Roll Angle Control of an Aircraft using Adaptive Controllers

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Abstract: **Roll angle control(RAC) is required for the lateral stability of an aircraft. Lateral stability makes the aircraft more stable around the longitudinal axis. In this paper, a roll control system for an aircraft that controls roll angle motion is considered and simulated. As the complexity of aircrafts increases, classical controllers(i.e., PID) becomes unsatisfactory to yield acceptable performance because of the changes in environmental conditions, variation in process dynamics by non-linear actuators and changes in character of the disturbances. To overcome the above problem adaptive controllers i.e., Model Reference Adaptive Controller and Self Tuning Controller are used for RAC, as adaptive controllers have the capability to change according to the environmental conditions. From the Simulation results, it is observed that Self Tuning Controller delivers the best performance.**

Keywords: Aircraft roll control, Classical PID controller, Model Reference adaptive controller, Self-tuning Controller, MATLAB.

I. Introduction

With the advancement and development in aircraft sector it became mandatory for control engineers to investigate the stability of the aircraft. It started way back in 20th century. Before this period the engineers consider that the term stability and control in respect to aircraft are the same. Around 1890, Otto Lilienthal of Germany and Samuel Pierpont Langley of America made a significant contribution in developing a man-carrying airplane which inspired and aided other aviation pioneers of that time[1].

On December 17, 1903, Wright brothers invented aircraft controls making fixed-wing powered flight possible. Their fundamental breakthrough was the invention of three-axis control, enabling the pilot to control the aircraft and maintain its equilibrium. This method remained standard on fixed-wing aircraft of all types. Their approach was different from other experimenters of their time as they focused on developing a reliable method of pilot control while others emphasised on developing powerful engines[1-2].

Sperry brothers designed the first automatic flight controller. This invention changed the whole aircraft manufacturing sector and also boost the invention of other technologies like, aerodynamics, structures, materials, population and flight control[3]. Ambitious aircraft programs and tough competition between manufacturers motivated sustained striving towards Flight Control System (FCSs), to provide improved and efficient performance [4]. In modern terminology stability is defined as the tendency of the airplane to return to its equilibrium position after it has been disturbed due to pilot’s action or atmospheric phenomenon which includes winds gusts, wind gradients, or turbulent air.

Roll angle, also known as the bank angle is the angle through which an airplane must be rotated about its longitudinal axis to bring its lateral axis into a horizontal plane. It is positive when the left wing is higher than the right wing. Greater the roll angle, more quicker the plane turns to the intended direction[4-6]. Roll angle control is carried out by the ailerons present on the rear edge of the wings. If the aircraft is required to roll to its right side, the pilot rotates the Yoke to the right. When doing this, the right aileron present on the right wing raises upward to produce drag, whereas the left aileron lowers down to produce lift. This lift and drag causes the plane to ‘tip’ to one side, i.e., the right side and hence, the plane turns to its right [7].

In [4] a Fuzzy Logic Controller (FLC), Linear Quadratic Regulator (LQR) and Self-Tuning Fuzzy Logic Controller (STFLC) has been designed for roll control system and it is shown that STFLC gives best results among three. In [5] authors have investigated stability of general Navion aircraft and designed a PID controller for the roll control system using MATLAB. In [7] closed loop PID controller has been modelled for an aircraft roll control and it is shown that PID controller performs better roll motion with more stability and less response time. In [8] authors have evaluated Model Reference Adaptive Controller for the roll control of large aircraft using MATLAB coded program. In [9] authors have used MATLAB Robust Control Toolbox for the synthesis of stabilizing K-controller for aircraft roll control system using data flight parameter. Many authors have worked for pitch and yaw control also[10-13].

In [14] authors discussed the application of adaptive control in chemical industries, power plants, aircraft control system, cement industries, electrical drives, steel and metallurgical industries, paper industries and some miscellaneous areas of process industries. In this paper, two main method for designing adaptive controllers, i.e., Model Reference Adaptive Control and Self-Tuning control has been used for designing the Roll Angle control for an aircraft.

This paper is organised in the following order. In section II discussion of the Roll angle control of the aircraft is carried out and the State Space model of the same is given. In section III the two control techniques namely Classical Controllers(PID controller), and Adaptive Controllers(Model Reference Adaptive Controller and Self-Tuning Controller) are discussed for designing Roll Angle Control System for the Aircraft. The next section is devoted to the simulations of control techniques considered above and the concluding section is given finally.

II. Problem Statement

The aircraft in flight, moves along three principal axis:

1. *Vertical Axis(Yaw):* The aircrafts rudder plays a crucial role in movement along this axis. Movement along this axis is termed as yawing.

2. *Lateral Axis(Pitch):* The aircrafts elevator plays a major role in movement along this axis. This movement is known as pitching.

3. *Longitudinal Axis(Roll):* In movement along this axis, the aircrafts ailerons(hinged control surfaces attached with the trailing edge of the wings) plays the crucial role. Figure 1 depicts the axes of an aircraft.

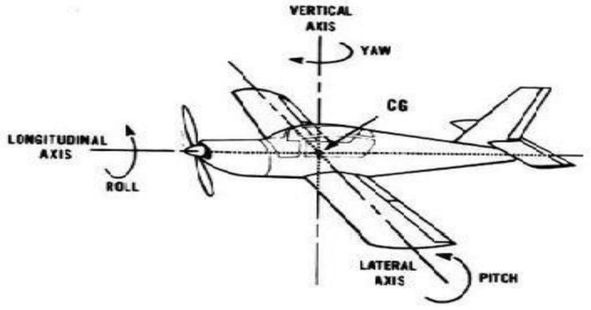

Figure 1: Axes of the Airplane [5]

Elevator, rudder and ailerons are the three main surfaces which is used for controlling an aircraft. Pitch control can be achieved by deflecting elevator and Yaw control can be achieved by deflecting rudder. By adjusting the roll angle we can control the rolling motion of an aircraft. It is a lateral problem and can be achieved by deflecting ailerons located outboard towards the wing tips in a differential manner. The two ailerons are interconnected and move in opposition to each other to bank the aircraft[4].

The State-Space Model of the aircraft system is given as[15]:

A= [-0.254 0 -1 0.182;
-16.02 -8.40 2.19 0;
4.488 -0.350 -0.760 0;
0 1 0 0];
B=[0; -28.916; -0.244; 0]
C=[0 0 0 1];
D=[0];

The continuous time transfer function from aileron deflection angle to roll angle is given by

$$G(s) = \frac{-28}{s^4+9.414s^3+13.975s^2+48.04s+0.4271}$$

III. CONTROL TECHNIQUES

3.1 *Classical Controllers- PID*

For PID control, the actuating signal is the summation of proportional error signal, derivative of error signals and integral of the error signals. Thus, the actuating signal for Plant is

$$e_a(t)=K_p e(t)+T_d \frac{de(t)}{dt}+K_i \int e(t)\, dt \qquad (1)$$

-

The Laplace Transform of the actuating signal including PID control is

$$E_a(s) = K_p\ E(s)+ sT_d\, E(s)+ \frac{K_i}{s} E(s)$$

or

$$E_a(s)=E(s)\left[K_p + sT_d + \frac{K_i}{s}\right] \qquad (2)$$

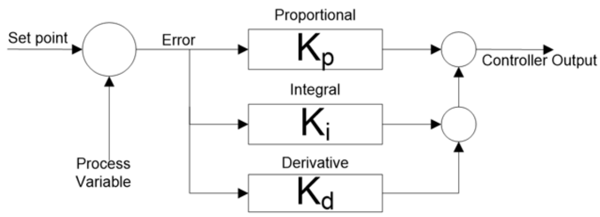

Fig. 2. Block diagram of PID control

PID control combines the advantages of proportional, derivative and integral control actions.

3.2 *Adaptive Controllers*

Adaptive control is a set of techniques for automatic adjustment of controllers in real time, therefore achieving and maintaining a desired level of control system performance when the parameters of the plant model are changed with time and/or unknown. Adaptive control system measure performance index(IP) using inputs, states, outputs and known disturbances. Adaptation mechanisms modify parameters of adjustable controller and generate an auxiliary control by comparing the measured performance index and a set of given ones to maintain their close approximations. An adaptive controller has an adjustment loop in addition to conventional feedback loop which makes it capable to give desired response in the presence of parameter disturbances[16-17].

3.2.1 *MODEL REFERENCE ADAPTIVE CONTROL (MRAC)*

MRAC is a technique for designing the adaptive controller which adjust the controller parameters such that the output of actual plant tracks the output of reference model with same reference input [8,18]. There are the three components in the model reference adaptive control system:

Reference model: It models the desired behaviour of closed-loop system. The system specifications of the reference transfer function are shown in Table 1.

Table 1: *The system specifications of the reference model*

Rise Time	0.413 sec
Settling Time	0.706 sec
Steady state Error	0

Controller: The goal of this part is to keep initial plant condition in mind and to achieve overall stability. Here, only roll angle, φ, describe the control law.

Adjustment mechanism: This part changes its output with respect to error between plant output and the reference model output. There are several methods which are used in adjustment mechanisms but in this paper the method used is MIT rule.

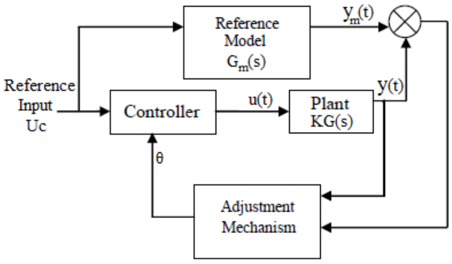

Figure 3:Block diagram of Model Reference Adaptive Control(MRAC) [19]

MIT Rule: MIT Rule(developed in 1960) is used for designing the autopilot system of aircraft. According to this rule, cost function is described as,

$$J(\varphi) = \frac{1}{2} e^2 \qquad (3)$$

Where '*e*' depicts the error between outputs of plant and model. Cost function is minimized to zero by adjusting parameter φ and therefore change in φ is kept in direction of negative gradient of cost function, i.e.,

$$\frac{d\varphi}{dt} = -\gamma \frac{\partial J}{\partial \varphi} = -\gamma e \frac{\partial e}{\partial \varphi} \qquad (4)$$

Where γ is a positive quantity indicating learning rate of controller, $\frac{\partial e}{\partial \varphi}$ is termed as sensitivity which indicates how the error is changing with respect to parameter φ. Eqn.(4) is showing the change in parameters φ with respect to time so that the cost function can be minimized to zero. [18].

3.2.2 *SELF-TUNING CONTROLLER(STC)*

A Self Tuning Controller is an adaptive scheme in which the parameters in the process model are updated as new data are acquired (using online estimation methods), and the control calculations are based on the updated model[16]. Self-tuning controllers generally are implemented as shown in Figure 4.

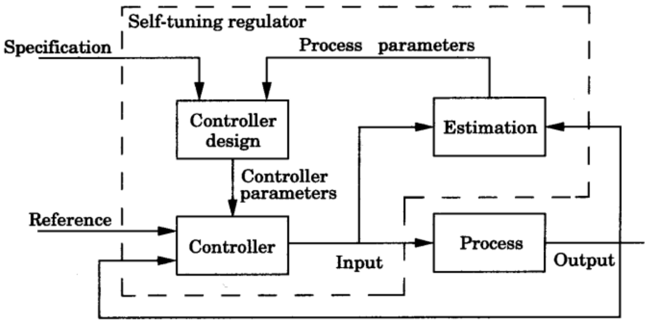

Fig. 4. Block diagram of Self- Tuning Controller [16]

In STC 3-sets of computations are employed:

- Estimation of the model parameters
- Calculation of the controller settings
- Implementation of the controller output in the feedback loop

Estimation of model parameters is done using Recursive Least Square(RLS) algorithm and controller design is done using Minimum-Degree Pole Placement(MDPP) Techniques[16].

IV. SIMULATIONS AND RESULTS

The step response of Roll control system without any controller is shown in figure 5.

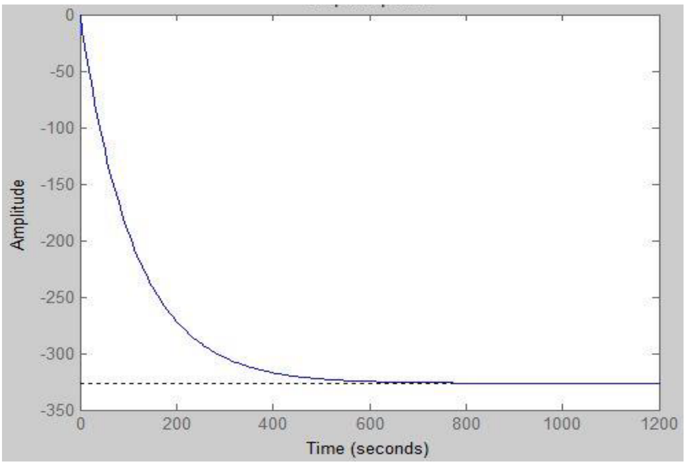

Fig. 5. Step response of plant without controller

It is observed from figure(5) that the system has inverted step response and the controller has to be designed to improve its response.

4.1 *Modelling of PID controller*

The MATLAB Simulink diagram of PID controller is as shown in Figure 6.

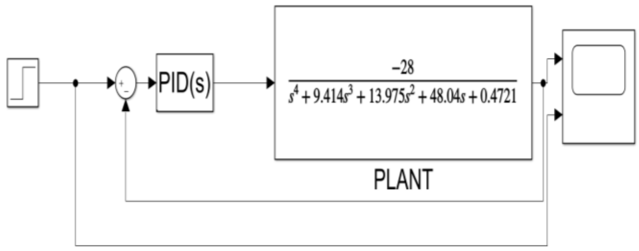

Fig. 6. Simulink model of PID controller

Using the PID tuner application in MATLAB, the value of PID controller to be used in this design are:

K_p = -2.1413 K_i = -1.2626 K_d = -0.123

The step response of the plant with PID controller is shown in figure 7 and it is observed that the system settles down in 3.0384 sec with an overshoot of 8.1672%.

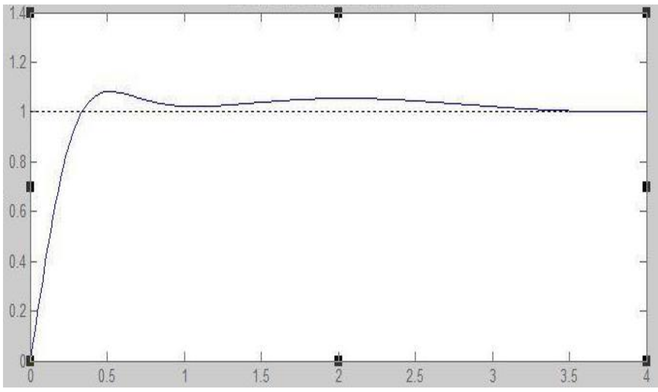

Fig. 7. Step response of plant with PID controller

4.2 *Modelling of MRAC*

The MATLAB Simulink diagram of MRAC is as shown in Figure 8.

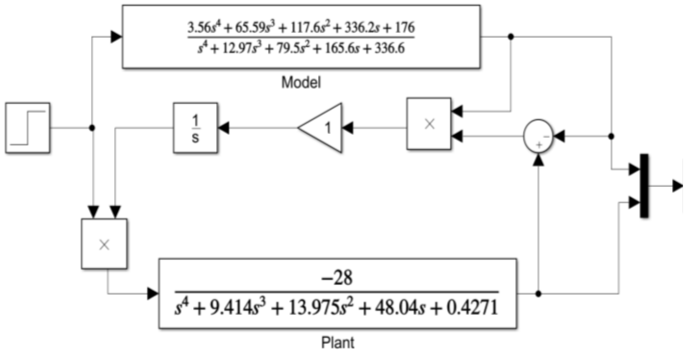

Fig. 8. Simulink model of MRAC

The step responses of the model reference adaptive control system for roll angle are shown in the figure 9.

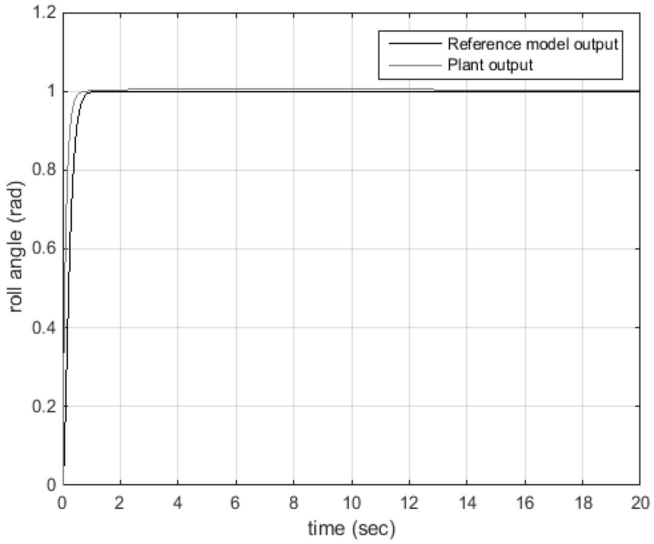

Fig. 9. The step response of the roll control system for $\gamma = 1$

It is observed from figure 9 that the system settles down in 0.706 sec without any overshoot.

4.3 *Modelling of STC*

The MATLAB Simulink diagram of STC is as shown in Figure 10.

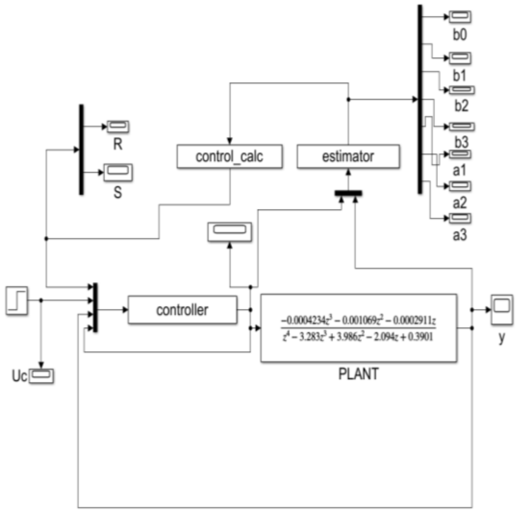

Fig. 10. Simulink model of STC

The step responses of the self-tuning control system for roll angle are shown in figure 11.

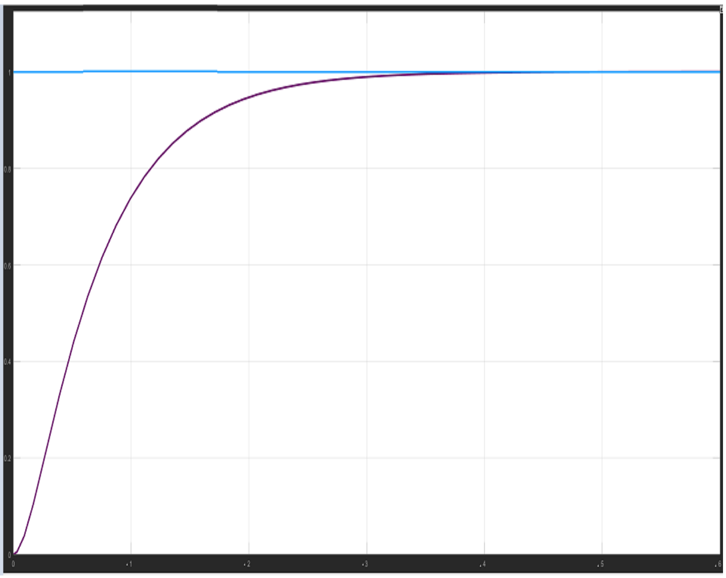

Fig. 11. The step response of self-tuning roll control system

By observing all the simulation results, a comparison table of the transient performance parameters is given in Table 2.

TABLE 2: *Comparison of different control algorithms*

Algorithm	**Rise time (sec)**	**Settling Time (sec)**	**Peak Overshoot (%)**
PID	0.2427	3.0384	8.1672
MRAC	0.413	0.706	0
STC	0.18	0.34	0

V. CONCLUSION

Roll angle control plays an important role in the stability analysis of an aircraft which can be controlled by using control techniques on ailerons. In this paper, comparison between the classical and adaptive controllers is shown. PID controller is tuned using auto tuning application of MATLAB. Here, the PID controller and MRAC is designed for fixed transfer function of aircraft and thus their response will change when plant parameters changes due to change in environmental conditions and non-linear actuators. Hence for PID and MRAC control techniques offline controller has to be designed and then implemented for every change in the plant, whereas, in STC online parameter estimation and controller design is done using RLS and MDPP technique to nullify the effect of changing plant parameters. Therefore, for better precision and accurate response STC is best suited for dynamic applications as shown from the results obtained. The results obtained are compared for different performance parameters like rise time, settling time, and peak overshoot. Obtained simulation results show that Roll control system with Self tuning controller takes only 0.18 sec for the response with an overshoot of 0% in comparison to PID and MRAC tuning algorithms which take 0.2427 sec and 0.413 sec respectively for the response and thus increases the speed of the system response.

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