Flight Stability and Dynamics (Axes of an Aircraft)

Any attitude change around these axes:

1, the Axis extending through the fuselage from nose to tail, Longitudinal (roll)

2, Axis from wing tip to wing tip, Lateral (pitch)

3, Axis from top to bottom, Vertical (yaw)

Flight Stability and Dynamics (Axes of an Aircraft)

• Roll, pitch and yaw controlled by the Control Surfaces

• Roll produced by Ailerons, at the wing trailing edges

• Pitch produced by Elevators, at the rear part of the horizontal tail

• Yaw produced by Rudder, at the rear part of the vertical tail

Stability and Control

• Stability is required for an aircraft to fly in a flightpath Proper response to controls for aircraft performance

Flight Controls moved by the pilot produce aerodynamic forces for following desired flightpath

• Controllable aircraft, if it responds easily and promptly to control movements, changing the airflow

Stability (static and dynamic): aircraft tendency to fly in a straightened-level flightpath

Maneuverability: aircraft ability to change direction (follow desired flightpath) and withstand the stresses imposed

Controllability: aircraft's capability to respond to pilot's commands (flightpath and attitude)

Stability and Control (Static Stability): aircraft tendency to fly in a straightened-level flightpath

Maneuverability: aircraft ability to change direction (follow desired flightpath)

Controllability: aircraft's capability to respond to pilot's commands (flightpath and attitude)

Stability and Control (Static Stability)

Aircraft's initial tendency: the initial tilt of the aircraft returns to equilibrium upon turbulence from (AOA), slip, bank.

Positive Static: tendency return back to the equilibrium.

Neutral Static: tendency remain in new condition.

Negative Static: tendency to continue away from equilibrium.

Stability and Control (Dynamic Stability))

Aircraft's response over time: when disturbed from a given AOA, slip, bank.

Positive Dynamic Stability: motion decreasing in amplitude and aircraft returning back to equilibrium.

Neutral Dynamic Stability: motion neither increasing nor decreasing in amplitude.

Negative Dynamic Stability: motion increasing in amplitude.

Stability and Control Longitudinal Stability (Pitching)

Stability about the lateral axis most affected in various flight conditions like:

1, Involves pitching motion as aircraft's nose moves up and down.

2, Longitudinally unstable aircraft: when aircraft tends to dive or climb progressively and difficult/dangerous to fly

Longitudinal stability affected by:

1, Wing location w.r.t. CG

2, Horizontal tail surfaces location w.r.t. CG

3, Area/Size of tail surfaces

For longitudinal stability: moments must be initially balanced and if aircraft suddenly nose up/down, wing and tail moments change to produce restoring moments bringing nose down/up

Stability and Control Longitudinal Stability (Pitching)

Centre of Lift Centre of Pressure): tends to move forward with increase of AOA and move aft with decrease of AOA. This tendency makes wing unstable.

In most aircraft CL rear of the CG, making aircraft nose heavy and requiring a downward force on the horizontal stabilizer for balance.

If CL rear of CG: horizontal stabilizer at a slight negative AOA.

Stability and Control Longitudinal Stability (Pitching)

Wing downwash produced: 1) strikes horizontal stabilizer and 2) downward pressure balances the aircraft

As airspeed increases: 1) downwash increases and 2) downward force on the horizontal stabilizer increases.

As airspeed decreases: 1) downwash decreases and 2) downward force decreases

For aircraft with fixed-position horizontal stabilizer: set at an angle for best balance when flying at design cruising speed and power setting.

As airspeed decreased, wing airflow decreased:

• Downwash decreased, less downward force on horizontal stabilizer.

• Pitch down tendency

• Wing's AOA and drag reduced

Airspeed increased:

• Downwash on horizontal stabilizer increased

• Downward force increased

• Pitch up tendency

Stability and Control Longitudinal Stability (Pitching)

This nose down – nose up movement produces a diminishing (damping) oscillation Until aircraft stabilized at an airspeed and attitude with all forces and moments counterbalanced.

Similar effect when throttle closed (less power):

• Less downward force on the horizontal stabilizer.

• Pitch down (nose down) tendency

• Airspeed increased and balanced once again

If throttle opened (more power):

• More downward force on the horizontal stabilizer

• Pitch up (nose up) destabilizing tendency

• High Thrust Line (High Thrust Line, line of thrust above CG offsets this tendency)

• As thrust increased, thrust moment counteracts nose up tendency from tail

High Thrust Line, line of thrust above CG:

• As thrust increased, thrust moment counteracts nose up tendency from tail

• Low Thrust Line, (thrust line below CG adds up to nose-up destabilizing tendency)

• If CG forward of CL and aerodynamic tail-down: force produced from tail, aircraft has a stabilizing tendency to return to safe flying attitude

Stability and Control (Lateral Stability (Rolling))

•Stability about the longitudinal axis and stabilizing the rolling effect (more lift in one wing than the other)

Four main design factors in lateral stability:

•1, Dihedral • 2, Sweepback • 3,Keel effect • 4,Weight Distribution

Stability and Control (Lateral Stability (Rolling))

Dihedral to produce lateral stability:

• Wings at an angle to the fuselage

• Slight V formed

• Dihedral measured by angle formed between the wing and the line parallel to the lateral axis

Stability and Control (Lateral Stability (Rolling).

Dihedral:

• When aircraft banked without turning Tendency to sideslip towards the lower wing

• Air on lower wing at a greater AOA than higher wing

• More lift in lower wing Aircraft tends to roll back to lateral balanced flight condition

As aircraft slip right relative wind strikes the under side of the low wing creating rolling motion to the lift.

Stability and Control (Lateral Stability (Rolling))

Dihedral:

1) Restoring force may move lower wing further up Process continues in a lateral damping oscillation until balanced wings-level flight reached.

2) Excessive dihedral has adverse effect on lateral maneuvering qualities (aircraft resist rolling).

3) Aircraft with fast roll properties have less dihedral.

Sweepback:

• Leading edges slopes backward When aircraft drops wing.

• Low wing at a perpendicular angle to the relative airflow Low wing produces more lift.

• Aircraft restored back to original flight attitude

Sweepback:

• Also contributes to directional stability When aircraft yaws to one side.

• One wing presents more frontal area than the other More drag produced, turning aircraft back to original path.

Stability and Control Lateral Stability (Rolling)

Keel Effect and Weight Distribution:

• Weathervane, tendency similar to ship's keel to turn towards the relative wind.

• When aircraft disturbed and wing dips, fuselage acts as a pendulum returning the aircraft to original attitude.

• Stable aircraft: have greater portion of keel above and behind the CG: When aircraft slips to one side, weight and airflow pressure against the upper portion of keel area rolls aircraft back to wings-level flight.

Stability and Control Vertical/Directional Stability (Yawing)

• Stability about the vertical axis, most easily achieved

Vertical stabilizer (fin) and fuselage sides contributors Necessary to have more vertical surface aft of pivot point than forward to produce stabilizing moment.

Necessary to have more vertical surface aft of pivot point than forward to produce stabilizing moment.

The further aft and greater the size of fin, the greater the vertical stability.

Stability and Control Vertical/Directional Stability (Yawing)

After a slight yawing to the right:

•Momentary restoring tendency of aircraft to turn to the left • Restoring tendency slow to develop.

• When tendency ceases, aircraft flying in a direction slightly to the right Pilot must re-establish initial heading

Stability and Control Vertical/Directional Stability (Yawing)

• Sweepback for improving directional stability

•Delays compressibility in high-speed flight Aids in locating CP aft of CG, for restoring yawing moment

For Centre of Pressure enough aft to produce stability:

• Wing must be mounted backward and with dihedral Or with Sweepback to move the CP aft Wing contribution to directional stability small, due to Sweepback.

Stability and Control Free Directional Oscillations (Dutch Roll)

• Coupled Lateral and Directional Oscillation (yawing-rolling combination)

• Usually dynamically stable but unsafe

• Damping may be weak or strong depending on aircraft

• Weaker directional stability than lateral stability

Stability and Control Free Directional Oscillations (Dutch Roll)

• Aircraft rolling around the longitudinal axis:

• Sideslip introduced

• Strong lateral stability begins restoring aircraft to level flight

• Weaker directional stability begins correcting sideslip to align aircraft with relative wind

• Restoring yaw moment lags behind restoring roll motion

• Yawing motion continuing in original roll direction

• Sideslip introduced in opposite direction

• Process reversed

• Aircraft nose making a figure 8, due to two oscillations out of phase

Stability and Control Free Directional Oscillations (Dutch Roll)

Dutch roll oscillations dampen out fast in most aircraft

Gusty winds and turbulence may introduce Dutch roll

To reduce Dutch Roll tendency, yaw dampers are used:

• Yaw rate sensors and processor provide signal to an actuator connected to the rudder

• On some aircraft, yaw damper operational at all times during flight above a specified altitude More desirable an aircraft to have strong static directional stability (spiral instability) than Dutch Roll tendency

Stability and Control PASSIVE AND ACTIVE STABILITY

• Passive Stability: when the vehicle is naturally (inherently) stable and does not require any artificial stabilization systems. This requires positive static stability and positive dynamic stability.

• Active Stability: using artificial stabilizing systems to improve the handling of vehicles which do not exhibit sufficient passive stability. An example of such a system would be an aircraft automatic stabilization system (Basic Autopilot).