Designing and Analysis Longitudinal Autopilot for a Jet Transport Aircraft's Takeoff

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***Abstract*— Longitudinal stability is the important part in aircraft takeoff scenario, because during takeoff the aircraft is only moving longitudinally not laterally. Longitudinal stability refers to the tendency of aircraft to return to its trim condition after disturbance in lateral axis. In this paper my intention is to design a longitudinal displacement autopilot for jet transport aircraft and to analyze its time response with respect to elevator deflection.**

***Keywords*— Longitudinal Stability, Takeoff, Autopilot**

I. INTRODUCTION

Takeoff is the phase of flight in which an aircraft goes from ground to flying. Normally the aircrafts have two types of takeoff horizontal and vertical. In horizontal takeoff the aircraft have three phases ground run, transition and climb. Ground run is the phase at which the aircraft rolls over the ground for attaining takeoff safety speed. Transition is the phase at which the aircraft lifts off from the ground and climb is the phase from 35ft to 1500ft which is done for attaining the altitude.

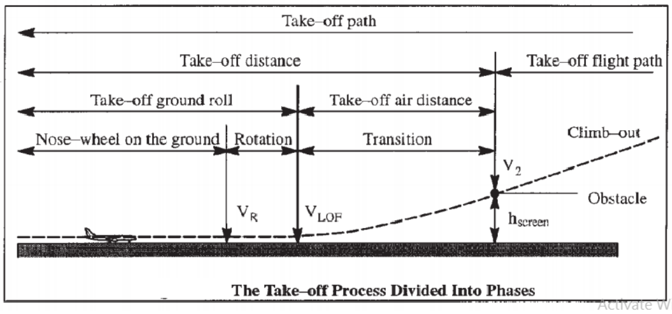

Figure 1. Takeoff Phase

In the takeoff phase the aircraft mainly depends on longitudinal motion which is in lateral axis. Even though some lateral motion is there in takeoff scenario it can be neglected. The lateral axis which is passes through the aircrafts wing tip to wing tip and the rotation about this axis is called as pitch. In longitudinal motion there are two movements pitch up and pitch down, during takeoff pitch up happens. Since the takeoff has only pitch up motion, the pitch up stabilization should be considered more.

Aircraft takeoff control is purely based on guidance and control theory. Guidance and control system technology used in the control of aircraft has been revolutionized by the development of digital computer. The two concepts which are central to modern control systems are the design based directly on the state variable. And the expression of performance specification in terms of a mathematically precise performance criterion which the yields matrix equations for control gains. The expected benefits of guidance control technology, which freed the crews of newer aircraft from dependence on location-to-location systems of navigation aids, were a reduction in human error and increased safety automation. As a result there was a demand for greater system precision and reliability.

Although many of these benefits have been realized, still serious problems arise which result in many in accidents and accidents. One must question whether the maximum possible automation is necessary or desirable, and consider a system that is more compatible with the capabilities and limitations of the human involved. The answer to this question is the design of better and more efficient systems suited for aircraft control. This paper is presenting an automatic takeoff stabilizing system which can automate the motion during takeoff.

The development of automatic control system has played an important role in the growth of civil and military aviation. Modern aircraft include a variety of automatic control system that aids the flight crew in navigation, flight management and augmenting the stability characteristics of the airplane. For this situation an autopilot is designed that can be used by the flight crew to lessen their workload during cruising and help them to takeoff and land the aircraft during adverse conditions. The autopilot is an element within the control system. It is a pilot relief mechanism that assists in maintaining an attitude, heading, altitude or flying to navigation or takeoff and landing references. Designing an autopilot requires control system theory background and knowledge of stability derivatives at different altitudes and Mach number for a given airplane [14].

Autopilot systems are very important both for stable and unstable aircrafts. In order to response correctly to pilots command and the condition of the aircraft, autopilot systems should be designed with great care. The simplest form of autopilot, which is the firstly to discovered, is the displacement type autopilot [14]. This type of autopilot is designed to hold the aircraft in straight and level flight with little or no maneuvering capability.

II. Longitudinal Motion

Longitudinal motion is the motion of aircraft about the lateral axis. The aircraft takeoff happens in the lateral axis. The longitudinal motion consist only two motions, they are pitch up and pitch down. During takeoff pitchup produces by the effect of elevator deflection.

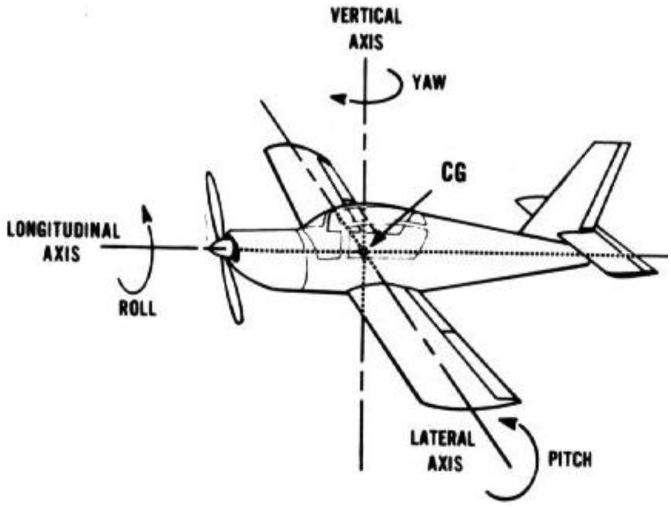

Figure 2. Aircraft Dynamics

Pitching happens with respect to the elevator deflection. The control of an airplane's pitch is dependent on the deflection of its elevator, a hinged surface located at the tail of the airplane. Airflow is redirected when the elevator is displaced. This causes of force and as a result the aircraft revolves about its pitch axis, located at the longitudinal center of gravity. In order to displace the elevator a control stick located in the cockpit is forward and aft. The elevator deflects in proportion to the degrees of stick rotation, and the resulting rotation about the CG is called pitchrate, measured in degrees of rotation per second.

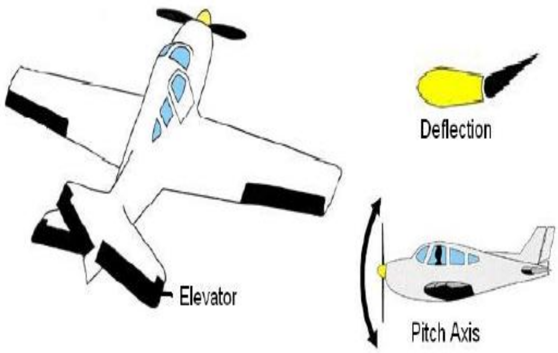

Figure 3. Aircraft's Pitch Control

During takeoff the elevator moves upwards and due to the motion a restoring moment produces ad the pitchup happens. Based on the conditions and type of aircraft the elevator deflection can be calculated.

III. Longitudinal Stability Analysis

A. Longitudinal Equation

As an introduction to longitudinal dynamics in order to obtain the transfer function of the aircraft, it us first necessary to obtain the equations of motion for the aircraft. In longitudinal dynamics in order to get linearized and Laplace transformed equations of motion, stability derivatives have to be calculated.

Some assumption has to be made for deducing the equation they are:

1. The mass of aircraft is constant
2. The aircraft is a rigid body.
3. The earth is an inertial frame.
4. The perturbations are small.

The equation is,

$$\left(\frac{mU}{Sq}\dot{u}-C_{X_U}u\right)+\left(-\frac{c}{2U}C_{X_{\dot{\alpha}}}\dot{\alpha}-C_{X_\alpha}\alpha\right)+\left[-\frac{c}{2U}C_{X_q}\dot{\theta}-C_W(\cos\theta)\theta\right]=C_{F_{X_\alpha}}$$

$$-(C_{Z_U}u)+\left[\left(\frac{mU}{Sq}-\frac{c}{2U}C_{Z_{\dot{\alpha}}}\right)\dot{\alpha}-C_{Z_\alpha}\alpha\right]+\left[\left(-\frac{mU}{Sq}-\frac{c}{2U}C_{Z_q}\right)\dot{\theta}-C_W(\sin\theta)\theta\right]=C_{F_{Z_\alpha}}$$

$$(-C_{m_u}u)+\left(-\frac{c}{2U}C_{m_{\dot{\alpha}}}\dot{\alpha}-C_{m_\alpha}\alpha\right)+\left(\frac{I_y}{Sqc}\ddot{\theta}-\frac{c}{2U}C_{m_q}\dot{\theta}\right)=C_{m_a}$$

(3.1)

After applying the assumption and in solving it is necessary to obtain the transient solution which is obtained from homogeneous equations, that is, with no external inputs $C_{m\alpha}=C_{Fza}=C_{Fxa}=0$.

B. Calculation of stability derivative for aircraft

The selected jet transport aircraft is taking off at a pitch angle of 7^o with an initial velocity of 279.11 ft/s and the compressibility effects are neglected. The values are given below.

W	6,36,000lb
U_o	279.11 ft/sec
g	32.2 ft/sec^2
S	5,500ft^2
I_{xx}	18.2*10^6 Slug-ft^2
I_{yy}	33.1*10^6 Slug-ft^2

Table 1. Aircrafts Parameters

C_L	1.11
C_D	0.102
$C_{L\alpha}$	5.701
$C_{D\alpha}$	0.666
$C_{m\alpha}$	-1.261
$C_{L\dot{\alpha}}$	6.7
$C_{m\dot{\alpha}}$	-3.2
C_{Lq}	5.4
C_{mq}	-20.8
C_{Lm}	-0.81
C_{Dm}	0
$C_{L\delta e}$	.3388
$C_{m\delta e}$	-1.342
C_{mM}	0.270

Table 2. Stability Derivatives

C. Transfer function for elevator deflcetion

Taking the Laplace transform for the linearized equations, the transfer functions were found for angle of attack, pitchrate, and velocity with respect to elevator deflection.

$$\frac{\alpha'(s)}{\delta e(s)} = \frac{-.033s^3 - .547s^2 - .0247s - .0120}{s^4 + 1.043\, s^3 + .7697s^2 + .01896s + .01106} \tag{3.2}$$

$$\frac{\theta'(s)}{\delta e(s)} = \frac{-.561s^2 - .293\, s - .0120}{s^4 + 1.043\, s^3 + .7697s^2 + .01896s + .01106} \tag{3.3}$$

$$\frac{u'(s)}{\delta e(s)} = \frac{-..0014\, s^2 + .0342\, s + .0289}{s^4 + 1.043\, s^3 + .7697s^2 + .01896s + .01106} \tag{3.4}$$

IV. MODELLING OF LONFITUDINAL AUTOPILOT

The modelling of the autopilot has done by Simulink and Matlab. A system is modelled using the conventional Simulink blocks such as transfer function, PID controller and summation. A PID controller is designed to minimize the errors in the control system. The main part of the Simulink model is angle of attack, velocity and pitch rate system which is commonly known as aircraft dynamics. An engine lag transfer function is used to reduce the velocity errors due to the engine performance characteristics. A pitch damper is also included to produce the natural perturbation which is occurred due to the environmental conditions and a step response is given as signal source.

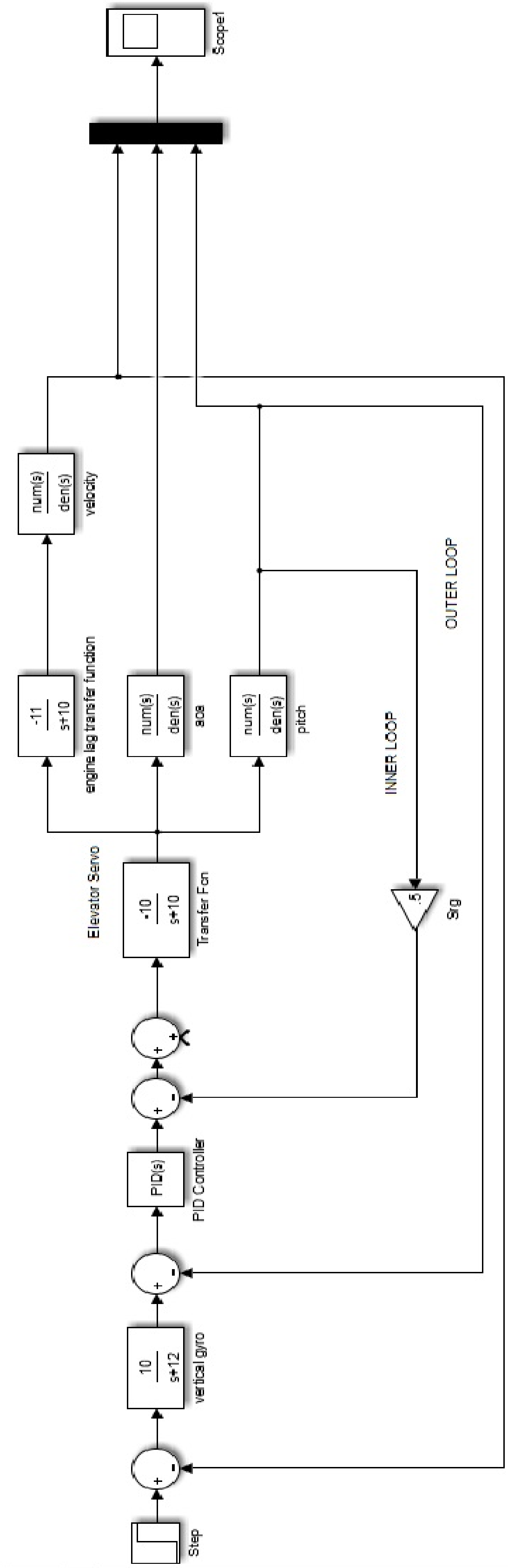

Figure 3. Longitudinal Autopilot

V. ANALYSIS LONGITUDINAL AUTOPILOT

The time response were found with a given step response with respect to the elevator deflection.

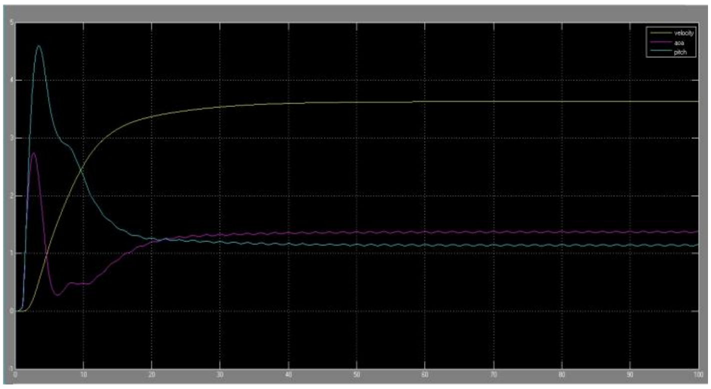

Figure 4. Step response of longitudinal autopilot

This time response for the given step input shows the settling time as 20 sec. With the use of pitch damper is used to control the non-linearized state of the pitch. This longitudinal autopilot a pitchrate feedback is used to maintain the pitch angle and a velocity feedback is given for check the takeoff speed is maintaining or not. As PID controller used the steady state error can be reduced.

VI. CONCLUSION

The importance of longitudinal stability during takeoff phase is studied. And a longitudinal autopilot system were designed for a jet transport aircraft using Simulink/Matalab and their time response were analyzed. The time response clearly shows that this system have the ability to reduce the oscillation during the takeoff phase. The future works includes the testing, verification and validation of this system in real time.

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