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*International Journal Of Engineering And Computer Science ISSN: 2319-7242*
*Volume 5 Issue 11 Nov. 2016, Page No. 19198-19211*

# Design and Modeling of Controllers for Aircraft Pitch Contol Movement

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## ABSTRACT

In the present paper intelligent controllers design methodology is presented to examine their overall performance primarily based on time response specification for controlling Pitch movement of aircraft. The aircraft pitch control system is designed for Linear and Non-linear models and the effect of various nonlinearities is studied based on the overall performance of various controllers in Flight control system (FCS). 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 which is used to control the movement of elevators. Elevators are control surfaces which are used to control longitudinal motion of aircraft by deflecting the flow of air and creating differential pressure on the wings. Aircraft pitch control movement is categorized under the longitudinal motion. The movement of these control surfaces is performed through Servomotors, for which mathematical modeling is provided. A baseline reference controller is used for determining the performance of other controllers and making a detail comparison. So while developing the other controllers we took Fuzzy Logic Controller as reference as carry forwarded the original cased study. A new hybrid combination of Fuzzy-PID with fuzzy compensation and ANN-PID Controller has been developed for controlling the pitch movement of aircraft for this particular model. A quantitative analysis of these controllers has been carried out in MATLAB Simulink© environment. It is concluded that combination of ANN-PID controller provides best results for Linear as well as Non-linear aircraft pitch control models.

Keywords- ANN, Pitch, Elevators, Aircraft, Flight Control System, FLC.

## 1. INTRODUCTION

There are three basic control movements of Aircraft i.e., Pitch, Roll and Yaw . One of the important parameters out of these is Pitch control movement. In the present work we have considered this problem as valuable approach and carried out work by applying intelligent control techniques for controlling the longitudinal motion of Aircraft. Aircraft Pitch control movement is a critical phase during takeoff phase as well as during steady flight. This parameter is of a concern as Aircraft can go into a stall condition if Pitch control of Aircraft is not calibrated properly. This is an important stage during which aircraft changes its transition from one state to another. There are three basic control movements of aircraft i.e., Pitch, Roll, and Yaw. The pitch movement of aircraft is categorized under longitudinal stability whereas roll and yaw are categorized under lateral stability.

A set of control surfaces known as elevator are used for controlling aircraft pitch movement. Elevators are movable control surfaces located at the back of fixed wing aircraft and hinged to the trailing edge of horizontal stablizer, running parallel to the main wings that cause this rotation of aircraft. The elevators 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[1].

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 raise and the nose to lower. Lowering the aircraft's nose increases forward speed, and raising the nose decreases the forward speed [1]. The following Fig.1 shows basic control surfaces of Aircraft.

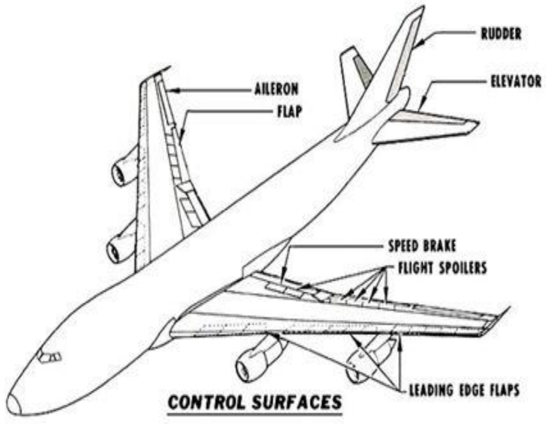


Fig.1.1 Basic control surfaces of Fixed wing Aircraft

A lot of work has already been initiated in this field. Some of the already applied techniques are mentioned here: The first kind of control technique used is based on Fuzzy active disturbance rejection control. In this paper, an active disturbance rejection control (ADRC) strategy based on fuzzy control is proposed, so as to realize the high performance of aircraft pitch control. The nonlinear active disturbance rejection controller is designed to improve the ability of anti-interference mean while, fuzzy control is adopted to adjust the ADRC parameters online, which makes control performance better [2]. The second technique used is based on GA tuned LQR and PID controller for aircraft pitch control. According to this technique Genetic Algorithm (GA) is used for tuning the parameter LQR and PID controllers. The controller design begins with the appropriate mathematical model to account the longitudinal motion of an aircraft. LQR and PID controllers are associated with their parameters which can either be tuned manually or by optimized methods like genetic algorithms to get better control and enhancement in the performance [3]. The third technique is based on Fuzzy-PID Controller used to control Aircraft Pitch. Fuzzy logic is used to tune each parameter of Proportional-integral-derivative (PID) controller by selecting appropriate fuzzy rules through simulation in Matlab and Simulink. 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. [4]. The fourth kind of control mechanism is derived by using Lyapunov Theory. According to this technique, it is possible to ensure, under a certain condition, the asymptotical stability of the helicopter [5]. The fifth control strategy used in literature is based on Linear Quadratic Regulator (LQR). As utilized by, 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). But the analytical solution to the Ricatti equation is difficult to compute [6]. The sixth control method used in the literature is of comparative assessment of LQR and Fuzzy Logic controller for pitch control of aircraft [7]. The seventh control technique used is based on Adaptive control of the aircraft pitch angular motion by using the dynamic inversion principle. The obtained adaptive control structures consist of parametric estimators, dynamic compensators and command filters. The estimated state and the estimated output are calculated with respect to the estimated vector of the aircraft parameters. The obtained control system is particularized for the adaptive control of the pitch angular rate and the pitch angle, respectively, in the case of an F-15 aircraft whose flight may be affected or not by wind shears [8].

In the present work we have considered a standard linearized model of a fixed wing aircraft for controlling its pitch movement. Although there are different aircraft models available, but in the present work we have taken the reference of original case study which shows comparative assessment of P, I, D, PI, PD, PID, and FLC, and shows the effect of various non-linearities on the aircraft system behavior, and how it is able to respond to non-linearities. Now continuing this work further, we developed different control techniques namely ANN. We have also developed a combination of ANN-PID controller and PID CONTROLLER WITH Fuzzy compensation technique. All the controllers are developed in MATLAB Simulink environment and comparative assessment of each controller is presented and discussed.

## 2. MATHEMATICAL MODELING FOR AIRCRAFT PICH CONTROL MOVEMENT

In this section of the paper, a brief description for modeling of aircraft pitch longitudinal movement is discussed. The following sub section discusses the components used in pitch control movement.

### COMPONENTS USED IN PITCH CONTROL

There are four set of components which are used for pitch control. These are:

a. **Vertical gyro**: The main function of vertical gyro is to generate electrical signals proportional to the aircraft's pitch attitude command.
b. **Rate gyro**: Whereas the rate gyro function is to generate electrical signals proportional to the aircraft's pitch rate command.
c. **Altitude controller**: The altitude controller is designed so as to give altitude hold signal when altitude hold mode is selected which is shown in Fig.2.1
d. **Servo unit**: The servo unit is considered to be an important part as it is used to control the elevator control surfaces. When the error signal is applied in case of stabilization mode and control signal from pilot is given in case of control mode, servo unit is designed to move the elevators [9].

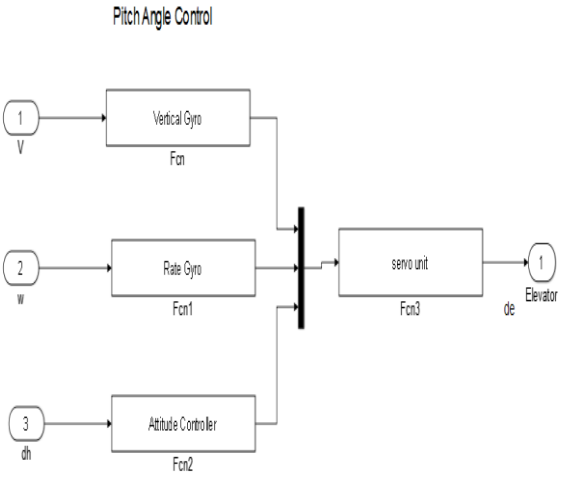


Fig.2.1 Pitch channel operation in altitude hold mode and synchronization mode block diagram

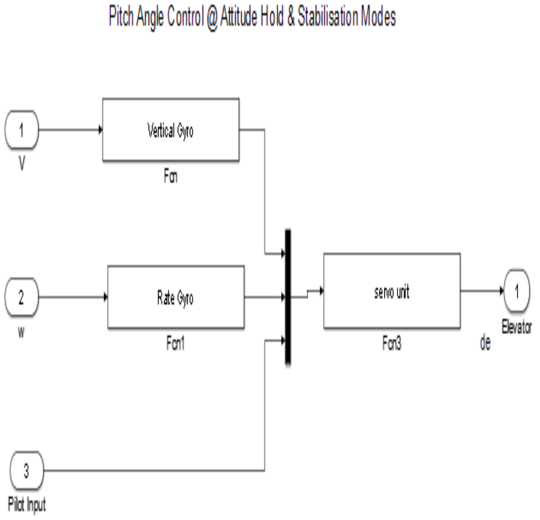


Fig.2.2 Pitch channel operation in control mode block diagram

### 2.1 MODELING OF COMPONENT USED IN AIRCRAFT PITCH CONTROL

The component which is modeled in the present paper is the servo motor, for which following transfer function is derived. Since aircraft pitch 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 fig.

Also, since we have considered generalized aircraft model, so the prime focus is on the servo unit.

Transfer function of pitch control system component

Transfer function of servo amplifier =$G_a(S) = K$

Transfer function of gears = 1/15 = 0.66

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

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

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

Rotor circuit

$$e_a = i_a R_a + L_a \frac{di_a}{dt} + V_b \qquad (2.1)$$

Rotor EMF

$$V_b = K_b \frac{d\theta_m}{dt} \qquad (2.2)$$

Mechanical torque

$$T_m = K_i i_a \qquad (2.3)$$

Equations governing mechanical port

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

$$e_a = \frac{L_a}{K_t}\frac{dT\quad m}{dt} + \frac{R_a}{K_t} T_m + K_b \frac{d\theta_m}{dt} \qquad (2.5)$$

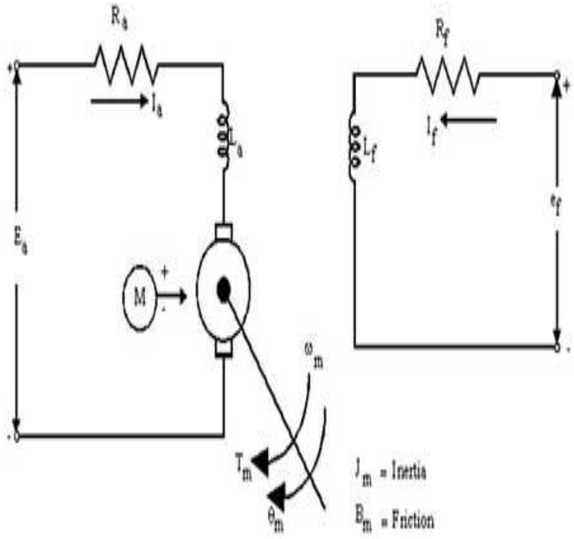


Fig.2.3Schematic of Servomotor

Transfer function of servomotor

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

Considering the values

$$K_t = 0.5\frac{Nm}{A}, K_b = 0.5\, Vs/rad$$

$$J_m = 0.03kg - m^2$$

$$D_{m=0.024}\frac{Nms}{rad},\ R_a = 8.1\Omega$$

$$L_a = 8H$$

$$T_m = \frac{J_m R_a}{K_t} = 0.69s, \gamma = \frac{D_m R_a}{K_t} = 0.34, T_a = 1$$

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 [9].

$$G(s) = \frac{0.25}{0.97s^3 + 1.61s^2 + 1.63s}$$

## 2.2 SIMULINK DIAGRAM FOR PITCH CONTROL.

In the present paper, we have considered two models for aircraft pitch control, one as the linear model and another one with non-linear model. Following are the three nonlinearities which are introduced in the pitch control system. These non-linearities are either deliberately introduced or they are present in the system itself. These are as follows:

1. Dead Zone Non-Linearity
2. Saturation Non-Linearity
3. Backlash Non-Linearity

The effect of Dead-zone nonlinearity is considered in pilots control column, Saturation nonlinearity is considered in servo amplifier and the effect of backlash nonlinearity is considered in pilot's control column. [9]

The following Fig.2.4 shows the pitch control Simulink model for aircraft for linear and nonlinear system.

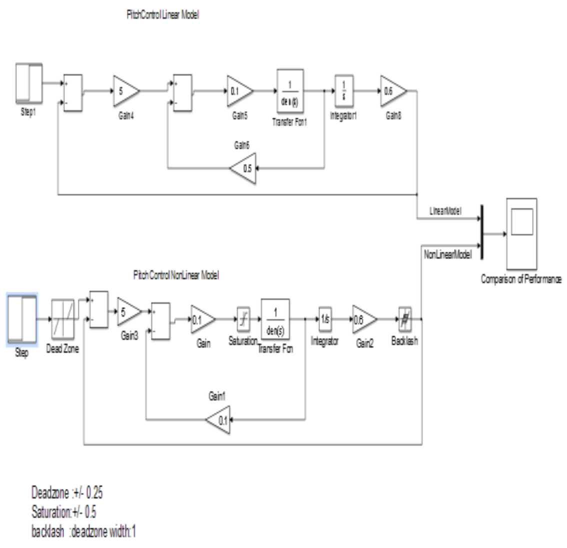


Fig.2.4 Aircraft pitch control for linear and non-linear model

## 3. METHODOLOGY

### 3.1 <u>Design of Controllers</u>

To control a process variable some control strategies are essential. A control strategy consists of two aspects:
(1) Control configuration and
(2) Controller.
Control configuration can be further categorized as:/feedback control configuration, feed forward control configuration, cascade control configuration etc. The second aspect of a control strategy is the controller, which gives the actuating signal to an actuator on the basis of computed error, which is calculated from the set point and measured value of process variable.

In the present paper, we have designed two new controllers: PID Controller with Fuzzy Compensation and ANN and combination of ANN-PID Controller which are discussed in following subsections. In the original case study PID and FLC were developed and comparison was made for linear and nonlinear system. In the original work a comparative assessment was done between different controllers and was concluded that FLC was able to handle nonlinearities better.

In our present work we have carried forward the work and developed new control techniques and designed the membership function required for our process.

A control system is generally required to meet following time response specifications: steady-state error, damping factor and settling time. If rise time is also taken into consideration then it would consistent in the specification of settling time as both of these depend upon steady-state error and damping factor. By considering proportional, integral and derivative error compensation the controller which meets all these specification is PID controller, which is discussed below.

#### 3.1.1 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.

$$u(n) = k_p e(t) + k_i \int_0^t e_t \, d(t) + k_d \frac{d}{dt} e(t)$$
(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 Fig. 5. 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 [10].

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

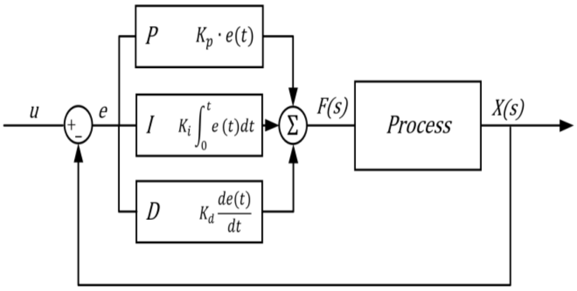


Fig. 3.1 Block diagram of PID controller

## FUZZY LOGIC BASE CONTROLLER

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 Fig.3.2.

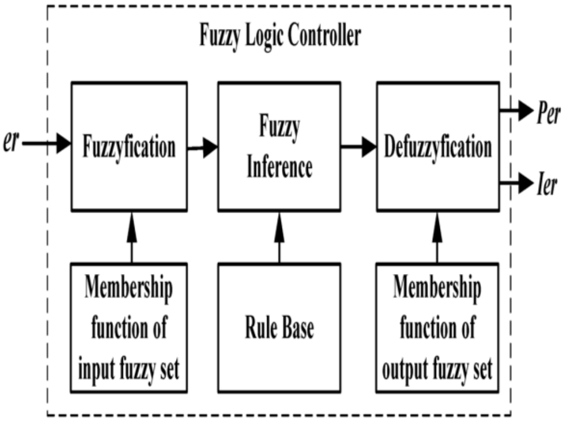


Fig.3.2 FLC block diagram

### 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 [11] and Takagi-Sugeno-Kang (TSK) FIS [12]. 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. Fig.5 shows how a two rule Mamdani FIS compute the overall output fuzzy set

when subject to crisp input $x_1$ and $x_2$ , using Min-Max composition of Mamdani FIS [11].

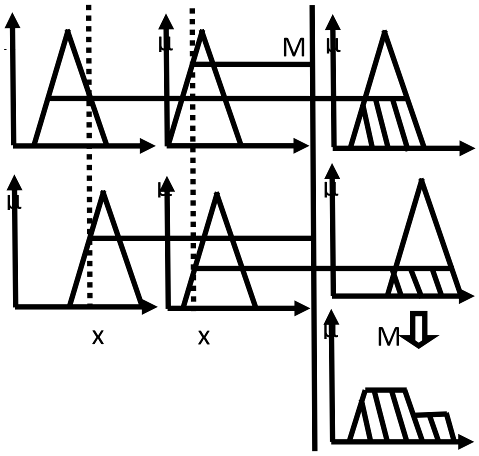


Fig.3.3 The Mamdani FIS using Min and Max operation

**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 [13].

### 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:

$$\mathrm{Z}_{\mathrm{COA}} = \frac{\int_{\mathrm{Z}} \mu_{\mathrm{A}}(\mathrm{z})\mathrm{z}\mathrm{d}\mathrm{z}}{\int_{\mathrm{Z}} \mu_{\mathrm{A}}(\mathrm{z})\mathrm{d}\mathrm{z}} \qquad (3.1)$$

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:

$$\int_{\alpha}^{Z_{BOA}} \mu_A(z)dz = \int_{Z_{BOA}}^{\beta} \mu_A(z)dz \qquad (3.2)$$

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:

$$Z_{MOM} = \frac{\int_{Z'} zdz}{\int_{Z'} dz} \qquad (3.3)$$

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.

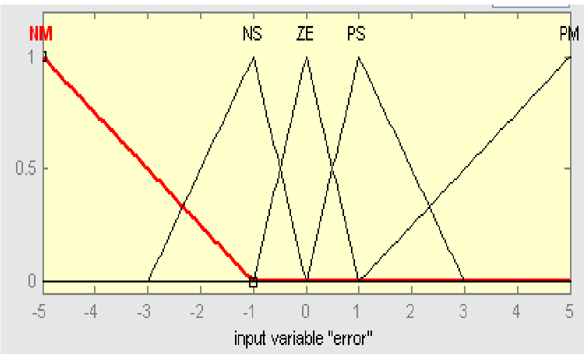


Fig.3.4 Membership functions for input (error)

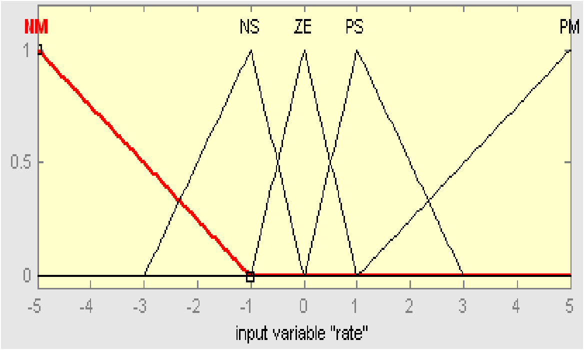


Fig.3.5 Membership functions for input (rate)

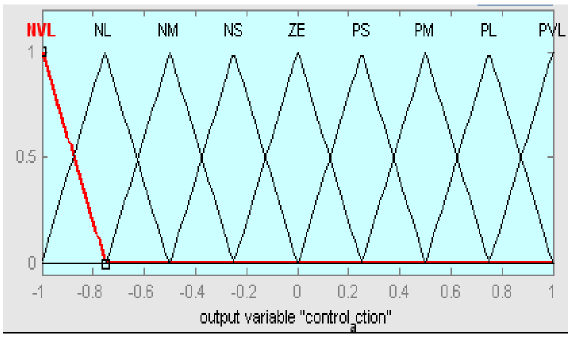


Fig. 3.6 Membership functions for output (control action)

**Table 1 Rule Table for FLC**

| e/de | NM | NS | ZE | PS | PM |
|---|---|---|---|---|---|
| NM | NVL | NL | NM | NS | ZE |
| NS | NL | NM | NS | ZE | PS |
| ZE | NM | NS | ZE | PS | PM |
| PS | NS | ZE | PS | PM | PL |
| PM | ZE | PS | PM | PL | PVL |

PID controllers generally 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 conventional PID controllers such auto-tuning and adaptive PID controllers.

Fig.8 shows the structure of Fuzzy-PID controller which has been developed for the aircraft pitch and roll control model. This model of Fuzzy-PID controller developed here is using fuzzy compensation technique. The purpose of compensation is to achieve the desired performance of the system. By using compensation we feed the output of the process back to FLC as input, till the process becomes stable.

Following values are obtained after tuning the controller in Matlab:

Proportional (P) = 5.19667069406397

Integral (I) =0.960069009932765

Derivative (D) =6.98307455878522

Filter Coefficient (N) = 144.222740324956

### 3.1.2 ARTIFICIAL NEURAL NETWORK

Simulated Neural Network is a control instrument utilized as a part of control hypothesis and is extremely 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

$o = [o_1\, o_2 \ldots o_m].^t$
$x = [x_1\, x_2 \ldots x_n].^t$

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 denote 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

$w_i \triangleq [w_{i1}\, w_{i2} \ldots w_{in}]$

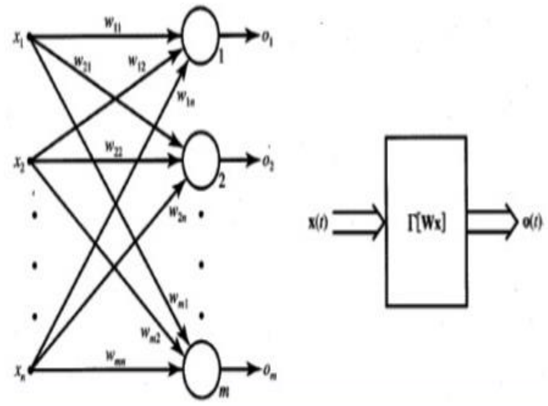


Fig.3.7 Single layer feed forward network

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 piece. This neural system square is supplanted in the pitch control SIMULINK obstructs with alternate controllers and the relating results are being noted. The accompanying figure demonstrates the SIMULINK piece outline for aircraft pitch control with ANN [14].

### 3.1.3 ANN-PID CONTROLLER

The PID controller has a simple structure and thus the performance of the system can be affected in terms of time response specification. Also, the conventional PID control method has poor adaptation ability, and it is difficult to find the optimal PID gains. Thus a sophisticated control scheme is required for an enhanced control performance. The PID and neural network are combined here to get optimum results. The placement of controllers is arranged in series as shown in the Simulink block diagram 4.5. A Proportional-Derivative controller is also placed in the forward loop. Both the PID and PD controller are tuned in Matlab and optimal gains are obtained for best performance. The values of $Kp, Ki$ and $Kd$ are obtained by tuning the controller in Matlab.The values of $Kp$, $Ki$, and $Kd$ are mentioned below.
Following values are obtained for PID and PD controller after tuning them.

*Values of PID controller for linear system*

Proportional (P) =39.4391254092514

Integral (I) =0.269108120085848

Derivative (D) =0.429017553956734

Filter Coefficient (N) = 228.514492280641

*Values for PD controller are mentioned below:*

Proportional (P) = 14.5465527331703

Derivative (D) = 1.45359581889392

Filter Coefficient (N) = 68.3898684841076

*Values of PID controller for Non-linear system*

Proportional (P) =45.5970735385281

Integral (I) =0.307431266372757

Derivative (D) =0.498431066408624

Filter Coefficient (N) =262.369741876539

*Values of PD Controller are mentioned below:*

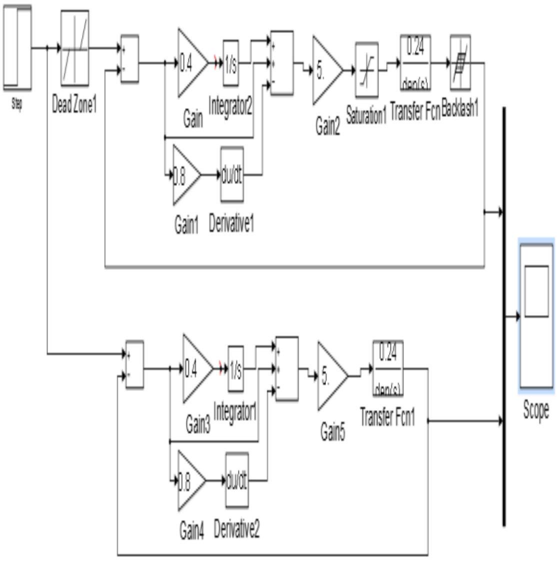
Proportional (P) = 19.204099695506

Derivative (D) = 2.37769924713268

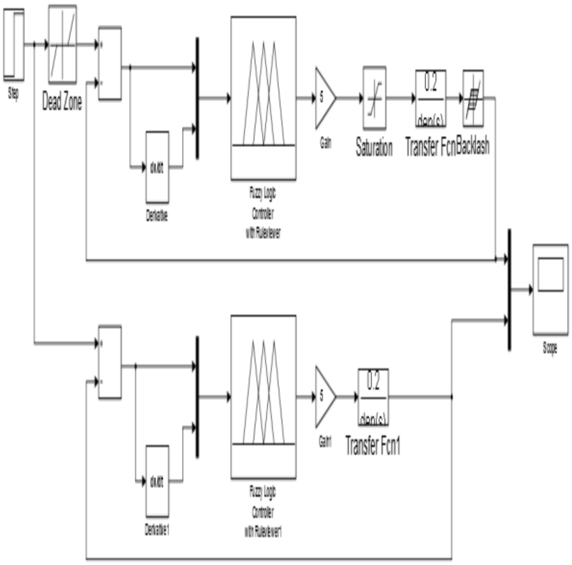
Filter Coefficient (N) = 744.961689197853

## 4. MATLAB Simulink models for Aircraft Pitch control

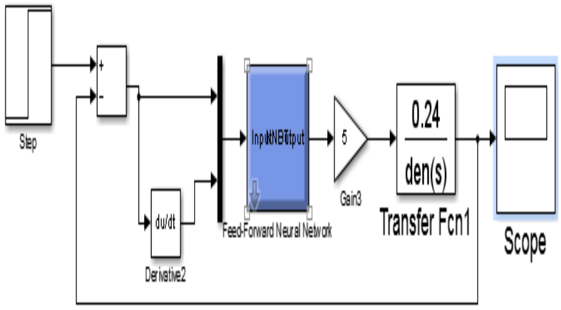
### 4.1 Aircraft pitch control model using PID Controller for linear and non-linear systems

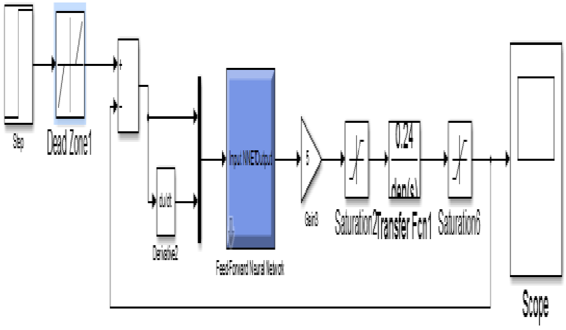


### 4.2 Aircraft pitch control model using FLC for linear and non-linear systems

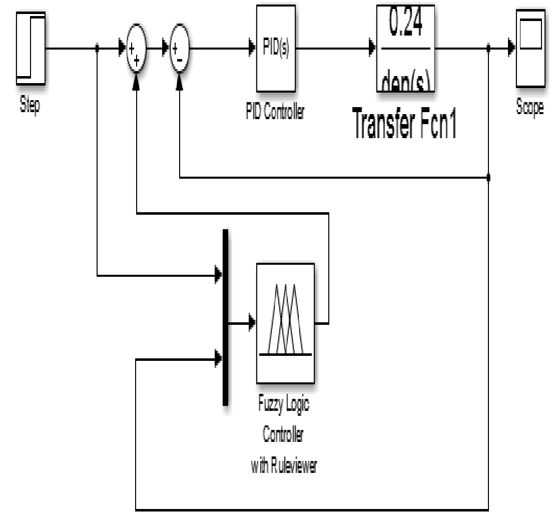


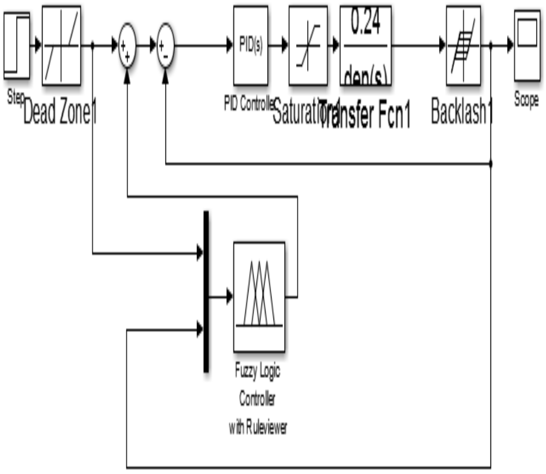
### 4.3 Aircraft pitch control model using ANN for Linear and Non-linear systems



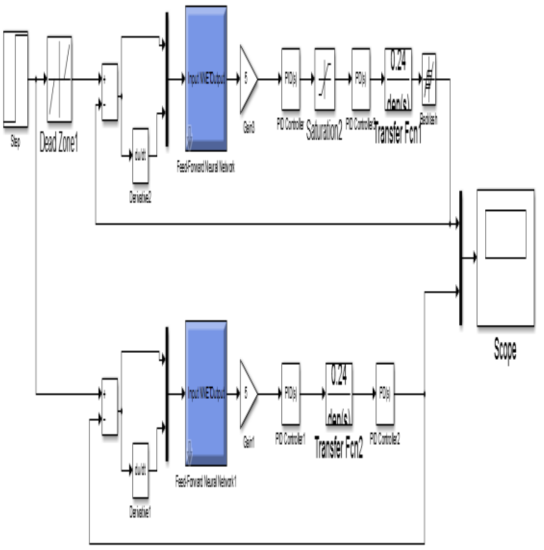


### 4.4 Aircraft pitch control model using PID controller with Fuzzy compensation for Linear and Non-linear systems





### 4.5 Aircraft pitch control using ANN-PID controller for Linear and Non-linear systems



## 5. SIMULATION RESULTS AND DISCUSSION

In this part of paper simulation, results for aircraft pitch control using different control techniques is presented. Following responses are obtained for SIMULINK models of Aircraft pitch control movement discussed in the previous section of paper. Using MATLAB SIMULINK model we can depict the behavior of the system as it would do in real conditions. MATLAB provides a real-time observation using PID, FUZZY, ANN, ANN-PID and FUZZY-PID controller to analyze the performance of the aircraft. All the SIMULINK models are created using MATLAB 2014a.

Fig. 5.1 and 5.2 shows step response of Aircraft for Pitch control movement for Linear and Non-linear system respectively. These responses show a comparison of five different controllers namely PID, FUZZY, FUZZY-PID, ANN, ANN-PID Controllers developed for controlling Pitch movement of Aircraft. The response of these controllers is measured in terms of time response specification i.e., Settling Time, Rise Time, Overshoot and Steady State error.

For Linear and Non-linear Aircraft Pitch control model, the simulation is performed for 150 sec. From the fig. 5.1 and Fig. 5.2 following conclusion is drawn:

All the controllers achieve stability instantaneously following the input. Though there is steady-state error in performance of all the controllers. This steady state error may be neglected, since we have considered a generalized model of Aircraft for pitch control movement. Overshoot may be observed in three controllers namely PID, FUZZY and ANN, which is not of a concern and may be neglected as well. For Non-linear Aircraft Pitch control model only one controller shows slight deviation after 130 sec of simulation, which could also be neglected as it is very minor, and the controller still follows the input. No overshoot is observed from any controller in Non-linear Aircraft Pitch control model and all the controllers get's settled instantaneously.

The following conclusions are made from the table 5.1 and 5.2 that combination of an ANN-P controller is able to handle the Pitch cont movement of Aircraft better when det comparison is done with other controllers terms of time response specification. It has a been observed that PID controller cannot han the process when different non linearities a introduced, making the system unstable. Fig. 5 showing the response of PID controller is plott when Backlash Non-linearity is not taken in consideration.

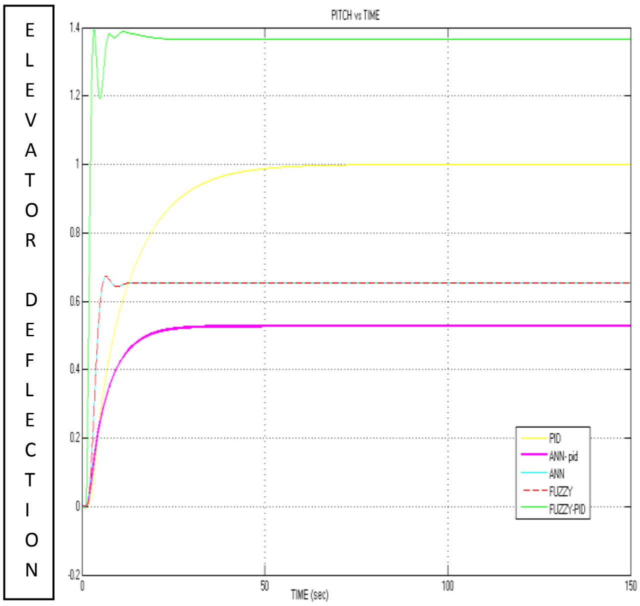


Fig.5.1 Step response of Aircraft Pitch control for Linear System

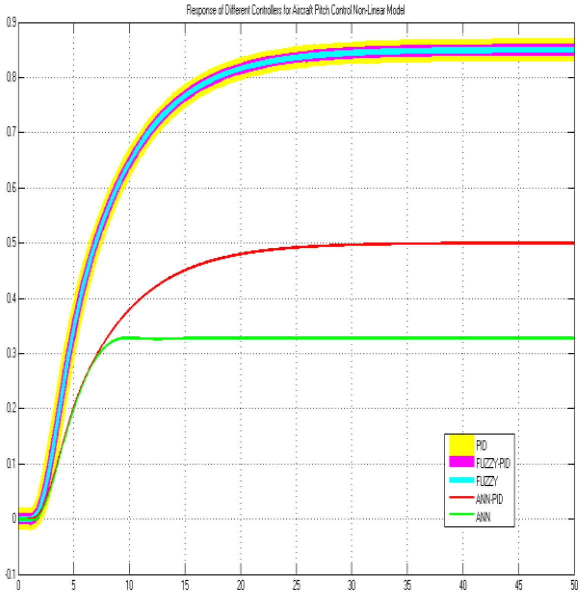


Fig.5.2 Step response of Aircraft Pitch Control for Non-linear System

**Table 5.1 Comparison of Different Controllers for Aircraft Pitch Control using Linear model**

| PARAMETERS | CONTROLLERS | | | | |
|---|---|---|---|---|---|
| | PID | FUZZY | FUZZU-PID | ANN | ANN-PID |
| Settling Time | 8.3 sec | 6.54 sec | 5.42 sec | 6.45 sec | 3.15 sec |
| Rise Time | 2.9 sec | 2.36 sec | 1.5 sec | 2.52 sec | 0.552 sec |
| Overshot | 14% | 4% | 2.93 % | 5.58 % | 5.55 % |
| Steady State error | 0 | 0.35 | 0.38 | 0.36 | 0.48 |

**Table 5.2 Comparison of Different Controllers for Aircraft Pitch Control using Non-Linear model**

| PARAMETERS | PID | FUZZY | FUZZY-PID | ANN | ANN-PID |
|---|---|---|---|---|---|
| Settling Time | 26.4 sec | 22.9 Sec | 5.42 sec | 22.3 sec | 2.51 sec |

| | | | | | |
|---|---|---|---|---|---|
| **Rise Time** | **16.52 sec** | **12. sec** | **1.24 sec** | **11.8 sec** | **0.277 sec** |
| **Overshoot** | 0% | **0%** | **2.93 %** | **2.94 %** | **1.93 %** |
| **Steady State error** | **0.66** | **0.15** | **0.15** | **0.68** | **0.5** |

## 6. CONCLUSION

In this paper, Pitch control of aircraft has been studied. The various controller's viz. PID, FLC, ANN, and a combination of PID with Fuzzy Logic compensation, and ANN-PID based controllers have been designed in MATLAB Simulink environment. With the gained results the following comparisons have been accomplished as shown in Table 6.1 and Table 6.2. The performance of these controllers has been analyzed in terms of common performance criteria for Linear and Non-linear system respectively for aircraft Pitch control.

Further, it may me noted that detail design aspect of Aircraft Parameters i.e., Pitch control movement is not taken into consideration. In the present work, we have considered a standard model for Aircraft Pitch control movement i.e., of the servomotor which is used to control the Elevator deflection which is used to control the pitch movement of Aircraft. Therefore all controllers have marginal steady state error which may be neglected for the present aircraft pitch control model.

Hence, following conclusions are made from the results:

PID controller is not able to handle the aircraft pitch control movement for the non-linear system, especially when Backlash a non-linearity is taken into consideration and the system is not able to linearize. The performance of PID controller could only be evaluated for Linear System.

For aircraft pitch control movement for linear and non-linear model combination of ANN-PID controller is able to handle the system better as compared to other controllers providing best transient response ( in terms of time response specification). For obtaining the desired results we have placed a PD (Proportional Derivative) controller in the loop so as to compensate for any distortions and getting the desired output. The combination of ANN-PID controller is more robust compared to other controllers.

From the Table 6.2 it is also concluded that for non-linear model individual controller cannot handle the non-linearities effectively, and thus having larger settling time. And when the hybrid combination is implemented then the time response specification of the system improves drastically.

Some other intelligent and adaptive controllers such as Neuro-Fuzzy, Adaptive Fuzzy, ANN based controllers can also be employed for the problem undertaken in this paper by considering detail design aspect of aircraft. Controllers used in this report can be optimized using various Optimization techniques such as Ant-colony optimization, Genetic Algorithm, Particle Swarm Optimization, Biogeography Based 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 and Roll control movement of aircraft. The following Parameters of Aircraft can also be designed using different intelligent techniques by considering details dynamics of the Aircraft.

## REFERENCES

[1] Airframe and Power plant Mechanics (AC 65-15A)-Airframe Hand Book FAA.

[2] D. We, H. Xiong, and J. Fu, " Aircraft autopilot pitch control based on Fuzzy Active Disturbance Rejection Control", IEEE Conference on Industrial Informatics-Computing Technology, Intelligent

Technology, Industrial Information Integration (ICIICII), pp.144-147, 2015.

[3] Vishal and J. Orhi, "GA tuned LQR and PID controller for aircraft pitch control", IEEE international conference on Power Electronics (IICPE), pp.1-6, 2014.

[4] I.N. Ibrahim and M.A. Al Akkad, "Exploiting an intelligent Fuzzy-PID system in nonlinear aircraft pitch control", IEEE International Siberian Conference on Control and Communication (SIBCON), pp.1-7, 2016.

[5] S. Kamalasadan and A.A. Ghandakly, "A Neural Network Parallel adaptive Controller for Fighter Aircraft Pitch Rate-Tracking", IEEE Transactions on Instrumentation and Measurement, Vol.60, pp.258-267, 2011.

[6] L. Chrif and Z.M. Kadda, "Aircraft Control System Using LQG and LQR Controller with Optimal Estimation-Kalman Filter Design", ELSEVIER 3rd International Symposium on Aircraft Airworthiness, ISAA, Procedia Engg., Vol. 80, pp. 245-257, 2014.

[7] N. Wahid and M.F. Rahmat, "Pitch control system using LQR and FLC", IEEE Conference on Industrial Electronics and Applications (ISIEA), pp.389-394., 2010.

[8] D.K. Chaturvedi, "Modeling and Simulation of Systems Using MATLAB and SIMULINK", CRC Press, pp. 435-473.

[9] A. Tewari, "Atmospheric and Space Flight Dynamics", Springer International Edition, ©2007 Birkhäuser Boston, pp. 471

[10] E.H. Mamdani and S. Assilian, "An experimental in linguistic synthesis with a FLC", International Journal of Man-Machine Studies, Vol. 7(1). pp.1-13, 1975.

[11] T. Takagi and M. Sugeno, "Fuzzy identification of systems and its application to modeling and control", IEEE Transactions on Systems Man and Cybernetics, Vol.15(1), pp.116-132, 1985.

[12] T. Takagi and M. Sugeno, "Fuzzy identification of systems and its application to modeling and control, IEEE Transactions on Systems Man and Cybernetics, Vol.15(1), pp. 116-132, 1985.

[13] S. Kamalasadan and A.A. Ghandakly, "A Neural Network Parallel adaptive Controller for Fighter Aircraft Pitch Rate-Tracking", IEEE Transactions on Instrumentation and Measurement, Vol.60, pp.258-267, 2011