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A Comparative Study of Aircraft Controlling Surfaces: Defense and Commercial Applications

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ABSTRACT

Aircraft Stability refers to the property of an aircraft to maintain its attitude or to resist displacement, and if displaced, to develop forces and moments tending to restore the original condition. On the other hand, aircraft control implies to direct the movements of an aircraft with particular reference to changes in attitude and speed. In the context of aircraft, stability plays a key role in the ability to maintain control. The opposite of stability is maneuverability. If an aircraft had infinite stability, it would have no maneuverability. In this case, there would be no way to change the flight path. A desirable middle ground must be designed, depending on the type of aircraft. Where an aircraft trainer or jet transport aircraft may require greater stability for safety and passenger comfort, a jet fighter needs maneuverability for combat situations. Positive stability means that when the aircraft is displaced it tends to return to the original attitude.

Neutral stability would result in the attitude remaining constant after displacement, neither returning nor continuing to displace. Negative stability would result in the attitude continuing to displace or diverge. Stability is also categorized as both static and dynamic. If, the pilot after increasing the pitch of an aircraft, releases the control yoke, the nose will return to level flight, demonstrating positive static stability. As a matter of fact, the nose of the aircraft does not simply return to level, but overshoots and enters a descent, followed by a series of shallower climbs and descents until level flight is eventually reached. These oscillations of smaller and smaller amplitude are a function of the aircraft's positive dynamic stability. If the aircraft had neutral dynamic stability, the oscillations would continue at the same amplitude indefinitely. If an aircraft had negative dynamic stability, the amplitude of the climbs and dives would get steeper and steeper. This paper focuses on the preliminary and comparative analysis of stability and corresponding control measures that are associated with different types of aircrafts. The result would prove the studied analytical concept of the various control surfaces used in the various aircrafts which can be used for commercial and fighter aircraft applications.

***Keywords* –** Control, Maneuverability, Stability, Civil and Fighter aircrafts

I. INTRODUCTION

Flight dynamics deals principally with the response of aerospace vehicles to perturbations in their flight environments and to control inputs. In order to understand this concept of dynamics, it is necessary to characterize the aerodynamic forces and moments acting on the vehicle, and the dependence of forces and moments on the flight variables, including airspeed and vehicle orientation. This paper has an introduction to the engineering science of flight dynamics, focusing primarily of aspects of stability and control [1].

1.1 Static Stability

Aircraft stability and control involves controlling the attitude and flightpath of an aircraft. Stability and control analysis is concerned with the aircraft at several levels of integration. Aircraft fly by generating a lift greater than or equal to their weight. Aircraft do this by holding a wing at a certain angle of attack, or incidence. *Longitudinal control* is the study of how to set, maintain or change that angle of attack whereas *stability* is the study of whether and how that angle of attack will remain fixed when the aircraft is subjected to small perturbations, due to atmospheric turbulence [2].

The issue for the control of the aircraft is how it can maintain its incidence at a given speed. When it takes off or lands, it does so by rotating -raising or lowering its nose-in order to change the incidence of the wing, altering the relationship between speed and lift [3].

1.2 Equilibrium and stability

The requirements of an aircraft control system are that it must be able to bring the aircraft into some required equilibrium and also maintain that equilibrium stably. **Equilibrium** of a system occurs when the sum of all the forces and moments acting on it are identically zero.

Static stability is all about the initial tendency of a body to return to its equilibrium state after being disturbed. To have a statically stable equilibrium point, the vehicle must develop a restoring force/moment to bring it back to the equilibrium condition.

Dynamic stability: a system is dynamically stable if, when disturbed from equilibrium, it does eventually return to the equilibrium configuration. It is basically concerned with the time history of the motion after the disturbance.

To investigate the static stability of an aircraft, can analyze response to a disturbance in the angle of attack: (a) At equilibrium point, expect moment about centre of gravity (c.g.) to be zero i.e. CMcg = 0
(b)If then perturb α up, need a restoring moment that pushes nose back down (negative)

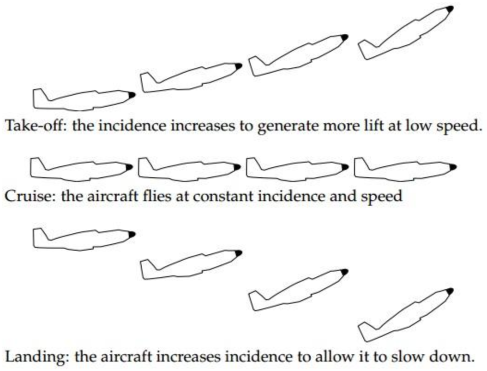

Fig.1 Phases of flight

Various Conditions for static stability:

- Cm = 0; $\frac{\partial Cm}{\partial \alpha} \equiv Cm_{\alpha} < 0$ (1)

Since $C_L = C_{L\alpha}(\alpha - \alpha_0)$ with $C_{L\alpha} > 0$, (2)

then an equivalent condition for static stability is that $\frac{\partial Cm}{\partial C_L} < 0$.

1.3 Functions of Aircraft Controls

The functions of an aircraft control system are to provide a means of changing the moments on an aircraft, to control, in this case, its incidence. There are many ways of doing this, but for the conventional aircraft we consider this is done by moving surfaces in order to change the aerodynamic forces on some part of the aircraft, thereby changing the overall moment [4].
The control surfaces are:

Elevator: It changes the total lift on the tail when it is deflected, causing a change in pitching moment on the aircraft. This allows the pilot to adjust the aircraft incidence;

Ailerons: These change the lift on each wing when they are deflected. They move in opposite directions—one goes up when the other goes down so that the lift on one wing increases and the other decreases. This generates a change in rolling moment and allows the aircraft to rotate about its axis to initiate turns, or allows it to oppose disturbances due to crosswind or gusts (Figure 1).

Rudder: It changes the side force on the vertical tailplane (or fin), generating a change in yawing moment, rotating the aircraft about a vertical axis. This can be used to resist yawing moments due to engine failure and crosswind and to aid in spin recovery and turn co-ordination.

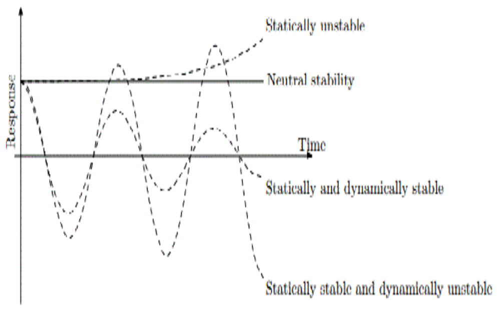

Fig.: 2 Terminology for study of stability

In steady level flight in still air, the rudder and ailerons will be deflected while the elevator will probably be at some deflection which depends on the aircraft loading. Under other conditions, or during a maneuver, all three controls may be used simultaneously. The controls can be operated directly by the pilot, through a system of mechanical actuators, possibly with aerodynamic or power assistance, or controls may be fully powered using a hydraulic or electrical system. These systems can be mechanically or electronically controlled (Figure 2).
The sign conventions for the controls and motions are shown in Figure 3.

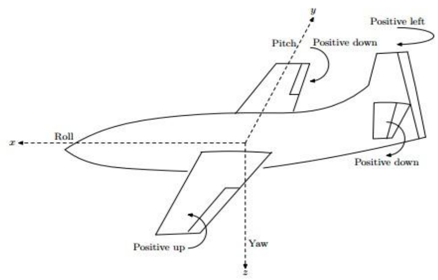

Fig. 3: Axes and sign conventions.

1.4 Trim and Stability

Figure 4 shows the basic configuration for the study of stability of an aircraft, labeled with the forces and moments and showing the corresponding sign conventions. The orientation of the aircraft is labeled with two angles, θ and α. The angle θ is the inclination of the aircraft which is the angle between the direction of flight and the horizontal; the angle α is the incidence, or angle between the direction of flight and the Zero Lift Line (ZLL). When α is zero, the Zero Lift Line is aligned with the flight direction and there is no lift acting on the aircraft, whatever might be is inclination θ.

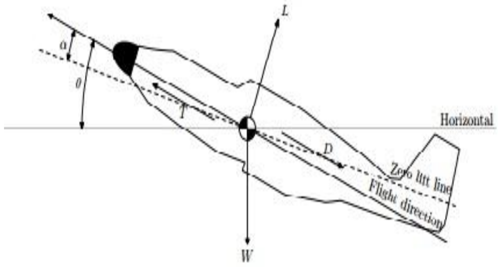

Fig. 4 Sign conventions for longitudinal stability

To examine the equilibrium and stability of the aircraft, we resolve forces parallel and perpendicular to the aircraft axis:

Parallel: $T - D - W \sin\theta = 0$, (3)

Perpendicular: $L - W \cos\theta = 0$, (4)

Moments about the c.g.: $M_{cg} = 0$. (5)

Moments about the centre of gravity (c.g.) cannot be due to the mass of the aircraft (by definition). This means that if Mcg = 0, the aerodynamic moments on the aircraft are in equilibrium and the aircraft is said to be trimmed or in trim. The basic problem of static stability is then: when an aircraft in trim is subjected to a disturbance which changes its incidence. This can be restated: if the aircraft pitches nose up, the change in aerodynamic moment about the centre of gravity ΔM_{cg} should be negative in order to push the nose back down or, $\partial M_{cg}/\partial\alpha < 0$.

Figure 5 shows various ways Mcg can vary with α, including how it is possible to trim an unstable aircraft and how is possible for an aircraft to be stable without being able to trim at a useful incidence.

1.5 Aerodynamic centre and neutral point

The forces and moments acting on an aircraft depend on the shape of the aircraft and not on the position of the centre of gravity so we consider the aerodynamic loads separately from the gravitational.

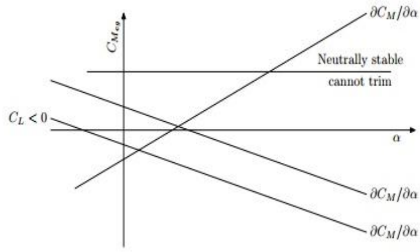

Fig. 5 Trim and Stability

Figure 6 shows a pressure distribution on an aerofoil section. The loads can be considered to act at a point, the centre of pressure, however, moves as the incidence varies, so it is not very useful as a reference point in calculations involving changing incidence.

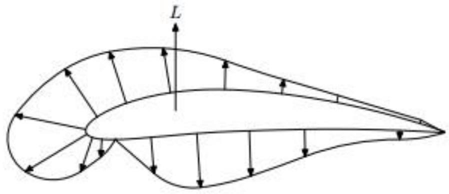

Fig. 6 Centre of Pressure

To make life easier, we can give up the requirement that the moment about our reference point be zero and, instead, allow it to have some finite value as long as the reference point is fixed and the moment is constant. We can do this by looking at the incremental pressure distribution, sketched in Figure 7.

If we think about the basic equation of stability, we can consider what happens to an aircraft which pitches slightly nose-up. Depending on the position of centre of gravity, relative to the aerodynamic centre, the aircraft will be stable, unstable or neutrally stable as shown in Figure 8.

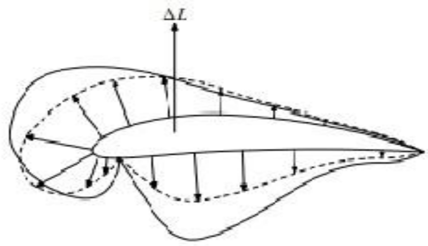

Fig. 7 Incremental Loads

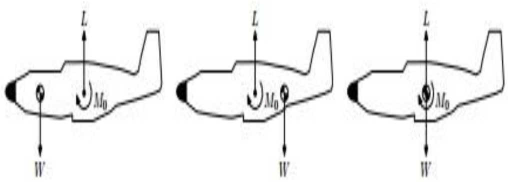

Fig. 8 Centre of gravity and aerodynamic centre Relationships

- If the centre of gravity is forward of the aerodynamic centre, $\frac{dM_{cg}}{d\alpha}$ is negative and the aircraft is statically stable.
- If the centre of gravity is aft of the aerodynamic centre, $\frac{dM_{cg}}{d\alpha}$ is positive and the aircraft is statically unstable.
- If the centre of gravity is at the aerodynamic centre, $\frac{dM_{cg}}{d\alpha}$ is zero and the aircraft is neutrally stable.

II. CONTROL AND STABILITY CHARACTERISTICS IN SUKHOI T-50 PAK FA

The aircraft has a fly by wire with adequate redundancy. This came in 2010 and now it expands its flight envelope. Depending on the flight conditions, signals from the control stick position transmitter or the FCS may be coupled to the remote control amplifiers. Now this aircraft perform sustained-altitude flat rotation manoeuvres and high angle of attack. Four T-50 prototypes have now flown and fifth one will come soon in the field and the production aircraft will enter service in 2016.

T-50 PAK FA (Perspektiyny Aviationny Kompleks Frontoyoy Aviatsii-Future Tactical Air System) Fighter is blended wing-body design, resembling the Su-27 in one key respect: the core of the structure is the “centroplane”, a long chord, deep-section inner wing to which the rest of the airframe components- the forward fuselage and widely separated engine nacelles, wings and tail surfaces are attached. Compared to the Su-27, however, the centroplane is deeper between the engines, to accommodate weapon bays.

The flight control system has 14 effectors-12 moving flight surfaces and the engine nozzles. The leading edge flaps are use symmetrically to maintain lift at high angles of attack and adjust the profile to the Mach number. The ailerons are used only at low speed and take-off and landing, when the flaperons are used to increase lift.

The moving vertical tails sit on short fixed pylons that contain the actuators and the air intakes for engine compartment cooling and heat exchangers.

The vertical tail replaces the airbrake, moving symmetrically to increase drag with minimal pitch moment.

The centerline structure on the T-50 has to be quite shallow, so that designing it to resist peak wing bending loads will be a very difficult challenge. The solution on the T-50 is to design the “centroplane” section as a stiff, integrated structure with two sets of full-depth longitudinal booms, located at the outer edges of the nacelles and at the wing-to-Centro plane junction. These are connected by multiple (the patent drawing shows eight) spanwise spars that also carry the wing attachment fittings. The result is a structure that spreads the bending loads over the Centro plane and reduces the peak loads at the centerline.

It is believed that the target maximum speed of the T-50 is around Mach 2. The goal was originally Mach 2.35, but this was reduced to Mach 2.1 and then to the current figure, compared to Mach 2.25 for the Su-35S. The main reason for the difference is that the T-50 uses more composite materials in its primary structure than the Su-35S, which makes heavy use of titanium. The T-50 aircraft flying today are equipped with the izdeliye (Type) 117 engine, described by its designer in a 2011 interview as being more advanced than the 117S used on the Su-35S. The 117S appears to be an evolution of the AL-31 engine series with some technology from the 117. The 117 is claimed to have a thrust/weight ratio of 10:1.

2.1 Stability and Control characteristics of Boeing-737

The primary flight controls are intrinsically safe. In the event total hydraulic system failure or double engine failure, they will automatically and seamlessly revert to control via servo tab. In this mode, the servo tabs aerodynamically control the elevators and ailerons.

2.1.1 Roll

Ailerons are powered by hydraulic systems. If the aileron system jams, the co-pilots wheel can be used to move the spoilers. There are balance tabs and balance panels on both ailerons.

Aileron trim moves the neutral position via the feel and centering mechanism. There are two aileron trim switches to prevent spurious electrical signals from applying trim.

2.1.2 Spoilers / speedbreakes

Flight spoilers augment the ailerons and are powers by hydraulic systems. On landing, if armed, all spoilers will deploy when the thrust levers at idle and any two wheels have spun up or right gear is compressed. If not armed, the speed breakers will deploy as well.

2.1.3 Yaw

The rudder is moved by a PCU powered by hydraulic system. There is no manual reversion for the rudder. The yaw damper system can move the rudder a maximum of 2 degrees (-1/200), 3 deg (-3/4/500), 2 deg (NG flap up), 3 deg (NG flap down), either side of the trimmed position. Yaw damper inputs are not fed back into the rudder pedals, which is why there is an indicator.

2.1.4 Pitch

The control column moves the elevators using hydraulics. If the elevator system jams, the stabilizer (trim) should still be available. There are balance tabs and balance panels on both elevators.

Pitch trim is applied to stabilizer. Trim can be applied by electric trim switches, autopilot or manual trim wheel. Speed trim is applied to the stabilizer automatically at low speed, low weight and most of take-offs.

2.1.5 Short-field Performance Enhancement Program

This package was developed in 2005/6 to allow GOL airlines to operate their 737-800s into the 1,465m (4,800ft) Santos Dumont airport. Various modifications enable weight increases of approximately 4,700kg (10,000lbs) for landing and 1,700kg (3,750lbs) for take-off from short runways. It includes the following changes:

- Flight spoilers are capable of 60 degree deflection on touchdown by addition of increased stroke actuators. This compares to the current 33/38 degrees and reduces stopping distances by improving braking capability.
- Slats only travel to Full Ext when TE flaps are beyond 25 (compared to the current 5). Autoslat function available from flap 1 to 25.
- Flap load relief function active from flap 10 or greater.
- Two-position tailskid that extends an extra 127mm (5ins) for landing protection. This allows greater angles of attack to be safely flown thereby reducing V*ref* and hence landing distance.
- Main gear camber (splay) reduced by 1 degree to increase uniformity of braking across all MLG tyres.
- Reduction of engine idle-thrust delay time from 5s to 2s to shorten landing roll**.**

III. CONCLUSION

The general equations and theory is almost same behind the manufacturing of all types of plane. Flight stability is the prime concern in which different axis stabilities as well as control measures are taken care in special concern. Flight dynamics is the science of air vehicle orientation and control in three dimensions. The three parameters are the *angles of rotation* in three *dimensions about the aircraft center of mass*, known as pitch, roll and yaw. Roll, pitch and yaw refer to rotations about the respective axes starting from a defined equilibrium state. We can conclude that mechanism is almost same in commercial and fighter aircraft only application of this concept if stability and control is applied in different ways.

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