STABILITY ANALYSIS AND ROOT LOCUS FOR THREE AXIS AUTOPILOT CONTROLLED AIRPLANE USING TIME AND FREQUENCY DOMAIN RESPONSES

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Abstract

The present paper describes the attitude of an aircraft is controlled by three sets of surfaces: elevators, rudder, and ailerons, by manipulating these surfaces, a pilot can set the aircraft on a desired flight path. An autopilot, which will be considered here, is an automatic control system that controls the roll angle Φ by adjusting aileron surfaces. The deflection of the aileron surfaces by an angle θ generates a torque due to air pressure on these surfaces. This causes a rolling motion of the aircraft. The aileron surfaces are controlled by a hydraulic actuator with a transfer function 1/s. This paper Analyses the 'root locus and step response for autopilot controlled airplane'

Keywords: Lateral axis, longitudinal axis, Vertical axis, Ailerons, Elevator, Rudder, Air brakes. Root locus.

I. Introduction:

Aircraft **flight control surfaces** allow a pilot to adjust and control the aircraft's flight attitude. Development of an effective set of flight controls was a critical advance in the development of aircraft. Early efforts at fixed-wing aircraft design succeeded in generating sufficient lift to get the aircraft off the ground, but once aloft, the aircraft proved uncontrollable, often with disastrous results. The development of effective flight controls is what allowed stable flight. This article describes the control surfaces used on a fixed wing aircraft of conventional design. Other fixed wing aircraft configurations may use different control surfaces but the basic principles remain. The controls (stick and rudder) for rotary wing aircraft (helicopter or auto gyro) accomplish the same motions about the three axes of rotation, but manipulate the rotating flight controls (main rotor disk and tail rotor disk) in a completely different manner.

Axes of motion: An aircraft is free to rotate around three axes that are perpendicular to each other and intersect at its center of gravity (CG). To control position and direction a pilot must be able to control rotation about each of them.

Lateral axis: The lateral axis passes through an aircraft from wingtip to wingtip. Rotation about this axis is called **pitch**. Pitch changes the vertical direction that the aircraft's nose is pointing. The elevators are the primary control surfaces for pitch.

Longitudinal axis: The longitudinal axis passes through the aircraft from nose to tail. Rotation about this axis is called **roll**. Rolling motion changes the orientation of the aircraft's wings with respect to the downward force of gravity. The pilot changes bank angle by increasing the lift on one wing and decreasing it on the other. This differential lift causes bank rotation around the longitudinal axis. The ailerons are the primary control of bank. The rudder also has a secondary effect on bank.

Vertical axis: The vertical axis passes through an aircraft from top to bottom. Rotation about this axis is called **yaw**. Yaw changes the direction the aircraft's nose is pointing, left or right. The primary control of yaw is with the rudder. Ailerons also have a secondary effect on yaw. It is important to note that these axes move with the aircraft, and change relative to the earth as the aircraft moves. For example, for an aircraft whose left wing is pointing straight down, its "vertical" axis is parallel with the ground, while its "lateral" axis is perpendicular to the ground.

Main control surfaces:

The main control surfaces of a fixed-wing aircraft are attached to the airframe on hinges or tracks so they may move and thus deflect the air stream passing over them. This redirection of the air stream generates an unbalanced force to rotate the plane about the associated axis.

Aileron:

Ailerons are mounted on the trailing edge of each wing near the wingtips and move in opposite directions. When the pilot moves the stick left, or turns the wheel counter-clockwise, the left aileron goes up and the right aileron goes down. A raised aileron reduces lift on that wing and a lowered one increases lift, so moving the stick left causes the left wing to drop and the right wing to rise. This causes the aircraft to roll to the left and begin to turn to the left. Centering the stick returns the ailerons to neutral maintaining the bank angle. The aircraft will continue to turn until opposite aileron motion returns the bank angle to zero to fly straight.

Elevator:

An elevator is mounted on the trailing edge of the horizontal stabilizer on each side of the fin in the tail. They move up and down together. When the pilot pulls the stick backward, the elevators go up. Pushing the stick forward causes the elevators to go down. Raised elevators push down on the tail and cause the nose to pitch up. This makes the wings fly at a higher angle of attack, which generates more lift and more drag. Centering the stick returns the elevators to neutral and stops the change of pitch. Many aircraft use a stabilator a moveable horizontal stabilizer — in place of an elevator. Some aircraft, such as an MD-80, use a servo tab within the elevator surface to aerodynamically move the main surface into position. The direction of travel of the control tab will thus be in a direction opposite to the main control surface. It is for this reason that an MD-80 tail looks like it has a 'split' elevator system.

Rudder: The rudder is typically mounted on the trailing edge of the fin, part of the empennage. When the pilot pushes the left pedal, the rudder deflects left. Pushing the right pedal causes the rudder to deflect right. Deflecting the rudder right pushes the tail left and causes the nose to yaw to the right. Centering the rudder pedals returns the rudder to neutral and stops the yaw.

Ailerons:

The ailerons primarily control roll. Whenever lift is increased, induced drag is also increased. When the stick is moved left to roll the aircraft to the left, the right aileron is lowered which increases lift on the right wing and therefore increases induced drag on the right wing. Using ailerons causes adverse yaw, meaning the nose of the aircraft yaws in a direction opposite to the aileron application. When moving the stick to the left to bank the wings, adverse yaw moves the nose of the aircraft to the *right*. Adverse yaw is more pronounced for light aircraft with long wings, such as gliders. It is counteracted by the pilot with the rudder. Differential ailerons are ailerons which have been rigged such that the down going aileron deflects less than the upward-moving one, reducing adverse yaw.

Air brakes:

Air brakes also called spoilers are used to increase drag. On a typical airliner, for example, the spoilers are a series of panels on the upper surface of the wing which deploy upwards to disrupt airflow over the wing, thus adding drag. The number of panels that deploy, as well as the degree to which they deploy, depends on the regime of flight in which they are used. For example, if a pilot must descend quickly without increasing speed, he may select a speed brake setting for the desired effect. In such a case, only certain spoiler panels will deploy to create the most efficient reduction in speed without overstressing the wing. On most airliners, spoiler panels on the wings mix with aileron inputs to enhance roll control. For example, a left bank will engage the ailerons as well as deploy certain spoiler panels on the down-going wing. Ground spoilers are essentially similar to flight spoilers, except that they deploy upon touchdown on the runway, and include all spoiler panels for maximum "lift dump". After touchdown, the ground spoilers deploy, and "dump" the lift generated by the wings, thus placing the aircraft's weight on the wheels, which accomplish the vast majority of braking after touchdown. Most jet airliners also have a thrust reverser, which simply deflects exhaust from the engines forward, helping to slow the aircraft down.

Problem statement:

A simplified block diagram for automatic control of an airplane is shown in Figure 2. Assume that $K_1=1$ and that the roll rate Φ is fed back using a rate gyro (of gain K_2). The desired step response has an overshoot less than 10% and a settling time (2% criterion) less than 9 seconds. Select parameters K_a (Amplifier gain) and K_2 to meet the desired overshoot and settling time.

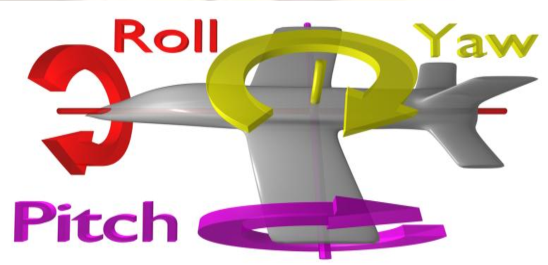


Fig:1 Airplane View

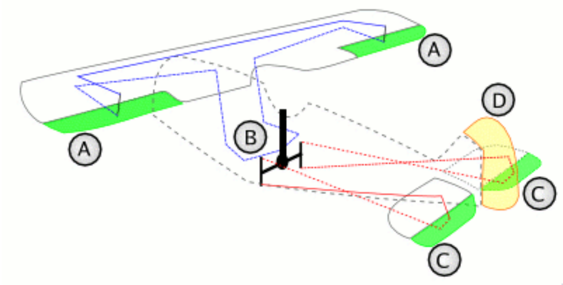
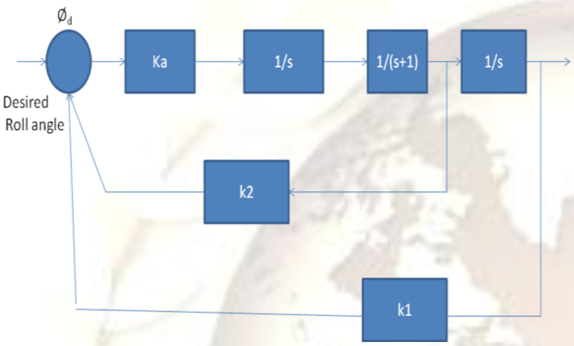
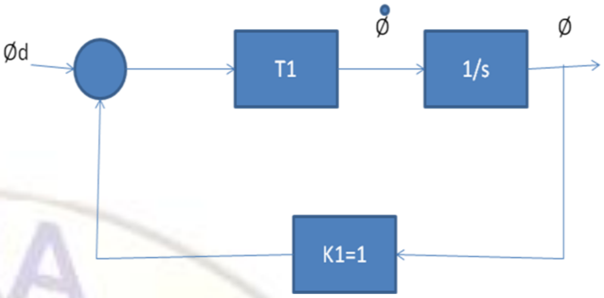


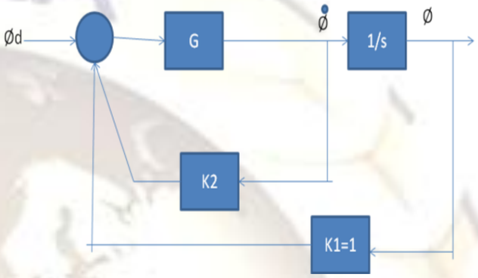
Fig:2 Inner View of Air Plane



Block diagram reduction:Step 1:

$$G(s) = K_a * \frac{1}{s} * \frac{1}{s+1} = \frac{K_a}{s(s+1)}$$





$$T_1(s) = \frac{G(s)}{1+G(s)K_2} = \frac{\frac{K_a}{s(s+1)}}{1+\frac{K_aK_2}{s(s+1)}} = \frac{K_a}{s(s+1)} * \frac{s(s+1)}{K_aK_2+s(s+1)} = \frac{K_a}{K_aK_2+s(s+1)}$$

$$T_2 = \frac{T_1 * \frac{1}{s}}{1+T_1 * \frac{1}{s}} = \frac{\frac{K_a}{K_aK_2s+s^2(s+1)}}{1+\frac{K_a}{K_aK_2s+s^2(s+1)}} = \frac{K_a}{K_aK_2s+s^2(s+1)} * \frac{K_aK_2s+s^2(s+1)}{K_aK_2s+s^2(s+1)+K_a}$$

$$= \frac{K_a}{s^3+s^2+K_aK_2s+K_a}$$

Results:

```
a =-0.3000 + 0.5800i

b =-0.3000 - 0.5800i

c =-0.4000

Ka =0.1706

K2 =3.9071

Ans =

Open-loop system

Transfer function:
0.1706
---------------------------------------------
1.666 s^3 + 1.666 s^2 + 0.6664 s

ans =

Closed-loop system

Transfer function:
0.1706
-----------------------------------------
s^3 + s^2 + 0.6664 s + 0.1706
```

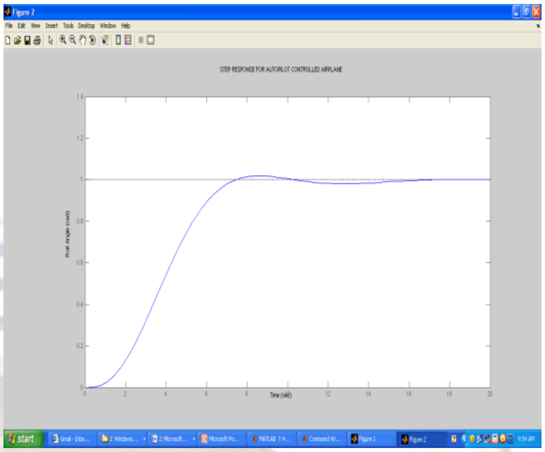


Fig 6: Impulse response of autopilot Controlled aero plane

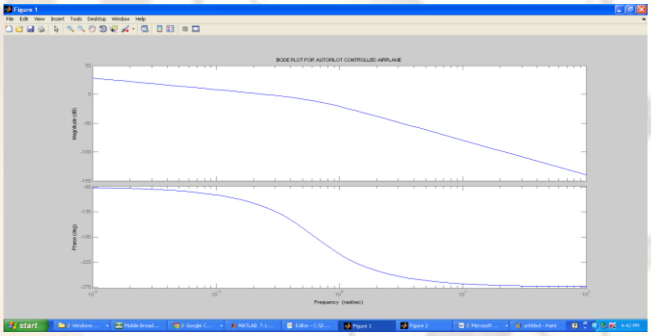


Fig 4: Step response of autopilot Controlled aero plane

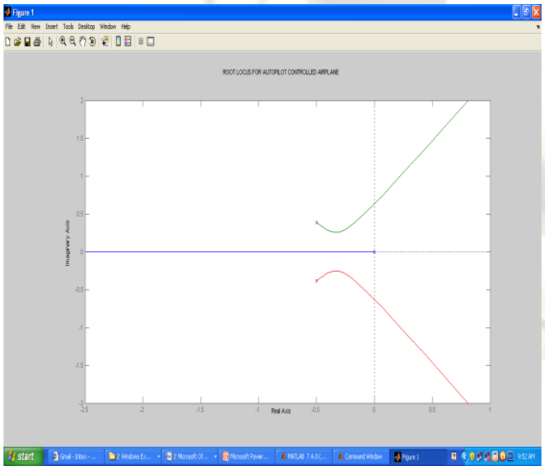


Fig 3:Root locus for auto pilot controlled Aero plane

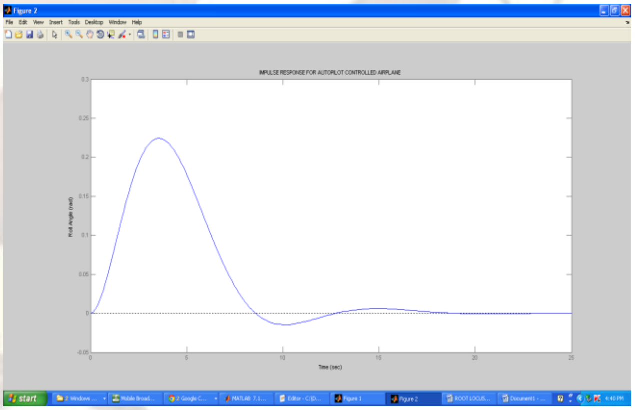


Fig 5: Bode Plot for auto pilot controlled Aero plane

Conclusions:

The root locus diagram as shown in fig 3 tells us the system will be marginally stable when the system gain K is around 3.9. When the gain K is smaller than 3.9, the system is stable with all closed-loop poles on the left-half plane. For gain greater than 3.9, the conjugate pole pair moves onto the right-half plane, resulting in system instability.

This problem required values for parameters K_a and K_2 to be selected such that the settling time is less than 9 seconds and the overshoot is less than 10%. A range of pole locations were selected and the resulting system evaluated in order to determine those which yielded the shortest settling time. The results show that this was the case for poles at -0.3+0.58i, -0.3-0.58i, and -0.4. The corresponding values for the system parameters were then found to be K_a=0.1706 and K_2=3.9071.

The step response was then plotted for this system, and is shown above Fig.4 The simulation shows this system meets the requirements of the problem, with a settling time of 7.02 seconds and overshoot of 1.85%, which is less than the 9 seconds and 10% (respectively) required.

The Frequency And impulse response was then plotted for this system, and is shown above Fig.5,6

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BIOGRAPHIES

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