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Dynamic Modeling and Control of Aircraft Surfaces Using Hybrid Intelligent Controllers

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Abstract: *This paper addresses the study of two control surfaces of aircraft namely Elevators and Ailerons for controlling longitudinal and roll control movement. The control surfaces are implemented with hybrid intelligent controllers, such as ANN (artificial neural network), ANFIS (artificial neuro- fuzzy inference system) and combination of PID controller with Fuzzy compensation techniques. Dynamic modeling of these controllers is presented here to examine the overall performance of controllers, primarily based on time response specification and also the behavior of control surfaces. Firstly, transfer function relating to Elevator input is developed by considering Servomotor which is used to control the movement of surface. This particular model is implemented for Linear and Non-linear models and the effect of various nonlinearities is observed on the performance of Flight control system (FCS), whereas for the aircraft roll control system it is designed with rate gyro and rate integrating gyro providing input to the ailerons.* ***The controllers are designed based on linearized model of aircraft so as to simplify the design process, with the idea of dynamic modeling of servomotor for aircraft longitudinal control by controlling the movement of elevators and modeling of rate and rate-integrating gyro for F-16 fighter aircraft by controlling ailerons. A quantitative analysis of controllers has been carried out in MATLAB Simulink© software. Finally, the research study results shows that the combination of Fuzzy-PID controller provides best results with reference to aircraft longitudinal and roll control movement respectively.***

Keywords*: Longitudinal, Roll, Elevators, Ailerons, FLC, ANN, ANFIS, FCS.*

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Nomenclature	***Abbreviation***
Φ(s)	Bank Angle
δ_a	Actual Aileron Deflection Angle
C_{l_p}	stability derivative representing damping in roll
$C_{l_{\delta_a}}$	stability derivatives representing the rolling moment due to aileron deflection angle
K_g	T.F Pitch Rate Gyro
J	Moment of Inertia
δ_{ac}	Commanded Aileron Deflection

I. INTRODUCTION

Three basic control movements of aircraft which are generally taken into consideration are: longitudinal, roll and yaw, and the control of these states in aircraft, is achieved by altering the command signal to elevators, ailerons and rudder respectively. Here in this paper we consider only two control movements of aircraft i.e., Longitudinal and Roll movement. These two control surfaces are designed and implemented with different intelligent controllers. These two movements of aircraft are considered important in flight during which aircraft changes its transition from one state to another. For controlling aircraft's longitudinal and roll movement a set of control surfaces are used known as elevator and ailerons respectively. Elevators are movable control surfaces located at the back of fixed wing aircraft and hinged to the trailing edge of horizontal stabilizer, running parallel to the main wings that cause this rotation of aircraft and cause the aircraft to climb and descend and also to obtain sufficient lift from the wings to keep the aircraft in level flight at various speeds. The elevators are movable control surfaces which can be moved up or down. If the elevator is rotated up, it decreases the lift force on the tail causing the tail to lower and the nose to rise. If the elevator is rotated downward, it increases the lift force on the tail causing it to rise and the nose to lower. Lowering the aircraft's nose increases forward speed, and raising the nose decreases the forward speed [1].

For controlling roll movement of aircraft set of control surfaces known as ailerons are used. These two set of ailerons are interconnected to each other and both move in inverse heading to each other. The ailerons are utilized to bank the aircraft. Therefore when pilot applies right push power on the stick, as the aileron on the conservative is avoided upwards, the aileron on the left wing is diverted downwards. As an aftereffect of this, lift on the left wing is expanded, while lift on the conservative is diminished. So the aircraft performs moving movement to the all right from the back of aircraft. The following figure 1 shows basic control surfaces of aircraft.

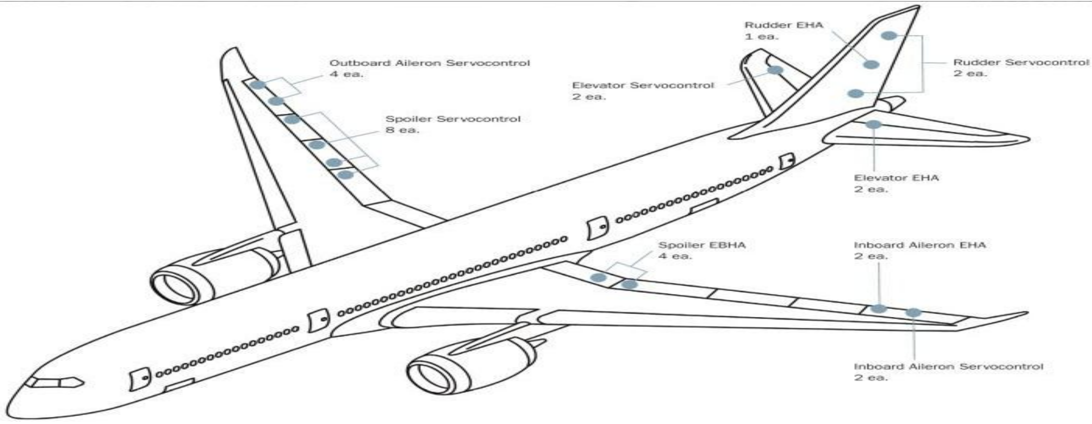

Fig.1 Control surfaces of Fixed wing Aircraft

In this research study we have considered two case studies and implemented new control techniques for particular models to determine the performance of controllers based on their dynamic responses. Number of control techniques already anticipated regarding this particular field of study, with each control technique having its own advantage and drawbacks. Starting with, control of longitudinal motion of aircraft 1st such technique discussed in paper, is based on Fuzzy logic control based on Takagi–Sugeno modeling approach is repotted. This model is used along the desired trajectory for state-space parallel decomposition controller (PDC) design. The anticipated control scheme guarantees stability of closed loop and asymptotical step pitch angle reference signal tracking. Simulation results performed on twin-engine short-range transport aircraft LET L410 indicate that the proposed control law can correspond to aircraft motion control and particularly in presence of model inaccuracies and disturbances, then the effect of elevator saturation on asymptotically stable tracking of a desired flight path angle of an aircraft is repotted and the desired reference trajectory is computed using a non-linear dynamic model of the longitudinal states of the aircraft incorporating control bounds, the third technique repotted is based on Fuzzy-PID Controller in which Fuzzy logic is used to tune each parameter of Proportional-integral-derivative (PID) controller by selecting appropriate fuzzy rules. The developed model describes the aircraft motion and its real dynamics accurately compared to other proposed models that allow studying and evaluating some pitch controllers beginning from traditional controller systems, fuzzy controller systems, and hybrid controller systems. The fuzzy-PID controller offered the best response by mixing the features of both the fuzzy and the PID controllers, and the ability to adapt to the fuzzy rules, fourth kind of control mechanism derived by using Lyapunov Theory ensures that under a certain condition, the asymptotical stability of the helicopter, the fifth control strategy presented in literature is based on Linear Quadratic Regulator (LQR) and the main advantage of this technique is that the optimal input signal turns out to be obtainable from full state feedback (by solving the Ricatti equation) and the 6th control method used in the literature is of comparative assessment of LQR and Fuzzy Logic controller for pitch control of aircraft [2-7].

Now regarding Aircraft Roll control movement, to begin with, first such control technique utilized is by implementing it with conventional FLC. In this paper Fuzzy tenets were produced to decide the fitting control surface avoidances to accomplish the sought move rate while guaranteeing that wing burdens are inside safe limits. The tweak of the damping element as indicated by the separation of the framework state from the objective state permits full use of the vehicle's increasing speed ability and brought about a change of the reaction time by an element of two, then in second technique Adaptive control framework for detachment of aircraft movement on roll and sideslip is repotted, the third strategy utilized depends on LQR and Fuzzy rationale controller. In this paper the Linear Quadratic Controller (LQR) and Fuzzy Logic Controller (FLC) are produced for controlling the move point of an aircraft framework [10]. The fourth strategy utilized for controlling aircraft move control depends on Fuzzy-PID controller. In this work a Fuzzy-PID controller has been outlined and executed in ASIC with a specific end goal to control move movement [8-11].

In this paper new hybrid intelligent controllers are proposed and implement with following aircraft control surfaces. Comparative simulation results obtained shows that Fuzzy-PID controller outperforms the other controllers considering the dynamic and steady-state performances.

The following paper is organized in six different parts, and it follows as: in section 2 mathematical modeling of aircraft parameters is presented, in section 3 methodology is presented giving details of controllers implemented and their designing, section 4 shows simulink models of aircraft for pitch and roll movement, in section 5 simulation results and their discussion is given in detail and finally section 6 shows conclusion and future scope of present work represented here.

II. MATHEMATICAL MODELING OF AIRCRAFT LONGITUDINAL AND ROLL CONTROL MOVEMENT

In this section of the paper, a brief description for modeling of aircraft longitudinal and Roll control movement is discussed. The following sub section discusses the components used in pitch control movement. The following figure 2 shows the movement of aircraft along the coordinate axis.

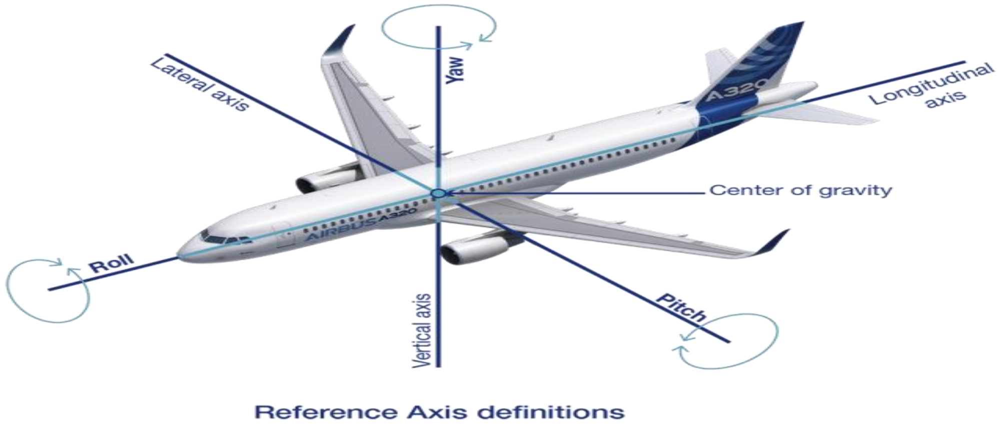

Fig.2 Directional stability of aircraft along co-ordinate axis

2.1 Modeling of Component Used In Aircraft Longitudinal Control

The component which is modeled in the present paper is the servo motor, for which following transfer function is derived. Since aircraft longitudinal control movement is controlled using elevators, which deflect the air flow, causing aircraft to climb or descend by creating pressure on wings. And the movement of these elevators is controlled using servo motor as shown in figure 3. Since we have considered generalized aircraft model, so the prime focus is on the servo unit and also we have made changes in the values of components for which following transfer function is derived and different from, as considered in original work. Also in section 5 we have implemented two models of aircraft longitudinal control movement i.e., with ANN and PID with Fuzzy compensation, though we have implemented it with PID and fuzzy separately also and calculated the results as mentioned in table 2 and 3 respectively, but not included their simulink models as they are already modeled.

Transfer function of longitudinal control system component

$$\text{Transfer function of servo amplifier } = G_a(S) = K$$

$$\text{Transfer function of gears } = 1/15 = 0.666$$

$$\text{Transfer function of pitch gyro } = K_{g1}$$

$$\text{Transfer function of pitch rate gyro } = K_{g2}$$

To get transfer function of the servomotor, we have to model its components.

Rotor circuit

$$e_a = i_a R_a + L_a \frac{di_a}{dt} + V_b \tag{2.1}$$

Rotor EMF

$$V_b = K_b \frac{d\theta_m}{dt} \tag{2.2}$$

Mechanical torque

$$T_m = K_i i_a \tag{2.3}$$

Equations governing mechanical port

$$J_m \frac{d^2\theta_m}{dt^2} = T_m(t) - D_m \frac{d\theta_m}{dt} \tag{2.4}$$

$$e_a = \frac{L_a}{K_t}\frac{dT_m}{dt} + \frac{R_a}{K_t} T_m + K_b \frac{d\theta_m}{dt} \tag{2.5}$$

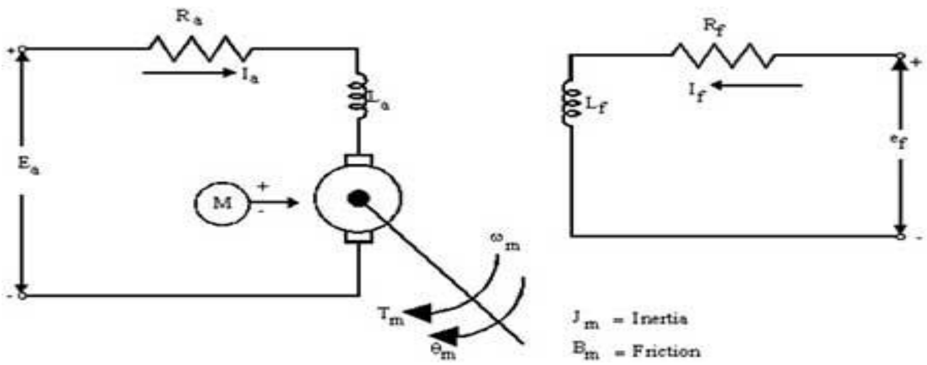

Fig.3 Schematic of Servomotor

Transfer function of servomotor

$$\frac{\theta_m}{E_a(s)} = \frac{1}{[T_a T_m s^2 + (T_m + \gamma T_a)s + \gamma + K_b]} \tag{2.6}$$

Considering the values

$$K_t = 0.65\frac{Nm}{A}, K_b = 0.65\ Vs/rad$$
$$J_m = 0.042kg - m^2$$
$$D_{m=0.025\frac{Nms}{rad}},\ R_a = 10\Omega$$
$$L_a = 10H$$
$$T_m = \frac{J_m R_a}{K_t} = 0.64s, \gamma = \frac{D_m R_a}{K_t} = 0.38, T_a = 1$$

Transfer function of servomotor can be written as $\frac{1}{S(0.69s^2+1.03s+1.83)}$

Further in the original research the PID controller is designed for aircraft pitch control using root locus technique for compensate and uncompensated system. The following transfer function is obtained [12].

$$G(s) = \frac{0.26}{0.98s^3 + 1.7s^2 + 1.63s}$$

2.2 Modeling of Component Used In Aircraft Roll Control

For modeling of aircraft roll control we consider the control of single degree of flexibility moving methods of aircraft and efficiently controlled rockets. Such a mode emerges from the de-coupling motion which constitutes vehicle's rotational flow and is spoken to, by the accompanying exchanges capacity between bank edge, Φ(s), and the aileron deflection angle δ_a :

$$\frac{\Phi(s)}{\delta_{a(s)}} = \frac{C_{l_{\delta_a}}}{s(\frac{J}{qSb}s - \frac{b}{2v}C_{l_p}})) \tag{2.7}$$

Where J is the moment of inertia about the roll axis, C_{l_p} is the stability derivative representing damping in roll, and $C_{l_{\delta_a}}$ is the stability derivatives representing the rolling moment due to aileron deflection angle. This plant has a first order time constant $T = -\frac{2vJ}{qSb^2 C_{l_p}}$ in addition to a pole at s=0. The aileron actuator can be assumed to be a linear, second-order transfer function with nonlinear saturation limits, $|\delta_a| \leq \delta_{max}$. Since the plant has a pole at origin, it can produce a desired step change in blank angle in a closed-loop, proportional feedback control system, such as the one approximately provided by a rate-integrating gyro.

Gyroscopic sensor

For mathematical modeling of gyroscope the first practical analog feedback device employed in a closed-loop flight control system is a ***gyroscope*** (also called ***gyro*** in short), where a spinning rotor mounted on a restrained ***gimbal*** could act as either a multiplier (gain) or an integrator of the error signal (an angular rate).

The dynamical equation for gimbal can be written as follows:

$$J\ddot{\theta}(t) + c\dot{\theta}(t) + k\theta(t) = -H_r\dot{\psi}(t) \tag{2.8}$$

Where J is the moment of inertia of the gimbal and rotor assembly along the axis oy. Equation (2.8) has following equilibrium solution $\theta(t) = \theta_e$. In the steady $(t \to \infty)$, obtained by letting $\theta = \dot{\theta} = 0$:

$$\theta_a = -\frac{H_r}{k}\dot{\psi} \tag{2.9}$$

This implies a gimbal angle proportional to the vehicle's rotation rate. Hence, the spinner is known as a rate gyro, as it can be adjusted to quantify a vehicle's consistent state rate about the information pivot. The time taken to achieve the consistent state for a given change in the vehicle's rate relies on the damping steady, c, and also the snippet of inertial, J, while the balance estimation of the gimbal point, Eq. (2.9), depends just upon the proportion of the rotor's precise energy, H_r with the spinning stiffness, k. By altering this later proportion, the rate gyro can be made increasingly (or less) delicate to the vehicle's rate. Then again, by conforming the damping consistent the gyro elements can be speeded up, or backed off, making it react rapidly (or gradually) to an adjustment in the vehicle's rate. If the restraining spring is removed from the rate gyro, the transfer function of the resulting mechanism (called ***rate-integrating***-or **displacement –gyro**) becomes

$$\frac{\theta(s)}{\psi(s)} = -\frac{H_r}{Js+C} \tag{2.10}$$

For mathematical modeling we consider a fighter aircraft with following specifications i.e., with wing span, $b = 15m$, platform area, $S = 57m^2$, moment of inertia about roll axis, $J = 35{,}000\ kg - m^2$, flying straight and level at constant speed, $v = 240\ m/s$ at standard altitude $12km$ where the dynamic pressure is $q = 8500\ N/m^2$, $C_{l_p} = -0.30/rad$, and $C_{l_{\delta_a}} = 0.050/rad$. The airplane is equipped with aileron actuator with the following first order transfer function between the commanded aileron deflection angle, δ_{ac}(s), and the actual aileron deflection angle δ_a:

$$\frac{\delta_a(s)}{\delta_{ac}(s)} = \frac{20}{s+20}$$

Structural limitations restrict the maximum aileron deflection at the given speed to$|\delta_a| \leq 10°$. A *roll autopilot* is designed with the rate-integrating gyro with following characteristics: $H_r = 10^4\ g - \frac{cm^2}{s}$, $J = 35\ g - cm^2$, $k = 3.02 \times 10^5\ g - cm^2/s^2$, and $c = 5000\ g - \frac{cm^2}{s}$. The simulation is carried out by simulink block diagram and shown in later sub section 4.2 of the paper [13].

III. DESIGNING OF CONTROLLERS

A control system is a means by which the user can control any quantity of his interest and maintain or alter its state in desired manner. A control system is generally required to meet following time response specifications: steady-state error, damping factor and settling time. By designing a control system we can make it to achieve its desired state. Here, in this section we show the design process of controllers implemented with following control surfaces of aircraft i.e., elevators and ailerons. The following hybrid intelligent controllers are considered in this paper for which detail explanation is given in respective controllers sub sections.

3.1 PID controller with fuzzy compensation

The Fuzzy-PID control structure used in the present work includes PID and Fuzzy logic controller, both of them arrange in cascade. Output from the process is again feed back to the fuzzy and the corresponding output of fuzzy to the PID controller again. This technique mentioned here is also known as compensation technique. In this technique PID controller is tuned online by using compensator formula and desired gains are obtained. The membership functions developed for aircraft pitch control are also fine tuned manually so as to keep the error within tolerance limit. The membership functions utilized here are triangular membership functions. Now let’s discuss both these controller individually.

PID controller

PID controller is widely used controller in process control industries. For determining the values $Kp, Ki,$ and Kd the controller needs to be tuned. Different tuning techniques are available for determining the values of the gains. The controller input is the error between the desired output and the actual output. This error is manipulated by the controller to produce a command signal for the process according to the relationship as given below.

$$u(n) = k_p e(t) + k_i \int_0^t e_t\ d(t) + k_d \frac{d}{dt} e(t) \tag{3.1}$$

The above equation represents control law known as proportional-integral-derivative (PID). The gains of $Kp, Ki, Kd,$ are suitably chosen by a design process called PID tuning in order to achieve desired transient response, as well as zero steady-state error for given desired output function. Due to excellent properties, PID controller is commonly used in closed-loop devices, especially in SISO plants. A block diagram of PID controller is shown in figure 4 in some flight control applications; the classical PID control may not offer the most efficient choice of feedback control, especially when multiple inputs and outputs are involved [14].

$$C = K_p\left(1 + \frac{1}{T_i}\frac{1}{s} + \frac{T_d s}{\frac{T_d}{N}s+1}\right) \tag{3.2}$$

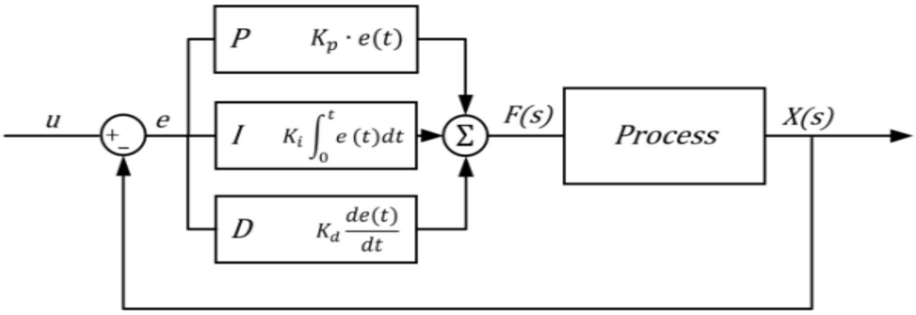

Fig.4 Block diagram of PID controller

Fuzzy logic base controller

The term 'fuzzy' used in FLC implies that the decisions made by a machine cannot be expressed as 'true' or 'false', but instead as partially 'true' and 'false' for defining each of the linguistic variables such as 'high', 'medium', 'low' . These partial 'truths' are expressed as membership functions ranging from zero to a user defined linguistic variable depending on the process for which it is to be implemented, quantifying the variables as stated above. The output of fuzzy controller to be determined is processed by the rule base consisting of all the linguistic variables and membership functions. Fuzzy-logic controller has a tendency to provide a natural, flexible and intuitive way to express the response of a system where the dynamics may be too complex or not known. Fuzzy-logic control can also be combined with conventional controllers such as PID controller, which traditionally only guarantees stability for linear systems, allowing it to control a non-linear system, hence providing improved robustness and response.

The FLC structure consists of four main building blocks: (1) The fuzzifier that maps crisp input either in direct form or normalized form i.e. input ranges between [-1 , 1], to corresponding type-1 fuzzy set, (2) The "rule base" consists of set of rules that depicts the knowledge of designer about actions to be taken by the controller, (3) The fuzzy inference system (FIS), interpret the type-1 fuzzy input set to type-1 fuzzy output set according to rules provided in rule base, and in the last, (4) The defuzzifier convert type-1 fuzzy output set of FIS to a crisp output. The block diagram of FLC is shown in figure 5.

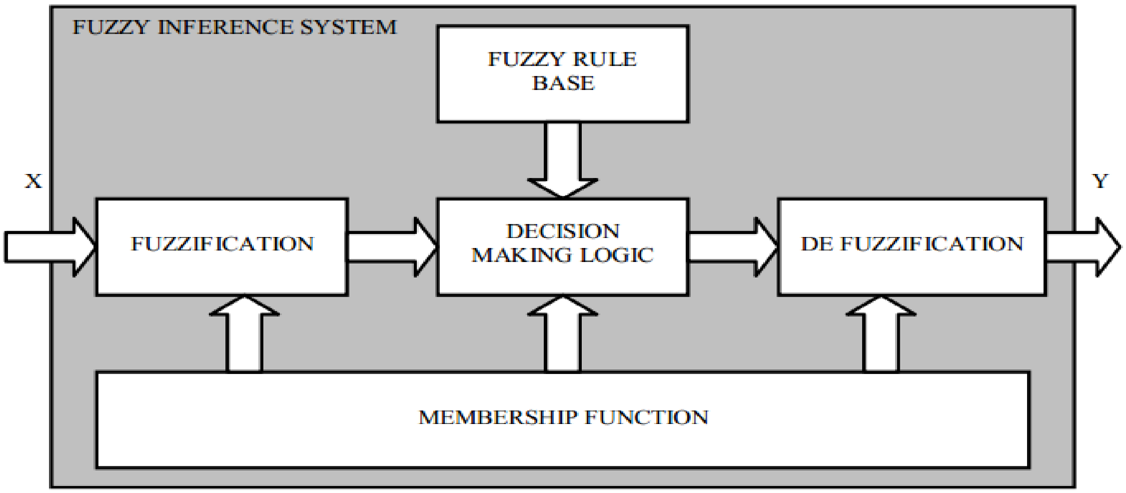

Fig.5 FLC block diagram

i. Fuzzification

The fuzzification operation, F can be defined as follows:

$$F: U_i \rightarrow U_i^*$$

The fuzzification transforms u_i to a fuzzy set $\widetilde{A_i}$, defined on the U_i, where

$$F_i = \widetilde{A}_i$$

ii. Rule Base

A linguistic variable can be characterized by (1) name of the variable, (2) its linguistic fuzzy sets, (3) Universe of discourse, (4) "syntactic rule" of fuzzy sets, and (5) "Semantic rule" of fuzzy sets.

Fuzzy if-then rule
In the simplest form, "fuzzy if-then rule" can be represented as:
If x_1 is A and x_2 is B **then** y is C,
Where A, B and C are linguistic values defined by fuzzy sets on the universe of discourse X_1, X_2 and Y, respectively. The part between 'if and then' is called "antecedent" and the part after 'then' is called "consequent".

iii. Fuzzy Inference System

There are two types of FIS that are widely used in applications: (1) Mamdani FIS and Takagi-Sugeno-Kang (TSK) FIS. The differences between these two FIS lie in the consequent part of their fuzzy rule, and thus they have different defuzzification accordingly.

Mamdani FIS

In Mamdani FIS the consequent part is also represented by a fuzzy set. Min-Max composition of Mamdani FIS is generally used. Figure 6 shows how a two rule Mamdani FIS compute the overall output fuzzy set, which subjected to crisp input x_1 and x_2, using Min-Max composition of Mamdani FIS.

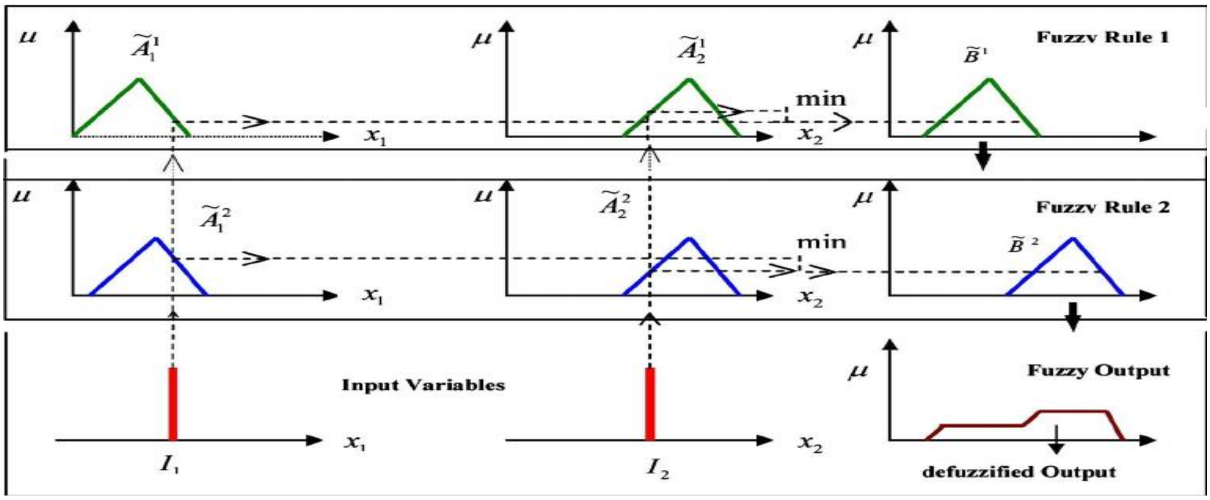

Fig.6 The Mamdani FIS using Min and Max operation

TSK FIS

In TSK FIS, the consequent part is represented by a conventional a polynomial function. A typical TSK fuzzy rule has the form:

IF x is A **and** y is B **then** z=f(x, y);

Where A and B are input fuzzy sets in the antecedent and f(x, y) is a polynomial of input variable x and y in the consequent. However, f(x, y) can be any function, until the output defined by it is within the fuzzy region specified by the antecedent of the rule.

iv. Defuzzification

Defuzzification is a process to extract crisp output from the type-1 fuzzy output set, provided by FIS. There are various defuzzification methods, some of the general defuzzification methods are explained in brief as follows.
Centroid of area
Using centroid of area method the crisp output, Z_{COA} is given as

$$Z_{COA} = \frac{\int_Z \mu_A(z) z dz}{\int_Z \mu_A(z) dz} \quad (3.3)$$

Where A is the output fuzzy set to be defuzzified defined in the universe of discourse z, $\mu_A(z)$ is the aggregated output of MFs.

Bisector of area
The crisp output, Z_{BOA} satisfies the following equation:

$$\int_{\alpha}^{Z_{BOA}} \mu_A(z)dz = \int_{Z_{BOA}}^{\beta} \mu_A(z)dz \quad (3.4)$$

Where α= min {z|z ϵ Z} and β= max {z |z ϵ Z}.

Mean of maximum

In this method, Z_{MOM} is the average of the maximizing z at which MF reach a maximum μ*, which can be mathematically represented as:

$$Z_{MOM} = \frac{\int_{Z'} z dz}{\int_{Z'} dz} \qquad (3.5)$$

Where z' = {z|$\mu_A(z) = \mu^*$}.

Smallest of maximum

In this method, the crisp output Z_{SOM} is the minimum of the maximizing Z.

Largest of maximum

In this method, the crisp output Z_{LOM} is the maximum of the maximizing Z [15].

The membership functions considered here with two inputs and one variable respectively are designed for both elevator and aileron control surfaces, as shown in figure 7-9. Same membership function are utilized for both the parameters and are different from as used in original work already mentioned.

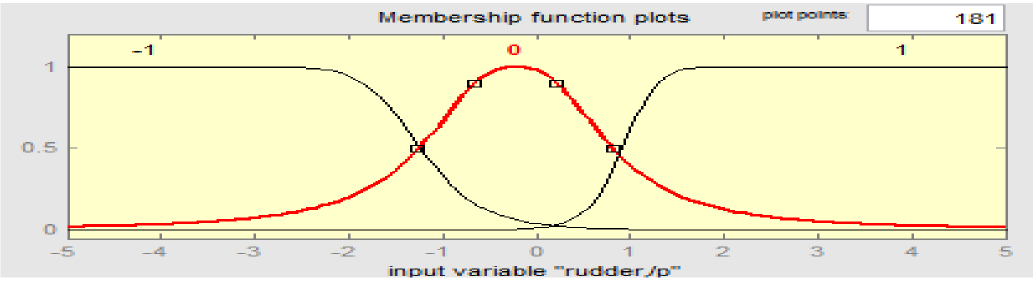

Fig.7 Membership functions for elevator/aileron input (error)

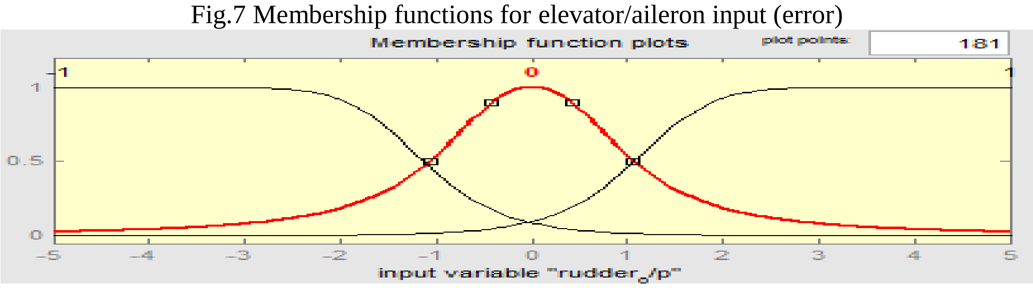

Fig.8 Membership functions for elevator/aileron input (rate)

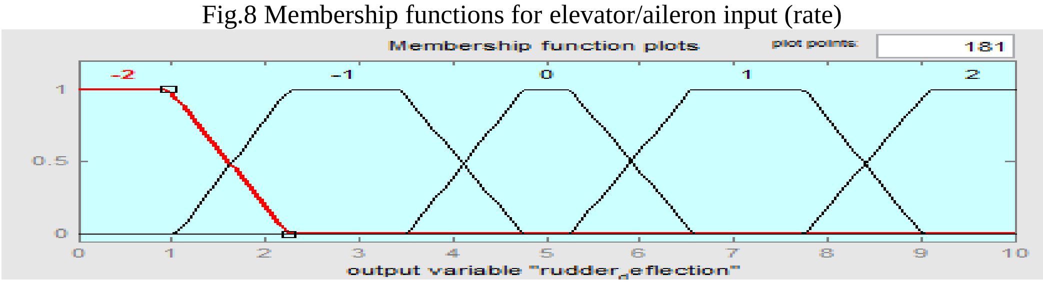

Fig.9 Membership functions for elevator/aileron output (control action)

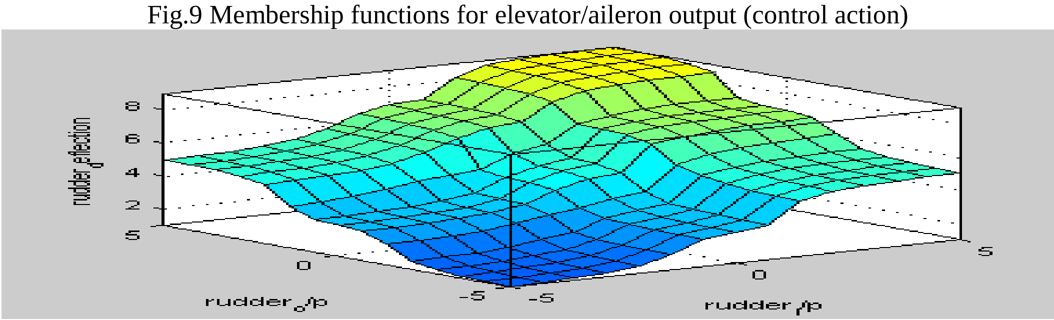

Fig.10 Surface viewer for aircraft elevator and aileron control surfaces

Here, we have considered gaussian membership function for input with three variables each and range kept from [-5 5], whereas for output control action trapezoidal membership functions are considered and range kept from [0 10] with six membership functions. The membership function are denoted by [-2, -1, 0, 1, 2]

respectively for simplicity, which can otherwise be denoted by (negative medium- NM, negative small-N, Zero-0, positive small-P, positive medium-PM) and so on depending on the individual.
The following table represents rules implemented for fuzzy logic controller.

Table 1 Rule Base for FLC

e/de	-1	0	1
-1	-2	-1	0
0	-1	0	1
1	0	1	2

PID controllers in general do not work very well for nonlinear systems, higher order and time-delayed linear systems, and particularly complex and vague systems that have no precise mathematical models. To overcome these difficulties, various type of modified PID controllers such auto-tuning, adaptive PID controllers and combination of hybrid structure involving PID controller are used.

Figure 11 shows the structure of Fuzzy-PID controller which has been developed for the aircraft longitudinal and roll control model. Fuzzy compensation technique is introduced in this particular model. The use of compensation technique is to achieve the desired state of the system. By using compensation we feed the output of the process back to FLC as input, till the process becomes stable.

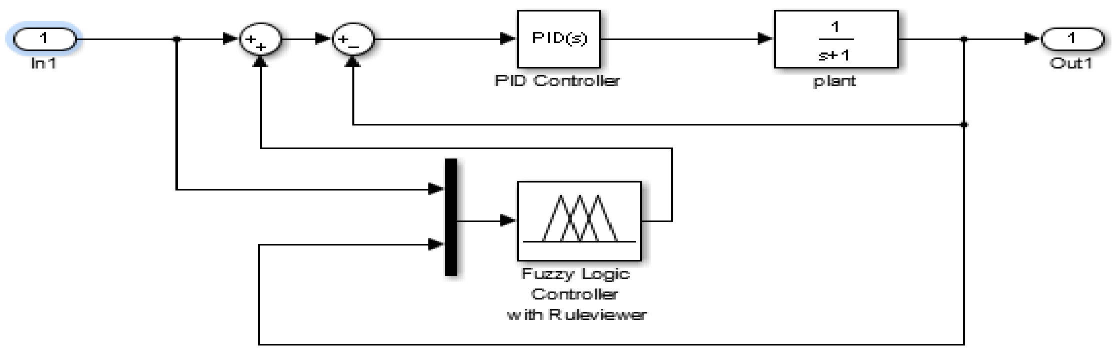

Fig.11 Fuzzy-PID controllers with fuzzy compensation

3.2 Artificial Neural Network (ANN)

Neural Network is a control mechanism utilized as a part of control theory and it is exceptionally successful in flight control framework planning.
In the present work, we are considering an elementary feed forward architecture of one neuron receiving two inputs. Its output and input vector are, respectively for both longitudinal and roll control movement.
$o = [o_1\ o_{2 \ldots} o_m]^t$ $x = [x_1\ x_2 \ldots x_n]^t$
Weight w_{ij} connects the i'th neuron with the j'th input. The double subscript convention used for weights is such that the first and second subscript denotes the index of the destination and source nodes, respectively. The activation value for the i'th neuron as
$net_i = \sum_{j=1}^{n} w_{ij}\ x_{ij}$, for i=1,2,…,m
The following nonlinear transformation eq. involving the activation function $f(net_i)$, for i= 1,2,…, m, completes the processing of x. The transformation, performed by each of the m neurons in the network, is a strongly nonlinear mapping expressed as
$o_i = f(w_i^t x)$, for i=1,2,…,m
Where weight vector w_i contains weights leading towards the i'th output node and is defined as follows
$w_i \triangleq [w_{i1}\ w_{i2} \ldots w_{in}]$

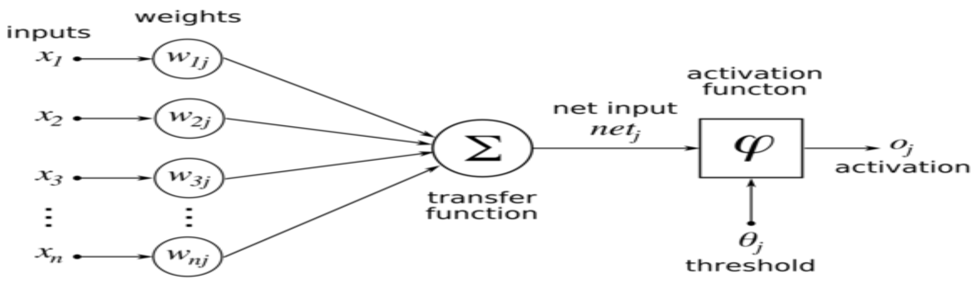

Fig.12 Single layer feed forward network

Introducing the nonlinear matrix operator Γ. The mapping of input space x to output space o implemented by the network can be expressed as follows

O=Γ$|Wx|$

Where W is the weight matrix, also called the connection matrix: When the accompanying system is executed the neural system begins preparing the information and executes a solitary ANN part. This neural system square is supplanted in the pitch control Simulink obstructs with alternate controllers and the relating results are being noted. The associated figure demonstrates the Simulink part outline for aircraft longitudinal control with ANN [16].

Figure 13 shows training of Artificial Neural Network in MATLAB.

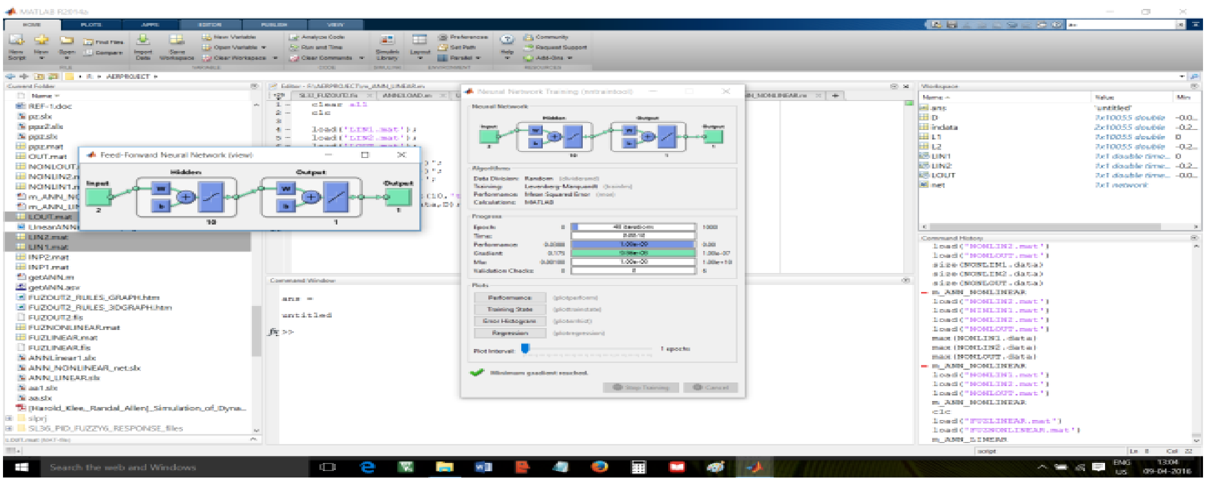

Fig.13 Neural Network training in MATLAB

3.3 ANFIS

A neuro-fuzzy inference system (ANFIS) is a hybrid structure consisting of neural system and fuzzy frameworks in such a manner that neural system is utilized to decide the parameters of fuzzy framework. ANFIS to a great extent expels the prerequisite for manual enhancement of the fuzzy framework parameters. A neural system is utilized to consequently tune the fuzzy parameters, for instance the participation capacities limits, prompting enhanced execution without administrator creation.

The ANFIS with the learning ability of neural system and with the benefits of the standard base fuzzy framework can enhance the execution altogether and can give an instrument to consolidate past perceptions into the arrangement procedure. In neural system the preparation basically fabricates the framework. Nonetheless, utilizing an ANFIS plan, the framework is worked by fuzzy rationale definitions and is then refined utilizing neural system preparing calculations.

The prospect of ANFIS is to discover the parameters of a fuzzy by method for taking in techniques got from neural system. A typical approach to apply a learning calculation to a fuzzy framework is to speak to it in an extraordinary neural system like design. At that point a learning calculation, for example, bolster forward is utilized to prepare the framework. In any case, neural system learning calculations are generally inclination plunge strategies. This can't be connected straightforwardly to a fuzzy framework, in light of the fact that the capacities used to understand the induction procedure are typically not differentiable. With a specific end goal to understand the framework, we have to supplant the capacities utilized as a part of the fuzzy framework (like min and max) by differentiable capacities or don't utilize a slope based neural learning calculation however a more qualified technique.

The learning procedure of an ANFIS takes the semantical properties of the essential fuzzy system into account. This results in constraints on the possible modification of the system's parameters. The fuzzy rules encoded with the system represent indistinguishable samples, and can be viewed as vague prototypes of the training data.

Generally, an ANFIS should not be seen as a kind of (fuzzy) expert system, and it has nothing to do with fuzzy logic in the narrow sense. It can be viewed as a special kind of feed forward neural network. The unit in this network uses t-norms or t-co-norms instead of the activation functions normally used in neural network. Fuzzy sets are encoded as (fuzzy) connection weighs.

ANFIS Architecture

The ANFIS is a fuzzy-Sugeno model put in the structure of versatile framework to encourage learning and adjustment appeared in Figure. Such structure makes the ANFIS displaying more efficient and less dependent on master learning. To display the ANFIS engineering, two fuzzy if-then guidelines in light of a first request Sugeno model are considered:

Rule 1: If (x is A1) and (y is B1) then (f1=p1x +q1y +r1)

Rule 2: If (x is A2) and (y is B2) then (f2= p2x + q2y + r2)

Where x and y are the inputs, Ai and Bi are the fuzzy sets, fi are the yields inside the fuzzy area indicated by the fuzzy principle, pi, qi and ri are the configuration parameters that are resolved amid the preparation procedure.

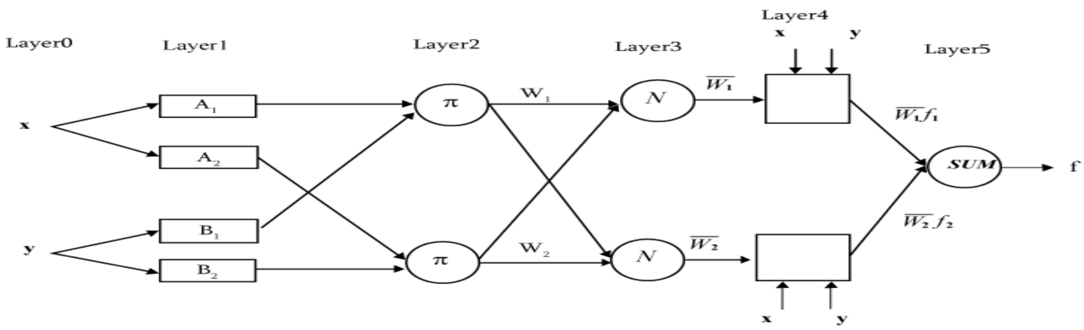

Fig.14 ANFIS basic structure

The node functions in the same layer are the same as described below:

Layer 1: all the node is adaptive nodes. The output of layer 1 is the fuzzy membership grade of the inputs, which are given by eq. (3.6) and (3.7)

O1i = μAi(x) i=1,2 (3.6)

O1i = μBi-2(y) i=3,4 (3.7)

Where, μAi(x), μBi-2(y) can adopt any fuzzy membership function. For example, if the Gaussian membership functions are employed, μAi(x) is given by (3.8)

$$\mu_{Ai}(x) = \frac{\exp(-0.5(x-c_i)2}{б_i^2} \quad (3.8)$$

Where ci and бi are the parameters of the membership function, governing the Gaussian functions accordingly.

Layer 2: The nodes are fixed. They are labeled with ∏, indicating that they perform as a simple multiplier. The outputs of this layer can be represented by eq. (3.9)

O2,I = wi = μAi(x) μBi(y) i=1,2 (3.9)

Which are so called firing strengths of the rules.

Layer 3: In the layer, the nodes are also fixed nodes labeled by N, to indicate that they play a normalization role to the firing strengths from the previous layer. The output of this layer can be represented by eq. (3.10)

$$O_{3,I} = w_i = \frac{w_i}{w_1} - \frac{w_i}{w_2} \quad i=1,2 \quad (3.10)$$

Which are so called normalized firing strengths.

Layer 4: In the fourth layer, the nodes are adaptive. The output of each node in this layer is simply the product of the normalized firing strength and a first order polynomial (for a first order Sugeno model).Thus, the output of this layer is given by eq. (3.11)

$$O_{4,i} = wifi = wi(pix + qiy + ri) \quad i= 1,2 \quad (3.11)$$

Layer 5: In the fifth layer, there is only single fixed node labeled with ∑.this node performs the summation of all incoming signals. Hence, the overall output of the model is given by eq. (3.12)

$$O_{5,i} = \frac{\sum i w_i f_i}{\sum i w_i} \quad i=1,2 \quad (3.12)$$

It can be observed that there are two versatile layers in this ANFIS design, specifically the first and the fourth layers. The parameters of first layer which are identified with the info participation capacities are the alleged parameters. The parameters of fourth layer which are altered parameters are the purported subsequent parameters [17].
Figure 15 shows implementation of ANFIS in Matlab Simulink.

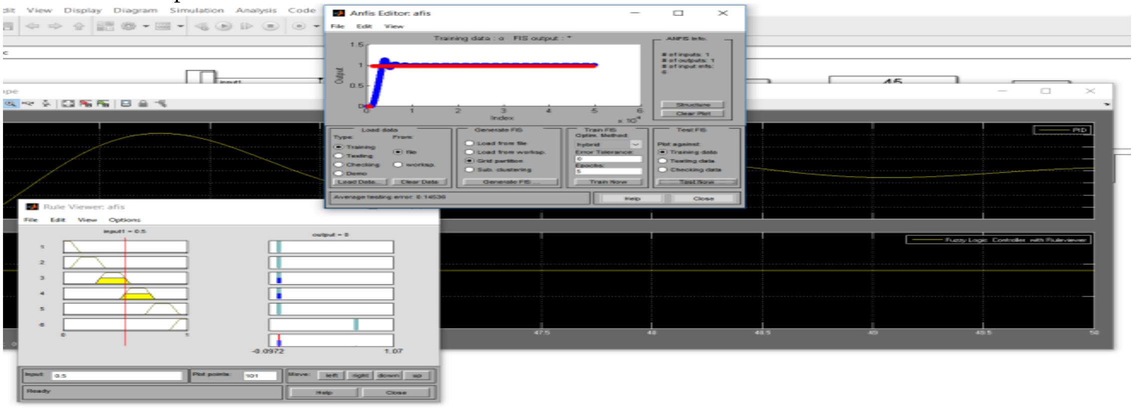

Fig.15 Training data of ANFIS in MATLAB

IV. MATLAB SIMULINK MODELS FOR AIRCRAFT MOVEMENT CONTROL

In this section of paper simulink models of aircraft showing elevators and ailerons are implemented with different controllers for controlling longitudinal roll movement respectively. Aircraft longitudinal control model is implemented for linear system and with non-linearities introduced into the system. Whereas aircraft roll control model is implemented for linear system only. For aircraft longitudinal control model we have modeled the elevator transfer function and implemented with ANN and hybrid combination of PID controller with fuzzy compensation and the results are compared with the already implemented controllers in the previous work.
For aircraft roll control movement the model is implemented with PID, Fuzzy, ANN and PID with fuzzy compensation as in original work the model was implemented without controller, and we have compared our own results showing the performance of each controller.

4.1 Simulink models for Aircraft Longitudinal Control

Figure 16-18 shows aircraft longitudinal control models implemented with ANN and PID controller with fuzzy compensation respectively for linear system and with non linearities introduce into the system.

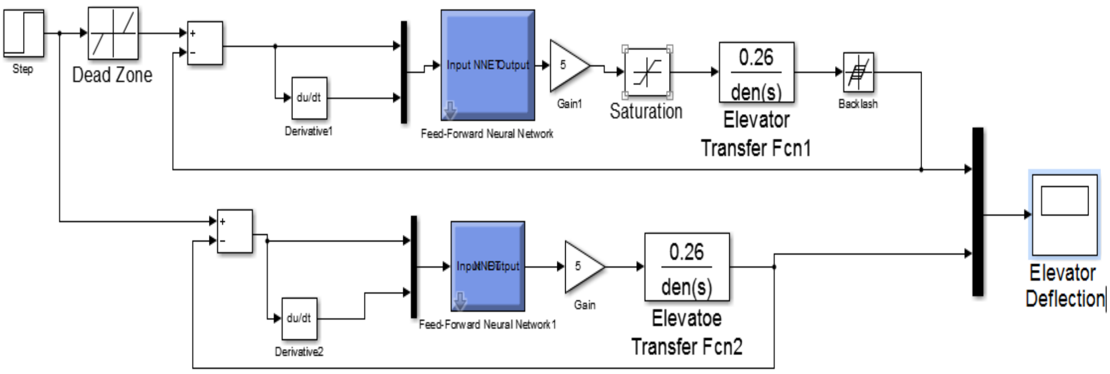

Fig.16 Aircraft Elevator control movement using ANN for Linear and Non-Linear Model

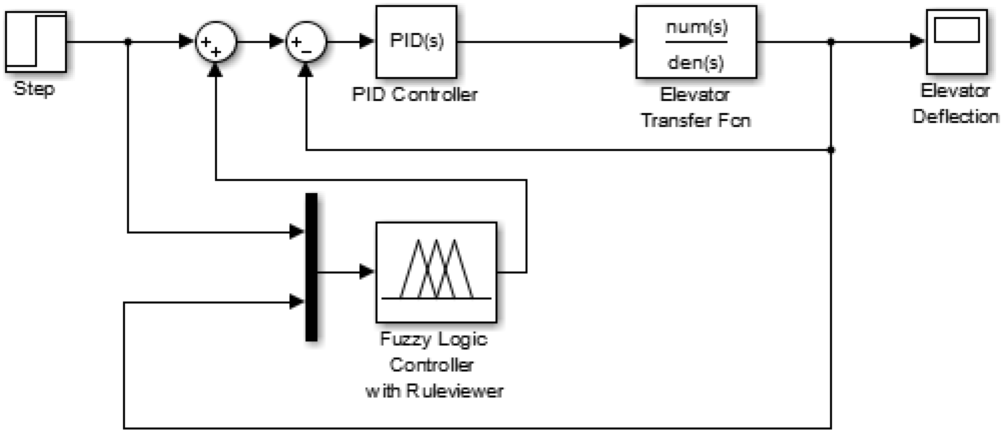

Fig.17 Aircraft Elevator control movement using PID controller with Fuzzy compensation linear model

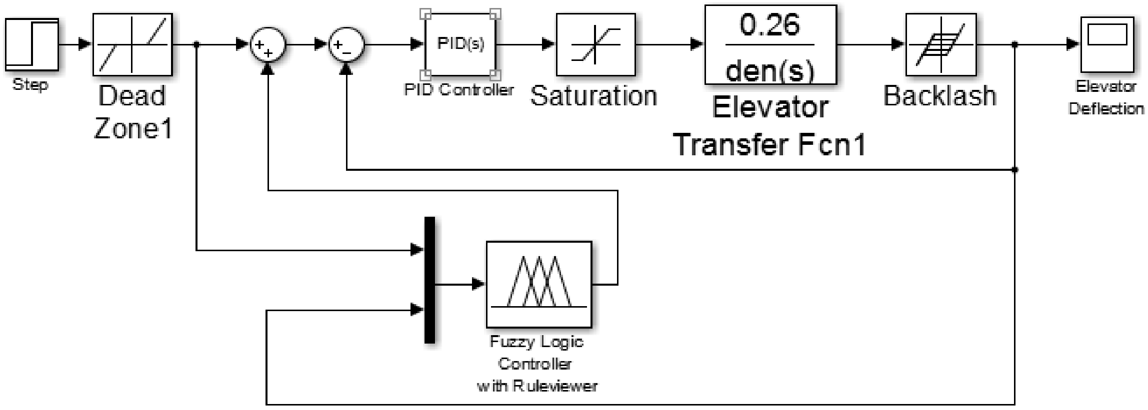

Fig.18 Aircraft Elevator control movement using PID controller with Fuzzy compensation with nonlinearities

4.2 Simulink model for Aircraft Roll Control.

Figure 19 and 20 shows Matlab simulink model for aircraft roll control using rate-integrating gyro and rate and rate-integrating gyro. On the basis of these models other controllers are developed and tuned.

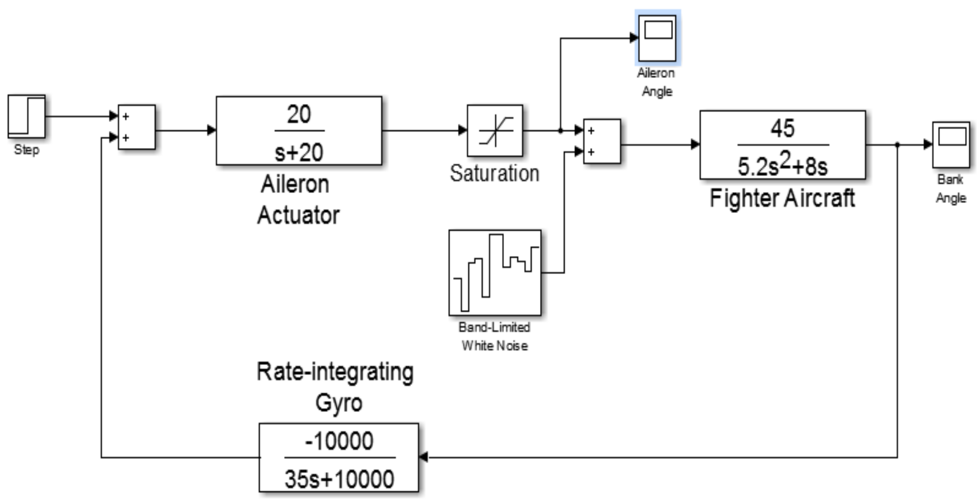

Fig.19 Simulink model of roll autopilot for fighter airplane with a rate-integrating gyro.

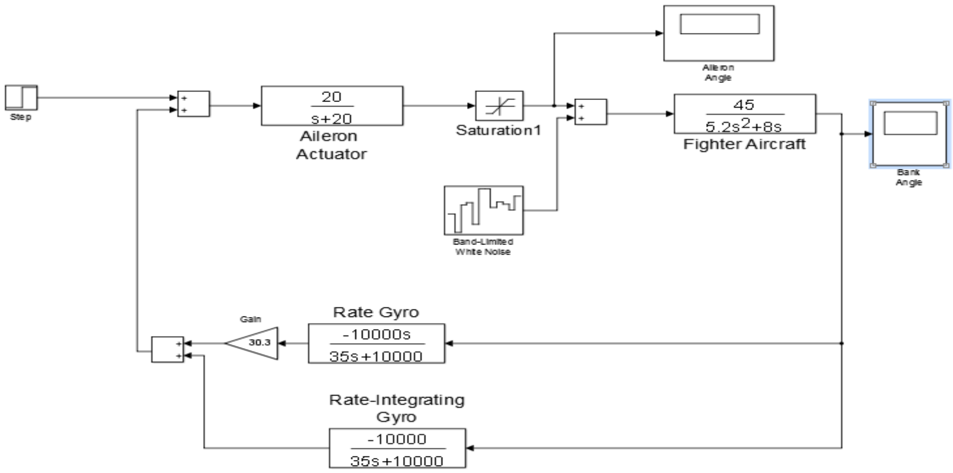

Fig.20 Simulink model of roll autopilot with rate and rate-integrating gyro

A. Aircraft Aileron control movement using PID Controller.

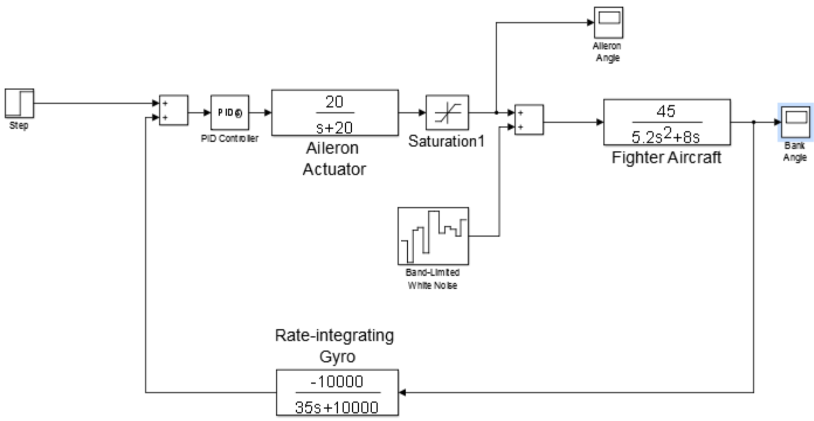

Fig.21 Simulink model of roll autopilot for fighter aircraft with rate-integrating gyro using PID

B. Aircraft Aileron control movement using Fuzzy Logic Controller

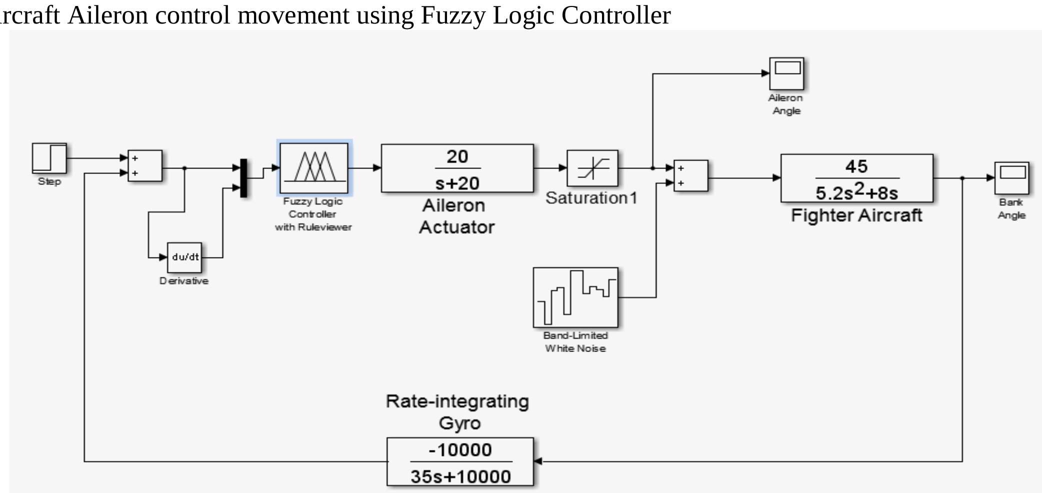

Fig.22 Simulink model of Aircraft Aileron control movement using Fuzzy Logic Controller with rate integrating gyro

C. Aircraft Aileron control movement using Artificial Neural Network (ANN)

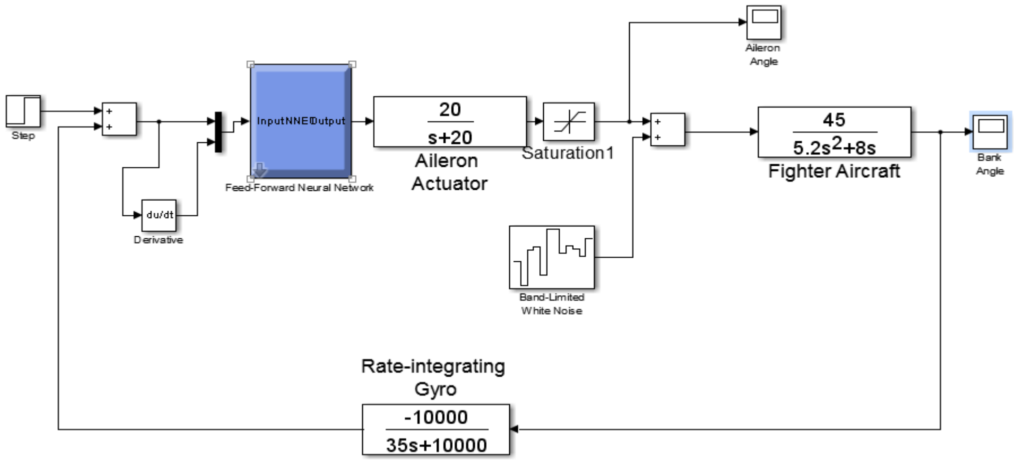

Fig.23 Simulink model of roll autopilot for fighter aircraft with rate integrating gyro using ANN.

D. Aircraft Aileron control using ANFIS

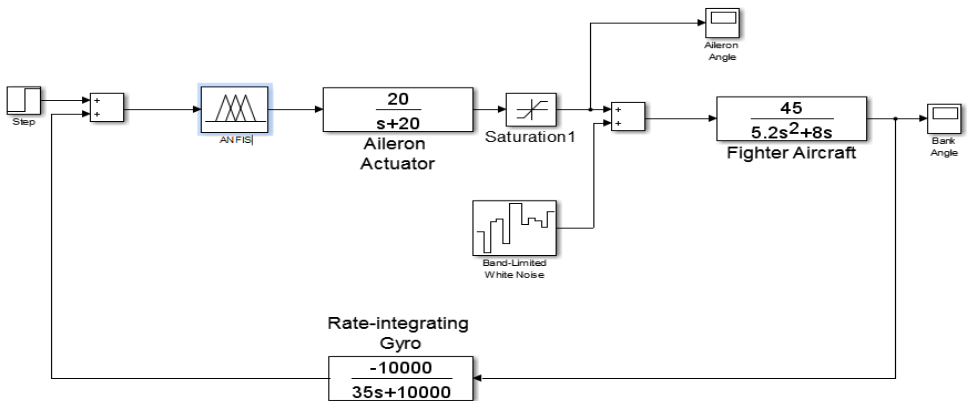

Fig.24 Simulink model of roll autopilot for fighter aircraft with rate integrating gyro using ANFIS

E. Aircraft Aileron Control using Fuzzy-PID Controller

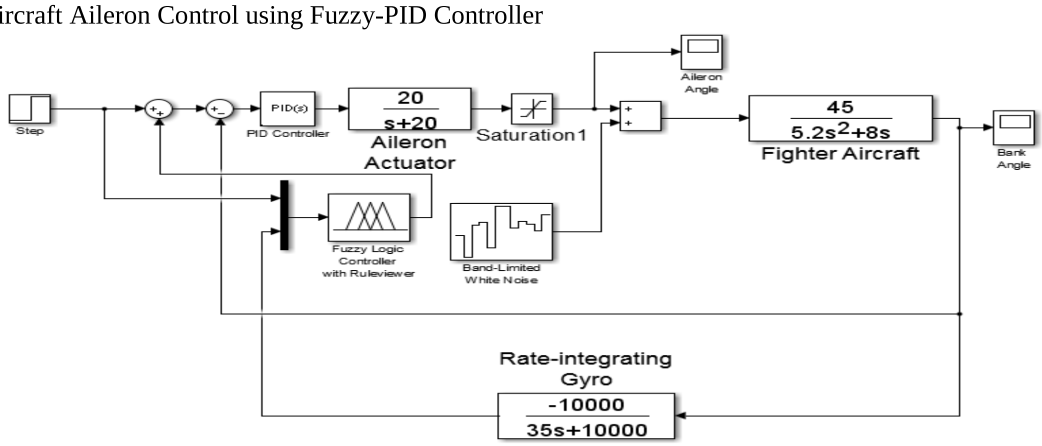

Fig.25 Simulink model of roll autopilot for fighter aircraft with rate integrating gyro using Fuzzy-PID.

V. DISCUSSION OF RESULTS

In this section of paper simulation results obtained using different control techniques is presented. Following responses are obtained for different models shown in figure 26-27 and 28-34 respectively. The simulation was performed using MATLAB simulink software by which we can depict the real time behavior of the aircraft control surfaces as it would do in real environment, since it provides a real-time observation of a system. Following controllers are implemented for the particular two models of aircraft: PID, FUZZY, ANN, ANFIS, and FUZZY-PID controllers respectively to analyze the performance of the aircraft.

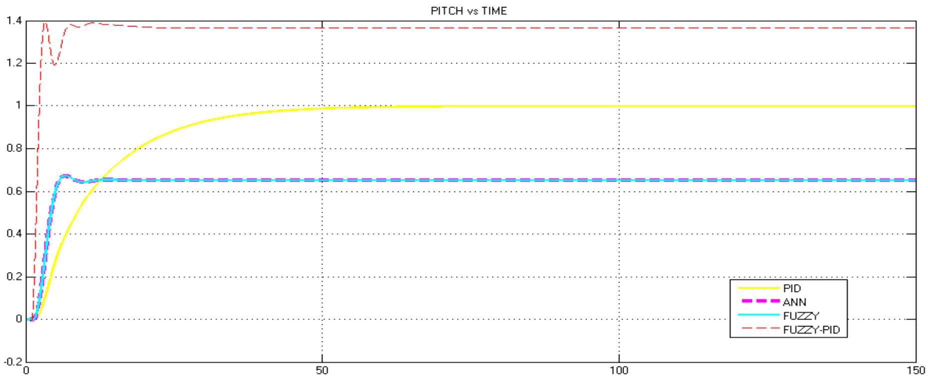

Fig.26 Step response of Aircraft Elevator for Linear System

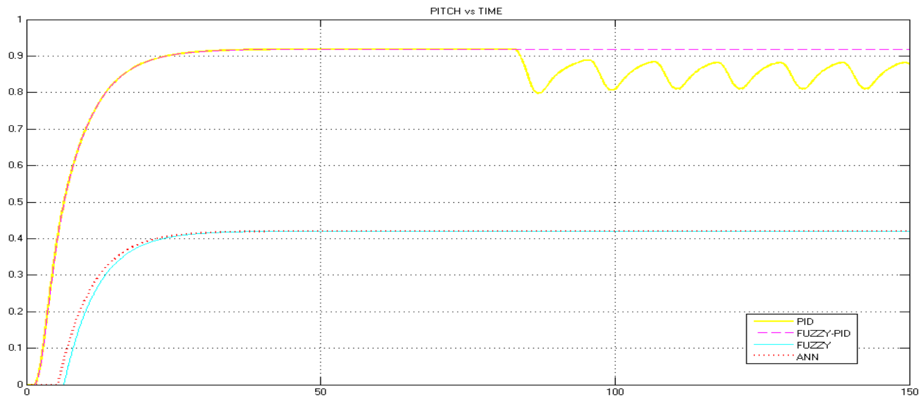

Fig.27 Step response of Aircraft Elevator for Non-linear System

Table 2 *Comparison of Different Controllers for Aircraft Longitudinal Control using linear model*

PARAMETERS	CONTROLLERS			
	PID	FUZZY	FUZZY-PID	ANN
Settling Time	8.1 sec	6.52 sec	5.40 sec	6.45 sec
Rise Time	2.8 sec	2.36 sec	1.5 sec	2.50 sec
Overshot	9.4%	3.8%	2.92%	5.56%
Steady State error	0	0.34	0.37	0.35

Table 3 *Comparison of Different Controllers for Aircraft Longitudinal Control using Non-Linear model*

PARAMETERS	CONTROLLERS			
	PID	FUZZY	FUZZY-PID	ANN
Settling Time	26.4 sec	22.9 Sec	5.42 sec	22.3 sec
Rise Time	16.52 sec	12. sec	1.24 sec	11.8 sec
Overshoot	0%	0%	2.93%	2.94%
Steady State error	0.66	0.15	0.15	0.68

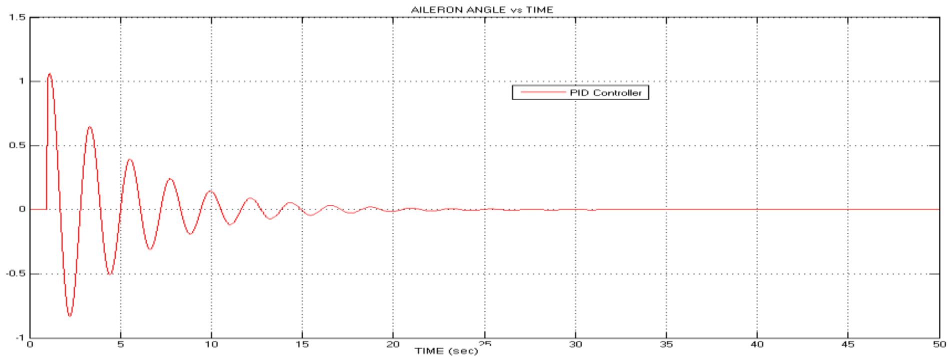

Fig. 28 Response of PID controller showing aileron Deflection angle with roll-rate integrating gyro

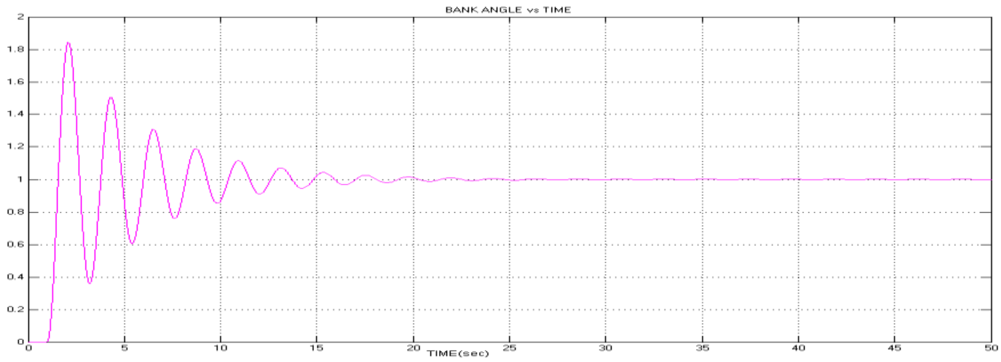

Fig.28 Response of PID controller showing Bank deflection angle with roll-rate integrating gyro

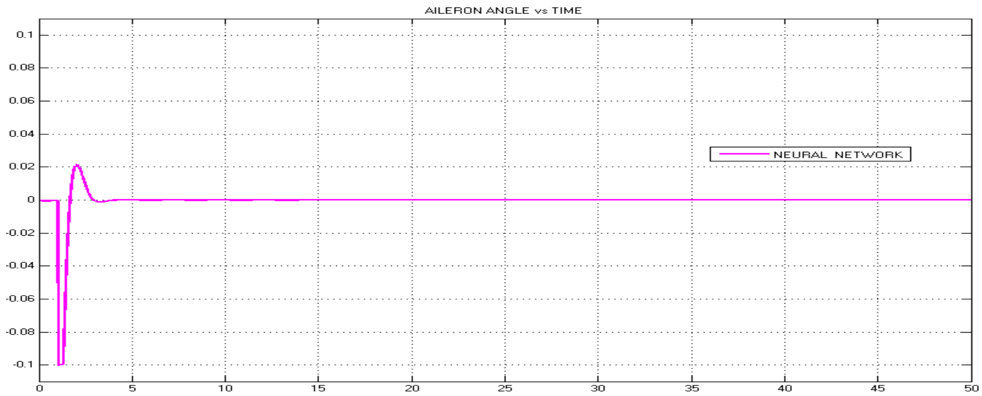

Fig.29 Response of ANN controller showing Aileron deflection angle with roll-rate-integrating gyro

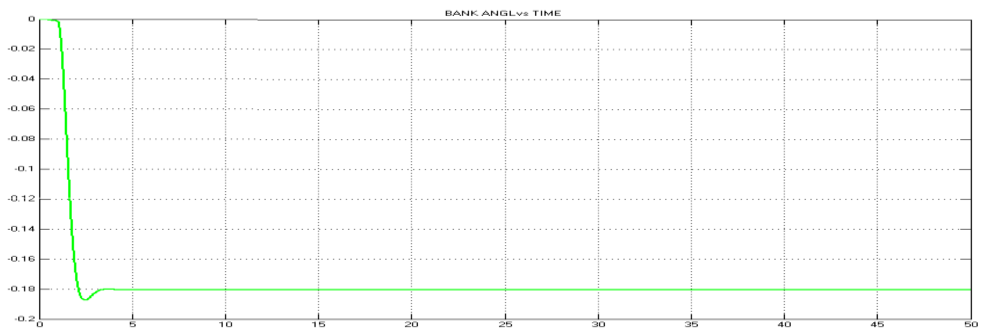

Fig.30 Response of ANN controller showing Bank deflection angle with roll-rate-integrating gyro

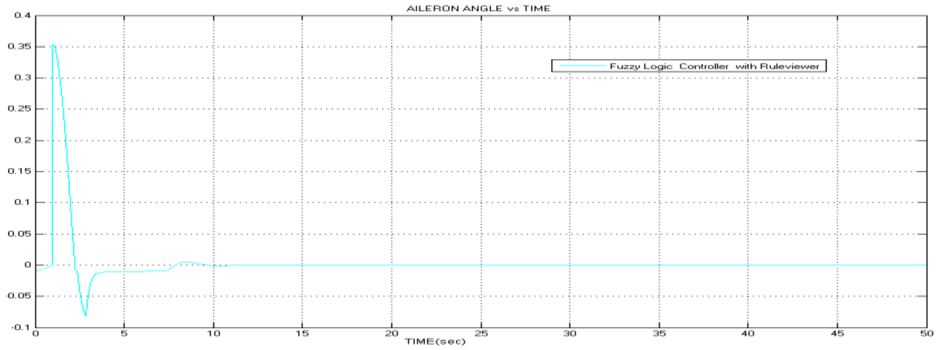

Fig.31 Response of Fuzzy controller showing Aileron deflection angle with roll-rate-integrating gyro

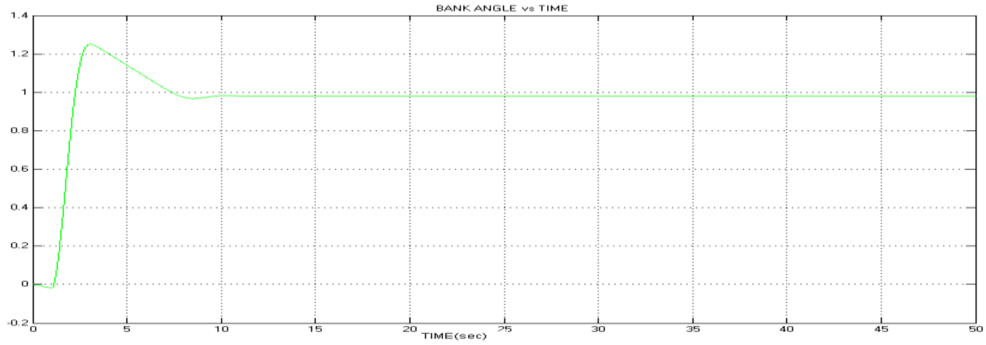

Fig.32 Response of Fuzzy controller showing Bank deflection angle with roll-rate-integrating gyro

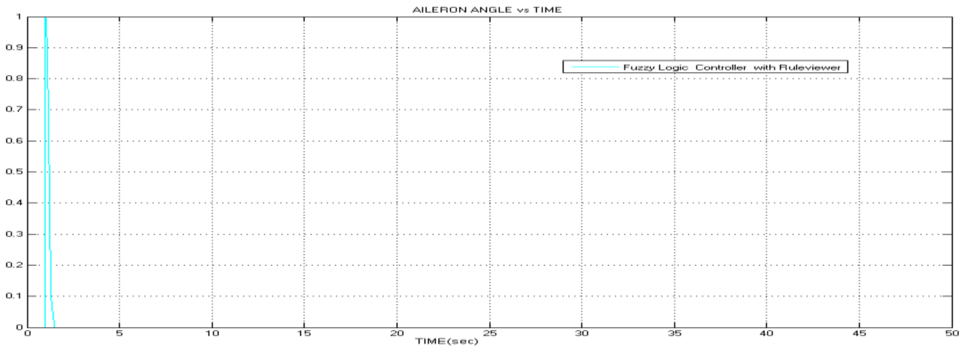

Fig.33 Response of ANFIS controller showing Aileron deflection angle with roll-rate-integrating gyro

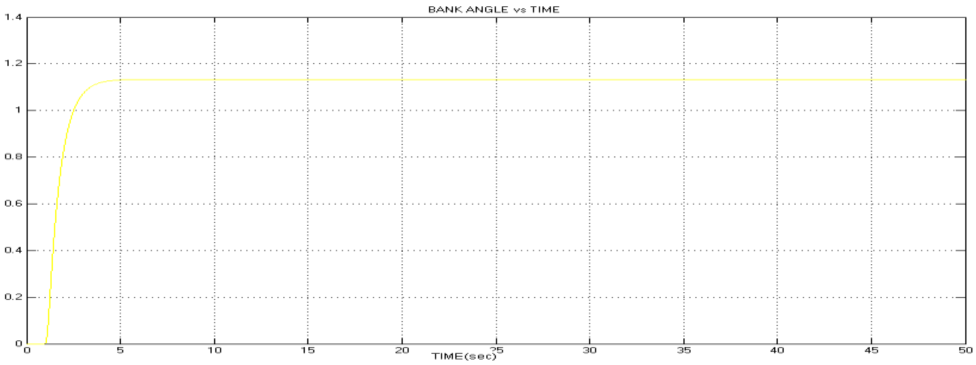

Fig.34 Response of ANFIS controller showing Bank deflection angle with roll-rate-integrating gyro

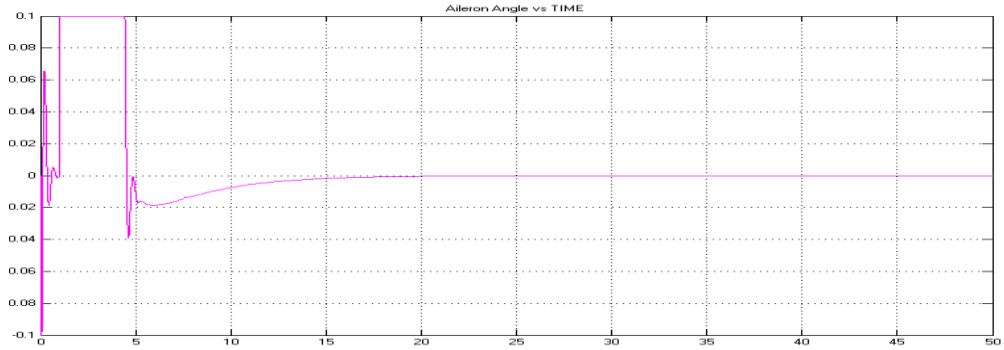

Fig.35 Response of Fuzzy-PID controller showing Aileron deflection angle with roll-rate integrat**ing** gyro

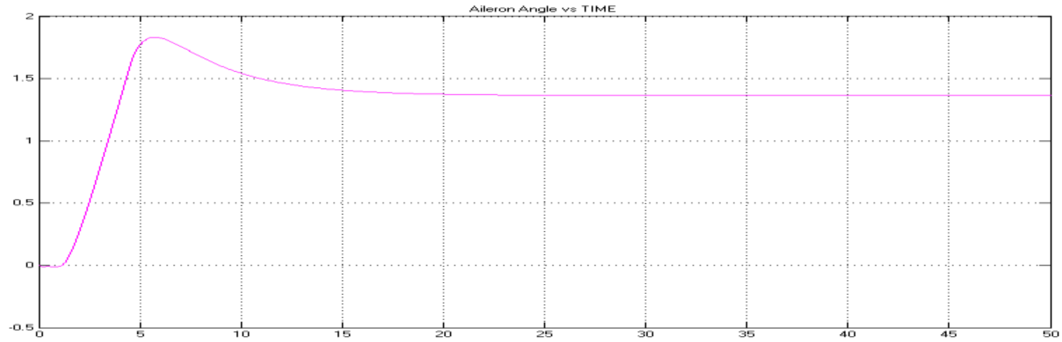

Fig.36 Response of Fuzzy-PID controller showing Bank deflection angle response with roll-rate-integrating gyro

Figure 26 and 27 shows step response plot of Aircraft elevator and figure 28-36 shows step response plots of aircraft aileron respectively. The response obtained for elevator and ailerons shows a comparison between three different controllers implemented for controlling Longitudinal and Roll control movement of Aircraft. The dynamic response of these controllers is measured in terms of time response specification i.e., Settling Time, Rise Time, Overshoot and Steady State error. Results obtained for different control surfaces and respective controllers implemented with these control surfaces are mentioned in Table 2, 3 and 4 respectively. Following conclusion is drawn from the simulation results that all the controllers achieve stability instantaneously following the input signal. The combination of hybrid FUZZY-PID controller is able to achieve desired result instantaneously when detail comparison is done with other controllers. Figure 26 and 27 shows plot of elevator deflection v/s time for aircraft longitudinal control, figure 28-36 shows plot of aileron and bank angle deflection v/s time in case of roll control movement respectively. Though there is marginal steady-state error in performance of some controllers, yet we may neglect it, since we have considered a generalized model of Aircraft. In aircraft roll control simulation model the results shown in figure 28-36, it is concluded that all the controllers settles instantaneously and converges to 0˚ and set-point 1 respectively except in ANN controller, which gives response in negative range, which can be neglected because it is in the tolerance band limit of 2% and very minor.

Table 4 Comparison of different controllers for roll control of aircraft

PARAMETERS	CONTROLLERS				
	PID	ANN	FUZZY	ANFIS	FUZZY-PID
Settling Time	1.24 sec	2.12 sec	2.45 sec	2.42 sec	0.176 sec
Rise Time	0.32 sec	0.18 sec	1.42 sec	2.14 sec	0.116 sec
Overshoot	4.6%	0%	0 %	0 %	1.48%

VI. CONCLUSION

In this research study we have modeled the elevators and ailerons control surfaces of aircraft for controlling longitudinal and roll control movement of aircraft respectively. The control surfaces were modeled and implemented with different intelligent controllers and their performance was evaluated based on time response specification of controllers. It is concluded from the performance of controllers that Fuzzy-PID controller produces the best desired results for both longitudinal and roll control movement. Controllers implemented in this study can be optimized using various Optimization techniques such as, Genetic Algorithm, Particle Swarm Optimization etc. In this paper all the observation are made without taking into account the effect of disturbances which occur in the environment acting on a body of Aircraft in the air, such as Hydrodynamic forces, radiation force, Excitation force and Drag Force. Further the techniques implemented in the present work can also be implemented for Yaw control movement of aircraft. The following Parameters of Aircraft can also be designed using different intelligent techniques by considering details dynamics of the Aircraft.

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