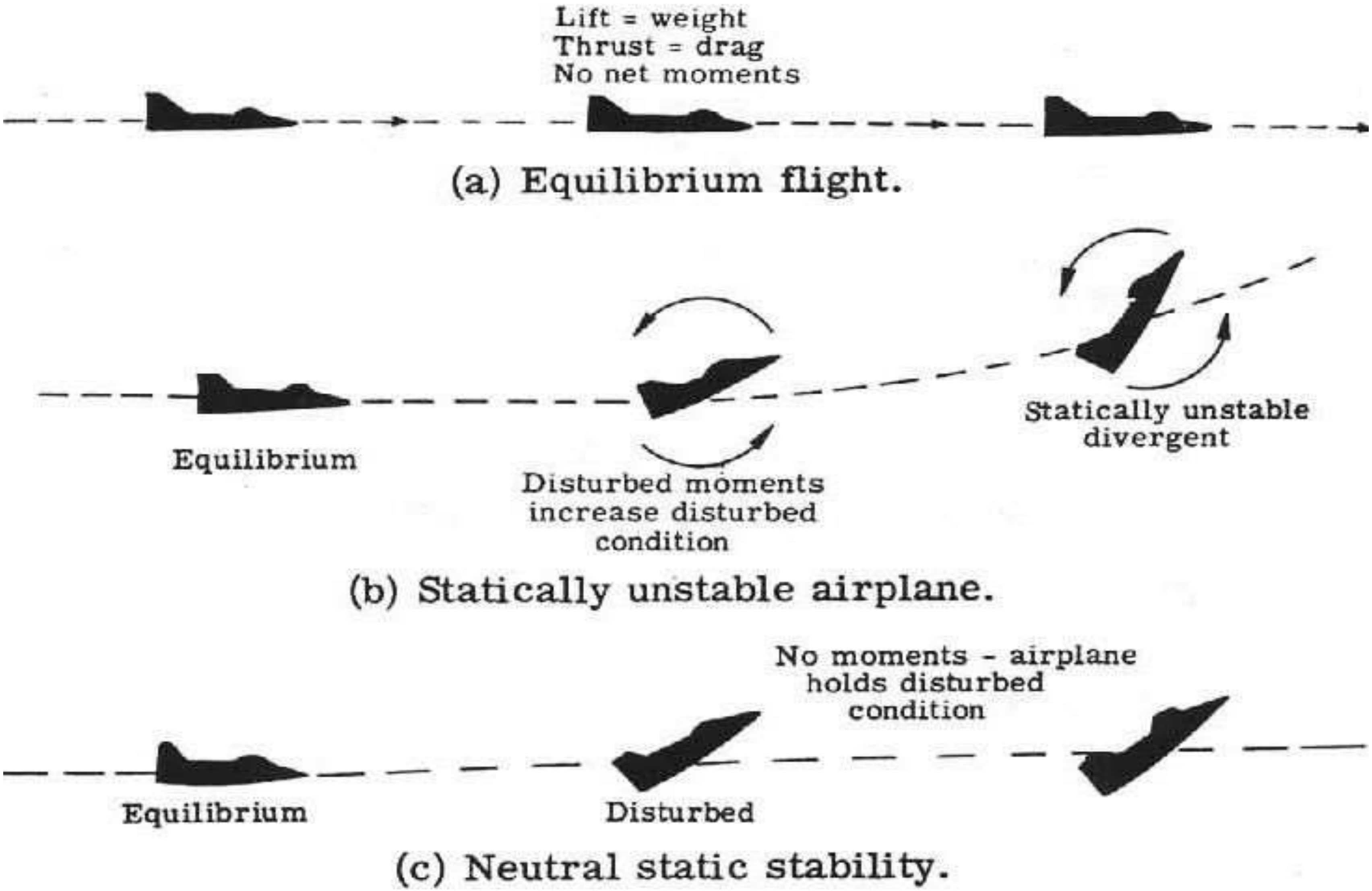
STATIC STABILITY - contd

- LATERAL STABILTY – An airplane is said to possess *lateral static stability* if after undergoing a disturbance that rolls it to some bank angle ø, it generates forces and moments that tend to reduce the bank angle and restore the equilibrium flight condition.

STATIC STABILITY - contd

Lateral and directional stability are interrelated. The motions of an airplane are such that a roll motion causes a yaw motion and a yaw motion causes a roll motion. Thus, cross-coupling exists between the directional static stability and lateral static stability and gives rise to the three important dynamic motions observed: directional divergence, spiral divergence, and Dutch roll.

STATIC STABILITY

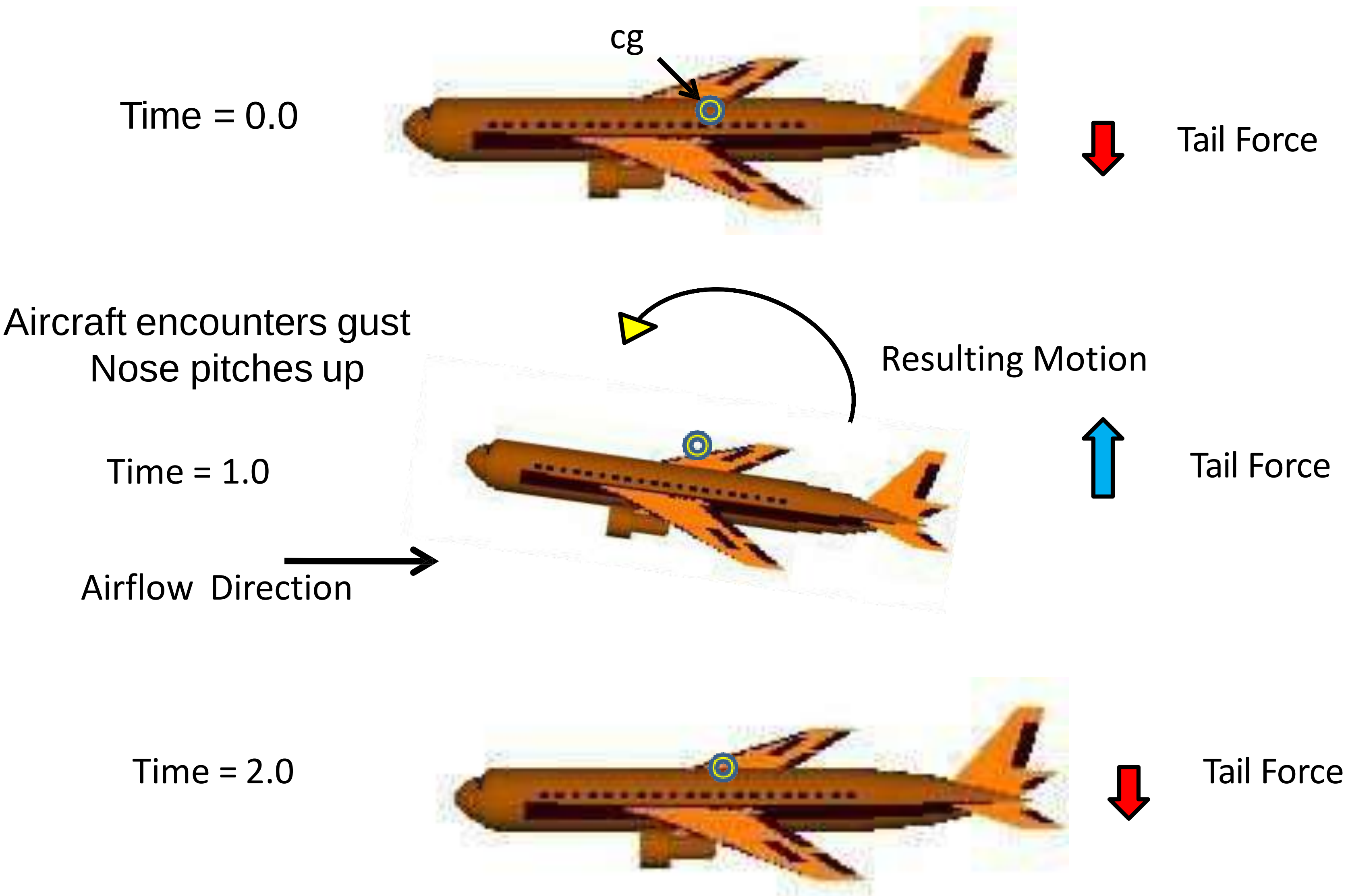


(a) Equilibrium flight.

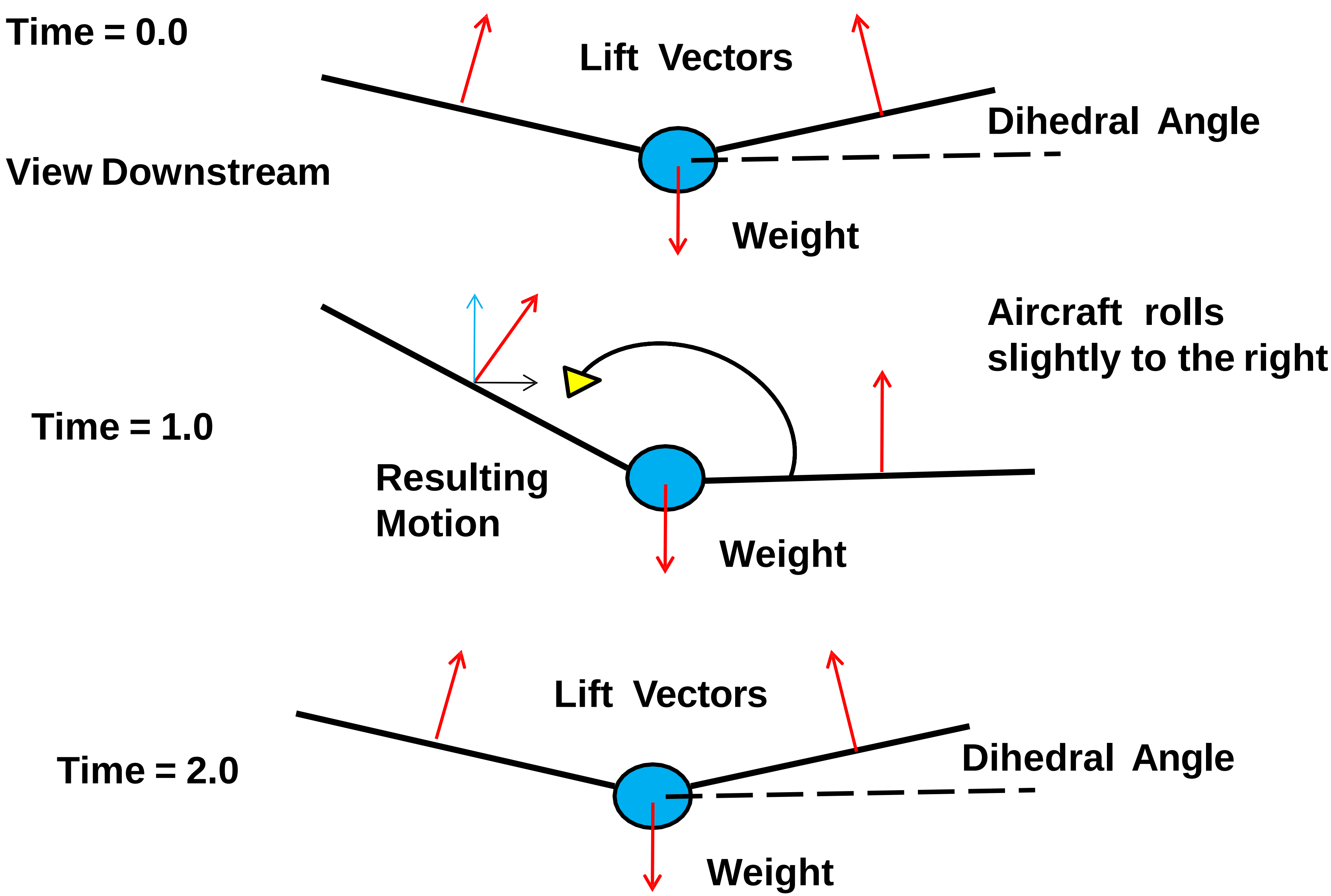
(b) Statically unstable airplane.

(c) Neutral static stability.

Longitudinal Static Stability



Lateral Static Stability



LATERAL CONTROL

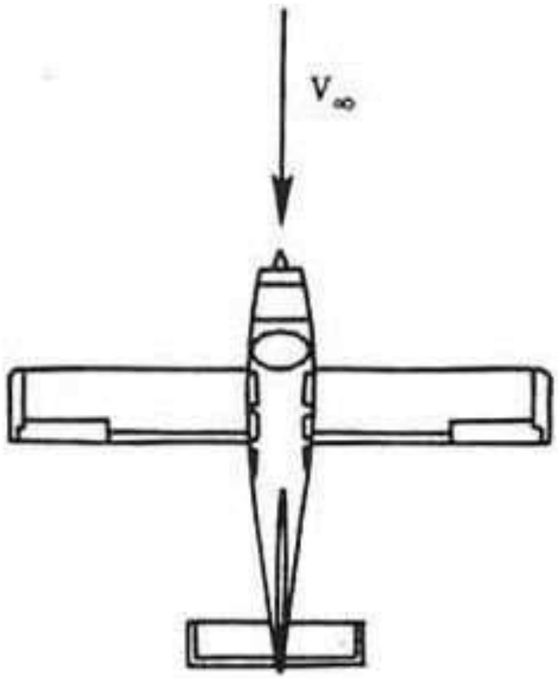
INDEPENDENT FUSELAGE AZIMUTH CONTROL

- PILOT COMMANDS FUSELAGE SIDESLIP

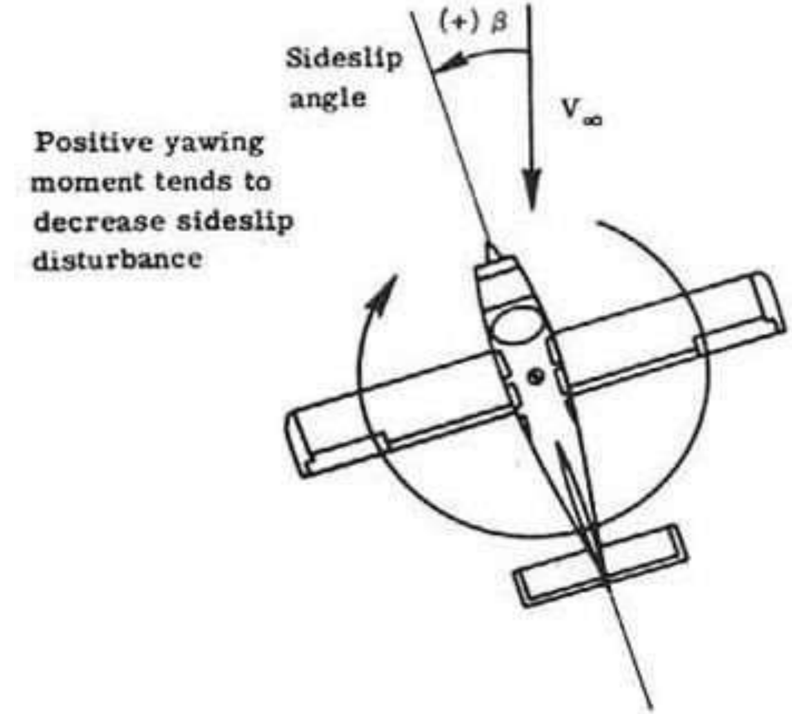
LATERAL TRANSLATION (DIRECT SIDEFORCE) CONTROL

- PILOT COMMANDS LATERAL LOAD FACTOR WITHOUT YAW RATE

STATIC DIRECTIONAL STABILITY



(a) Equilibrium condition of zero yaw.

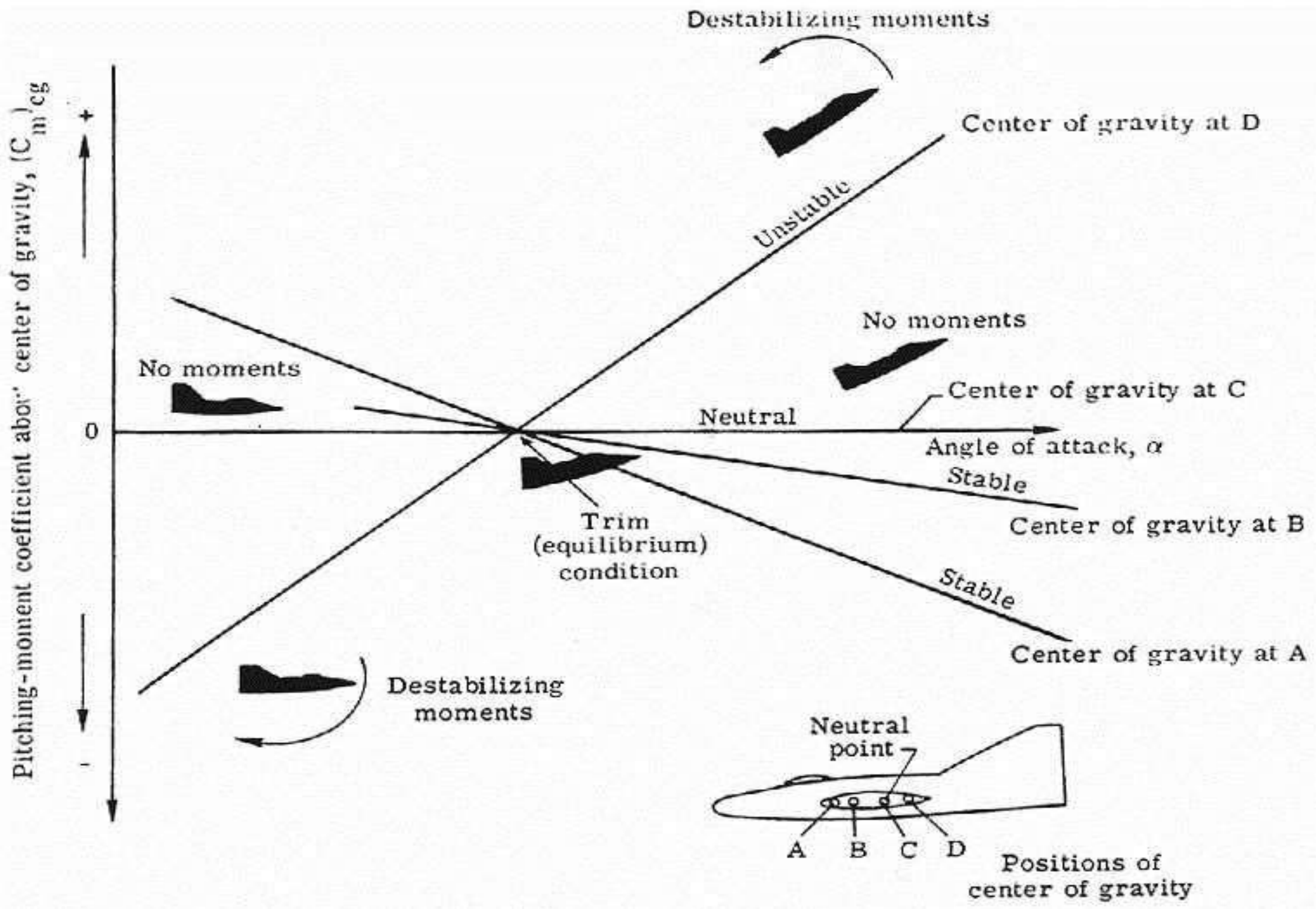


(b) Sideslip disturbance.

a) STATICALLY STABLE AIRPLANE

b) RESTORING MOMENT in yaw direction

ANGLE OF ATTACK vs PITCHING MOMENT



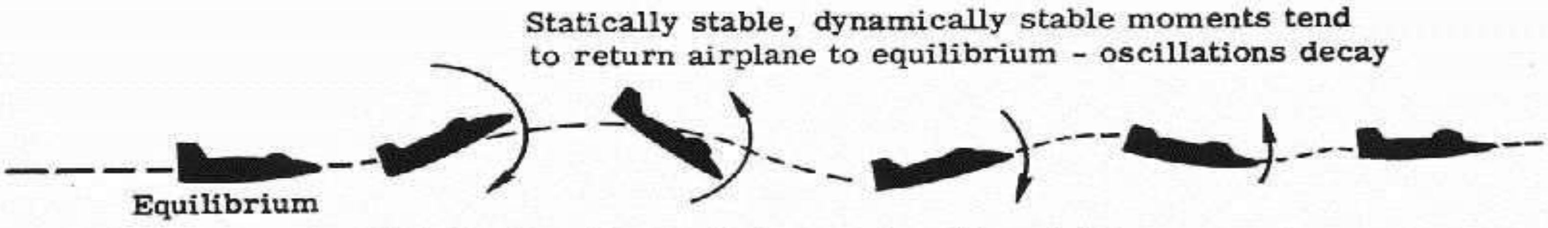
3.DYNAMIC STABILITY

- It deals with the time history of aircraft motion after the aircraft is disturbed from an equilibrium or trim condition.
- If the aircraft goes to its original condition as the time goes to infinity, it is said to have positive dynamic stability.
- If the aircraft neither returns to trim nor diverges further from the disturbed condition, it is said to have neutral dynamic stability.
- If the aircraft diverges from the trim condition and the disturbed condition as time goes to infinity, it si said to have dynamic instability

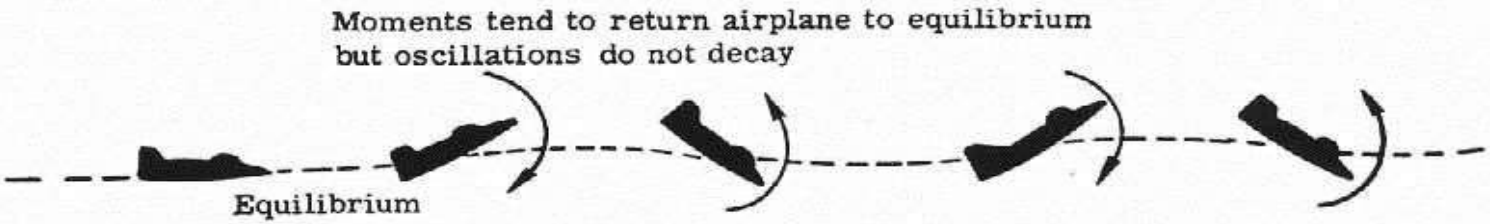
DYNAMIC STABILITY – Contd.

- The study of dynamic stability is important to understand aircraft handling qualities and design features that make an airplane fly or not as well while performing specific mission tasks.

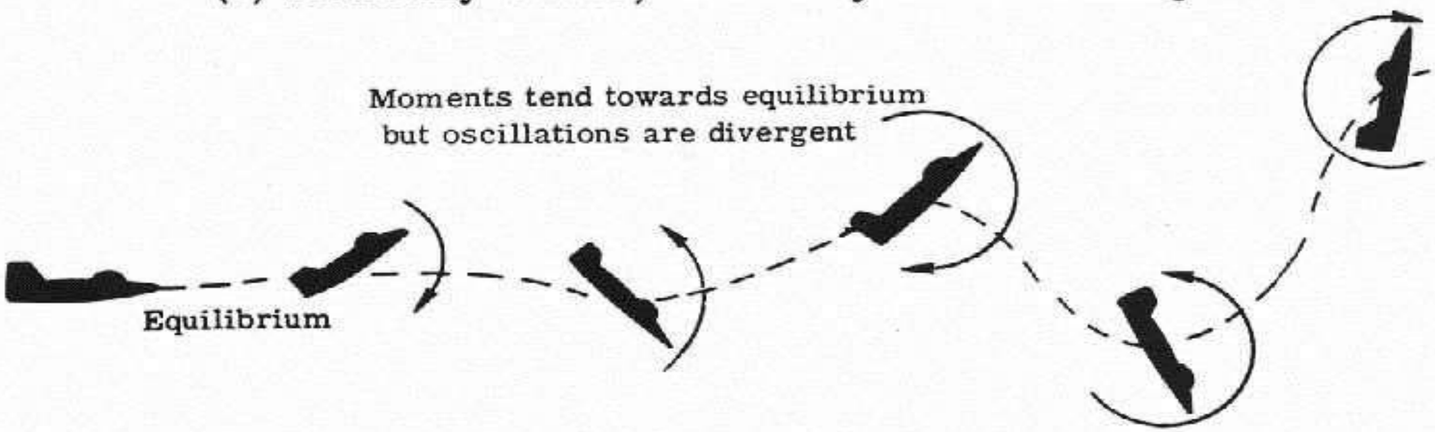
DYNAMIC STABILITY



(a) Statically and dynamically stable.



(b) Statically stable; neutral dynamic stability.

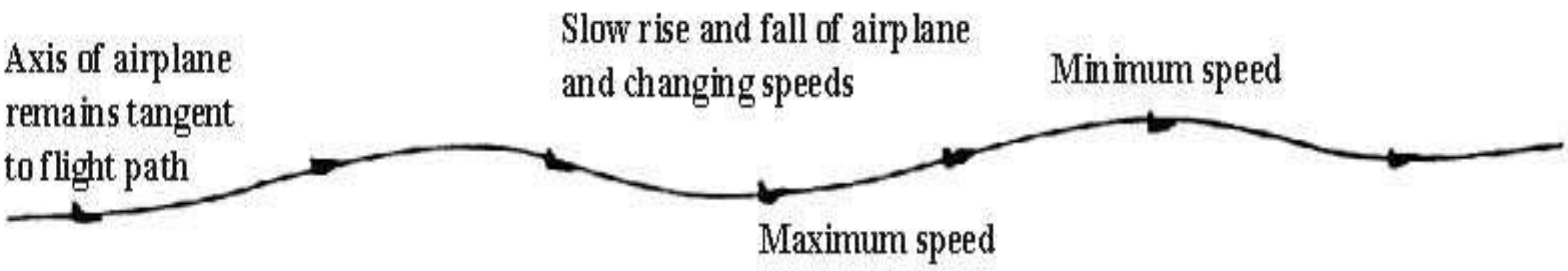


(c) Statically stable; dynamically unstable.

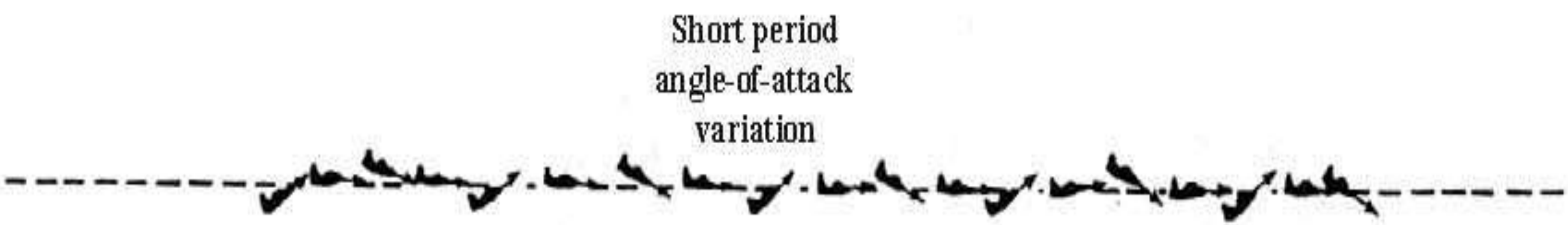
DYNAMIC STABILITY – Contd.

- LONGITUDINAL DYNAMIC STABILITY
  - Deals with statically stable airplane
  - Two types of oscillations
    - Phugoid mode of oscillation – long & slow
    - Short period variation with angle of attack

Phugoid and short period oscillations



(a) Phugoid longitudinal oscillation.



(b) Short-period longitudinal oscillation.

LONGITUDINAL DYNAMIC STABILITY

- PHUGOID MODE LONGITUDINAL OSCILLATION
  - is a long-period, slow oscillation of the airplane's flight path.
  - The pilot generally can control this oscillation himself

LONGITUDINAL DYNAMIC STABILITY

- SHORT PERIOD VARIATION WITH ANGLE OF ATTACK
  - this oscillation decreases very quickly with no pilot effort.
  - But, with its natural short period, the oscillation may worsen if a pilot attempts to lessen it by use of a control because of the pilot's slow reaction time where he may get "out of phase" with the oscillation, and thus induce dynamical instability that may eventually lead to destructive forces.

UNIT-II

ESTIMATION OF AERODYNAMIC FORCE AND MOMENT DERIVATIVES OF AIRCRAFT

LONGITUDINAL DYNAMIC STABILITY

SHORT PERIOD VARIATION WITH ANGLE OF ATTACK

- occurs if the elevators are left free.
- This is called the "porpoising" mode, and is influenced by the elevator balance.
- The main effect is vertical accelerations of the airplane that may get out of hand if a coupling between the free elevator and airplane occur. Proper design is essential to avoid this type of instability.

Contributions of power plant to C_{mcg} and $C_{m\alpha}$

- The contributions of power plant to C_{mcg} and $C_{m\alpha}$ have two aspects namely direct contribution and indirect contribution.

Direct contribution of power plant to C_{mcg} and $C_{m\alpha}$

- The direct contribution appears when the direction of the thrust vector does not coincide with the line passing through the c.g.
- The direct contribution is written as : $M_{cgp} = T \times Z_p$ (2.59)

  where, T is the thrust and Zp is the perpendicular distance of thrust line from FRL; positive when c.g. is above thrust line.

- In non-dimensional form Eq.(2.59) is expressed as:

$$C_{mcgp} = M_{cgp}/(\tfrac{1}{2}\,\rho V^2 S\,\epsilon\,)$$

- The thrust required varies with flight speed and altitude. Hence, C_{mcgp} would vary with flight condition.

- However, the thrust setting does not change during the disturbance and hence, there is no contribution to $C_{m\alpha}$.

- This fact is also mentioned in Ref.1.9. p.506.

- The contribution to $C_{m\alpha}$ comes from another cause. Consider a propeller at an angle of attack . The free stream velocity (V) is at an angle (α)to the propeller axis.
- As the air stream passes through the propeller it leaves in a nearly axial direction. This change of direction results in a normal force (N_p) in addition to the thrust (T).
- N_p acts at distance l_p from the c.g. (Fig.2.26) and hence, produces a moment $N_p \times l_p$.

- It may not return to the equilibrium position namely divergent oscillation and undamped oscillation.
- Only when the system finally returns to the equilibrium position, the system is said to be dynamically stable.
- Otherwise, it is dynamically unstable. With this criterion, the damped oscillation and subsidence are the only dynamically stable cases.

- The value of N_p depends on the angle of attack of the propeller and hence the term N_p x l_p depends on α. This will contribute to $C_{m\alpha}$. $C_{m\alpha}$ due to normal force depends on many factors like thrust setting, number of blades in the propeller and advance ratio.

Indirect contributions of power plant to C_{mcg} and $C_{m\alpha}$

The effect of propeller on the horizontal tail has been discussed. In the case of an airplane with a jet engine, the exhaust expands in size as it moves downwards and entrains the surrounding air.

This would induce an angle to the flow; the induced angle would be positive in the region below the jet.

In military airplanes where the engine is located in rear fuselage the engine exhaust would affect the horizontal tail, generally located above the rear fuselage, by inducing a downwash in addition to that due to wing.

This effect will also come into picture in case of passenger airplanes with rear mounted engines. To alleviate this, the horizontal tail is mounted above the vertical tail

Slope of lift curve ($C_{L\alpha}$) and angle of zero lift (α_{0L}) of the airplane:

- Let, L denote lift of airplane. Then, $L = L_{wb}+L_t$.
- For airplanes with large aspect ratio wings (A>5), the lift of the wing body combination is approximately equal to lift produced by the gross wing i.e.. $L_{wb} \approx L_w$
- Noting that $L_t = ½\rho V_t^2 S_t C_{L\alpha t} (\alpha - s + i_t)$ and $L_w = ½ \rho V^2 S C_{Lw}$; the slope of the lift
- curve of the airplane ($C_{L\alpha}$) can be written as :

$$C_{L\alpha} = C_{L\alpha w} + \eta (S_t/S) C_{L\alpha t} \{1-(ds/d\alpha)\}$$

Angle of zero lift (α_{0L}) for airplane:

- Assuming that the wing is set such that during cruise the angle of attack of the airplane (α_{cr}) is zero, the lift coefficient during cruise (C_{Lcr}) can be written as :

$$C_{Lcr} = C_{L\alpha} (\alpha_{cr} - \alpha_{0L}) = C_{L\alpha} (0 - \alpha_{0L})$$

Hence, $\alpha_{0L} = - C_{Lcr} / C_{L\alpha}$

Stick-fixed neutral point

- It may be pointed out that the c.g. of the airplane moves during flight due to consumption of fuel. Further, the contribution of wing to $C_{m\alpha}$ depends sensitively on the location of the c.g. as it is proportional to ($\frac{x_{cg}}{c} - \frac{x_{ac}}{c}$).

- When the c.g. moves aft, x_{cg} increases and the wing contribution becomes more and more positive. There is a c.g. location at which $(C_{m\alpha})_{\text{stick-fixed}}$ becomes zero.

- This location of c.g. is called the stick-fixed neutral point. In this case, the airplane is neutrally stable.

- If the c.g. moves further aft, the airplane will become unstable. The C_m vs. α curves for the statically stable, neutrally stable and unstable cases are schematically.

- It may be recalled that the aerodynamic centre of an aerofoil is the point about which the pitching moment is constant with angle of attack.
- Similarly, the aerodynamic centre of the wing (x_{ac}), by definition, is the point about which C_{macw} is constant with angle of attack.
- With this background, the quantity x_{acwb} can be called as the aerodynamic centre of the wing - body - nacelle combination.
- Further, when the c.g. is at neutral point, $C_{m\alpha}$ is zero or C_{mg} is constant with α.
- This refers the neutral point as the aerodynamic centre of the entire airplane.

UNIT-III

STICK FREE LONGITUDINAL STABILITY, CONTROL FORCES TO TRIM AND LATERAL- DIRECTIONAL STATIC STABILITY

INTRODUCTION

- The motion of the airplane takes place in the plane of symmetry i.e. along x-and z-axes and about y-axis.

- This chapter and the next one, deal with the motions along y-axis and about x-and z-axes.

- These motions lie outside the plane of symmetry.

- The translatory motion along y-axis is sideslip and rotations about x-and z-axes are the rolling and yawing respectively.

- The lateral stability and control, deal with the equilibrium and its maintainability about the x-axis.
- However, the lateral and directional motions cannot be separated completely because a change in one of them leads to change in the other.

- The directional stability and control, deal with the equilibrium and its maintainability about the z-axis.
- For example, when an airplane has a rate of roll, the unequal changes in the drag of the two wing halves create a yawing moment.
- Besides the rolling and yawing motions, the sideslip also creates forces and moments affecting lateral and directional motions.
- The six effects caused by rolling, yawing and sideslip are listed below.

- Rolling moment due to rate of roll.
- It is called damping in roll.
- Yawing moment due to rate of yaw.
- It is called damping in yaw.
- Rolling moment due to rate of yaw.
- It is called cross effect.
- Yawing moment due to rate of roll.
- It is called adverse yaw.
- Rolling moment due to side slip.
- It is called dihedral effect.
- Yawing moment due to sideslip.
- It is called weather cock effect.

•The directional static stability and control are considered.

Criteria for equilibrium and static stability about z-axis

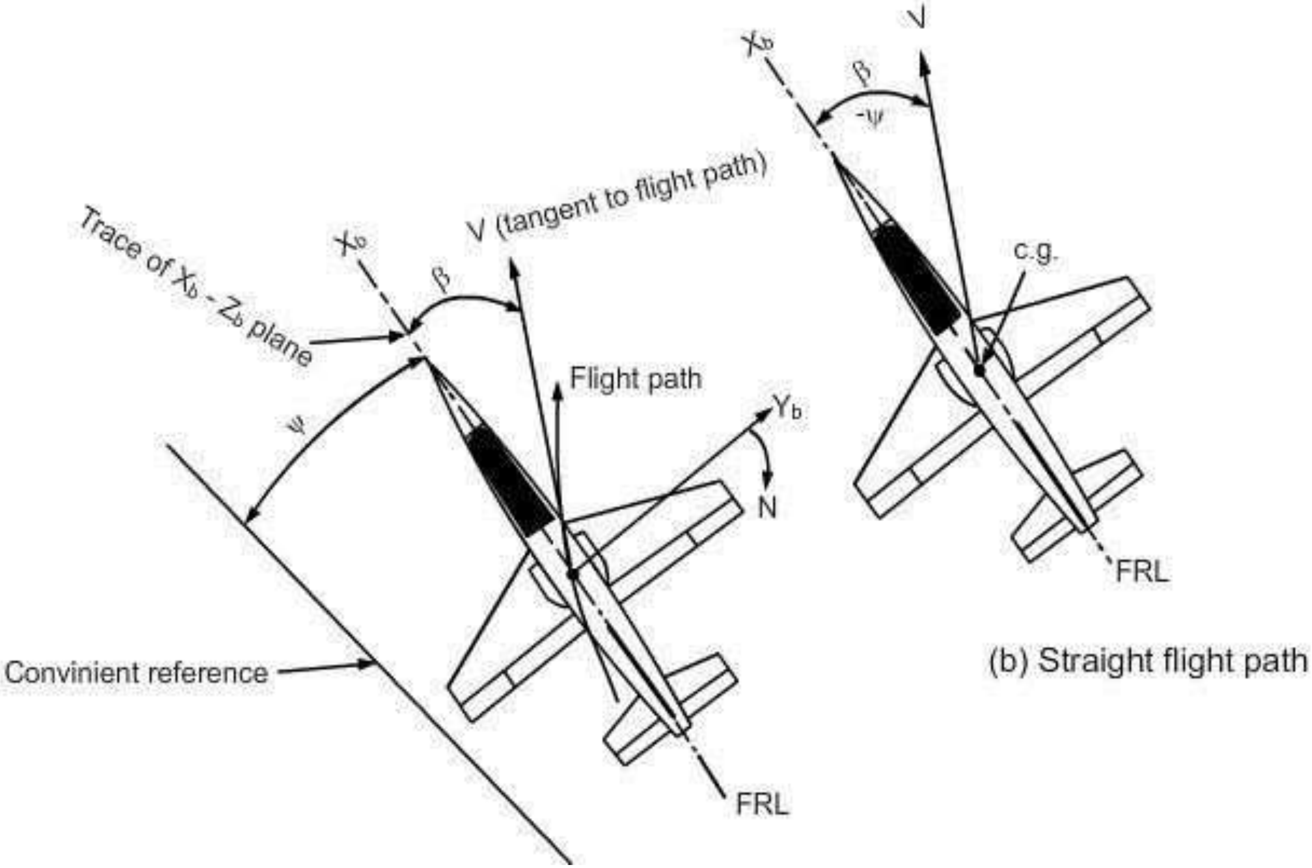
In an equilibrium flight, the airplane flies in the plane of symmetry with sideslip and yawing moment both being zero.

Before discussing the criteria for equilibrium and static stability about z-axis,it is useful to recapitulate a few relevant concepts.

Sideslip and yaw

- Sideslip is the angle between the plane of symmetry of the airplane and the direction of motion.
  It is taken as positive in the clockwise sense.
- It is denoted by ‘β’. It may be recalled that the tangent to the flight path is the direction of motion.
- It may be further pointed out that a positive β is due to a positive side slip velocity which is the component of airplane velocity along the y-axis.

- Angle of yaw is the angular displacement of the airplane center line, about a vertical axis, from a convenient horizontal reference line.
- It is measured from the arbitrarily chosen reference direction and taken as positive in the clockwise direction . It is denoted by ‘y



(b) Straight flight path

Criterion for directional static stability

- The conventions for positive yawing moment and sideslip (β).
- Consider that in equilibrium flight, the airplane is flying with $\beta = 0$.
- Now, let a disturbance cause the airplane to develop positive sideslip of $\Delta\beta$.
- It is observed that to bring the airplane back to equilibrium position i.e. $\beta=0$, a positive yawing moment (ΔN) should be produced by the airplane. Similarly, a disturbance causing a negative $\Delta\beta$ should result in $-\Delta N$ i.e. for static directional stability,

  $dC_n/d\beta$ or $C_{n\beta}$ should be positive.

UNIT-IV

ARICRAFT EQUATIONS OF MOTION, PERTURBED MOTION, LINEARIZED, DECOUPLED EQUATIONS

Static stability and dynamic stability

- In the cases it is observed that, as soon as the the system is disturbed, it tends to return to the undisturbed position. Such systems are called statically stable.
- The tendency of the system, immediately after the disturbance, is to turn away from the equilibrium position. Such a system is said to be statically unstable.
- When the tendency of the system, after the disturbance, is to stay in the disturbed position, then it is said to have neutral static stability.
- Even when the system has a tendency to go towards the undisturbed position

- It may not return to the equilibrium position namely divergent oscillation and undamped oscillation.
- Only when the system finally returns to the equilibrium position, the system is said to be dynamically stable.
- Otherwise, it is dynamically unstable. With this criterion, the damped oscillation and subsidence are the only dynamically stable cases.

Body axes system

- To formulate and solve a problem in dynamics we need a system of axes.
- To define such a system, we note that an airplane is nearly symmetric in geometry and mass distribution about a plane which is called the plane of symmetry.
- This plane is used for defining the body axes system.
- It shows a system of axes (OXbYbZb) fixed on the airplane which moves with the airplane and hence called body axes system.

- The origin ‘O’ of the body axes system is the center of gravity (c.g.) of the body which, by assumption of symmetry, lies in the plane of symmetry.
- The axis OXb is taken as positive in the forward direction. The axis OZb is perpendicular to OXb in the plane of symmetry, positive downwards. The axis OYb is perpendicular to the plane of symmetry such that OXbYbZb is a right handed system.

Effect of elevator deflection on C_{mcg} vs α curve

- When an elevator is deflected it produces a moment about c.g.
- Then the value of C_{m0} of the airplane changes and the C_{mcg} vs α curve is shifted.
- However, $C_{m\alpha}$ does not change due to the elevator deflection and the slope of the curve is same as that with zero elevator deflection.
- This figure also indicates that elevator deflection brings about change in the value of α at which C_{mcg} is zero or the airplane is in trim.
- It may be pointed out that the elevator deflection is denoted by 6_e and downward deflection of elevator is taken positive (see section 2.4.5 for further details).

UNIT-V

LONGITUDINAL, LATERAL AND DIRECTIONAL DYNAMIC STABILITY

Cmcg and Cmα expressed as sum of the contributions of various components of the airplane

Using wind tunnel tests on a model of an airplane or by Computational

- Fluid Dynamics (CFD), the Cmcg vs α curve for the entire airplane can be obtained.
- However, CFD has not yet advanced enough to give accurate values of the moments and these computations are not inexpensive.
- Wind tunnel tests are very expensive and are resorted to only at the later stages of airplane design. Hence, the usual practice to obtain the Cmcg vs α curve is to add the contributions of major components of the airplane and at the same time take into account the interference effects

- . The contributions of individual components are based on the wind tunnel data or the analyses available in literature. References 1.1,1.8,1.9, 1.12, 2.1 and 2.2 are some of the sources of data.
- The contributions to C_{mcg} and $C_{m\alpha}$ are due to the wing, the fuselage, the power plant and the horizontal tail. Figure 2.8 shows the forces and moments produced by the wing and the horizontal tail. The contributions of fuselage, nacelle and the power plant are shown as moments about c.g. and denoted by
- $M_{f,n,p}$. The fuselage reference line is denoted by FRL. It may be recalled that the

Stability and control

- angle of attack (α) of the airplane is the angle between free stream velocity (V) and FRL.
- The c.g. of the airplane is also shown in the figure. The wing is represented by its mean aerodynamic chord (m.a.c.).
- It is set at an angle of incidence iw to the FRL. Hence, the angle of attack of wing (αw) is α + iw.
- Following the usual practice, the lift of the wing (LW) is placed at the aerodynamic centre of the wing (a.c.) along with a pitching moment (Macw).
- The drag of the wing (Dw) is also taken to act at the aerodynamic centre of the wing.
- The wing a.c. is located at a distance xac from the leading edge of the m.a.c. The airplane c.g. is at a distance xcg from the leading edge of the m.a.c.

- The horizontal tail is also represented by its mean aerodynamic chord.
- The aerodynamic centre of the tail is located at a distance *l*t behind the c.g.
- The tail is mounted at an angle it with respect to the FRL.
- The lift, drag and pitching moment due to the tail are Lt, Dt and Mact respectively. As the air flows past the wing, it experiences a downwash s which is shown schematically.
- Owing to this the angle of attack of the horizontal tail would be (α + it - s). Further, due to the interference effects the tail would experience a dynamic pressure different from the free stream dynamic pressure. These aspects will be elaborated.

Contributions of wing to Cmcg and Cmα

- The forces (lift, Lw and drag, Dw) and the moment (Macw) due to the wing and the relative locations of the c.g. of the airplane and the aerodynamic centre of the wing.
- The angle of attack of the airplane is the angle between the relative wind and the fuselage reference line (F'L). This angle is denoted by α.
- The wing is represented by its mean aerodynamic chord (m.a.c.).
- The wing is set at an angle iw to the FRL. This is done so that the fuselage is horizontal during cruising flight. Thus, αw = α + iw or α = αw – iw.
- xac is the distance of the a.c. from the leading edge of the m.a.c..
- xcg is the distance of the c.g. from the leading edge of the m.a.c..
- Zcgw is the distance of the a.c. below c.g.

- An important aspect of the above derivation may be pointed out here.
- The expression for Cmαwh involves CL or the slope of Cmcgw vs α curve depends on CL or α.
- Hence, Cmcgw become slightly non-linear.
- The usual practice, is to ignore the contributions of the horizontal components to Cmαw.
- However, the following aspects may be pointed out. (a) A high wing configuration is slightly more stable than a mid-wing configuration.
- A low wing configuration is slightly less stable than the mid-wing configuration. (b) In the simpler analysis the Cmcgw vs α curve is treated as straight line but the Cmcg vs α curves, obtained from flight tests on airplanes, are found to be slightly non-linear. One of the reasons for the non-linearity in actual curves is the term Megwh.