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A Fuzzy Logic Strategy on Attitude Controlling of Longitudinal Autopilot for Better Disturbance Rejection.

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***Abstract:** This paper explains the attitude controlling of a Longitudinal Autopilot. We assume a General Aviation Aircraft as an illustration of Longitudinal Autopilot. The common methods for designing PID controllers are based on fixed algorithms. Initially we design this system with these methods for different values of disturbances. It is to be found that these techniques are not withstand for disturbance occurrences. Hence this paper employs a fuzzy logic control strategy for designing of PID controller for better disturbance rejection. The distinctiveness with this controller is It generates PID gains for various disturbance occurrences in the system based on either disturbance or error. The entire system is modelled and simulated by using MATLAB/Simulink software. The results show that the proposed FUZZY-PID controller has better disturbance rejection than conventional PID controlling tuning methods.*

***Keywords** — Longitudinal Autopilot, Elevator, Aileron, Rate Gyro, MATLAB/Simulink, Fuzzy Logic Strategy, PID Controller, Conventional PID Tuning methods*

I. INTRODUCTION

The main use of an autopilot is it must provide smooth control and avoid sudden and irregular behaviour [1]. The intelligence for control must come from sensors such as gyroscopes, accelerometers, altimeters, airspeed indicators, automatic navigators, and various types of radio-controlled data links.

A typical flight control system is either a primary or secondary system. Primary flight controls provide longitudinal (pitch), directional (yaw), and lateral (roll) control of the aircraft. Secondary flight controls provide supplementary lift during takeoff and landing, and lessen aircraft speed during flight, as well as supporting primary flight controls in the movement of the aircraft about its axis.The main aim of an autopilot is to follow the required input command.

For our Autopilot we are considering a General Aviation Aircraft as shown in figure.1 taken as an example from reference [2]. Here the pilot attitude is to maintain the pitch angle at safe level.

From the short period approximation [1] the transfer function of the General Aviation Aircraft is given in equation (1).

$$\frac{\theta(s)}{\delta_e(s)} = -\frac{11.8(s+1.97)}{(s^2+5s+12.96)} \tag{1}$$

The Elevator Servo actuator to deflect the aerodynamic control surfaces here considered it as an electric motor. δ_e is elevator deflection angle, k_a is elevator servo gain, e_g is input error voltage, τ_s is Servo motor time constant. For a typical servo motor τ_s fall in the range 0.05-0.25s the transfer function for servo elevator is given by equation. (2)

$$\frac{\delta_e(s)}{e_{\delta e}(s)} = -\frac{1}{s+12.5} \tag{2}$$

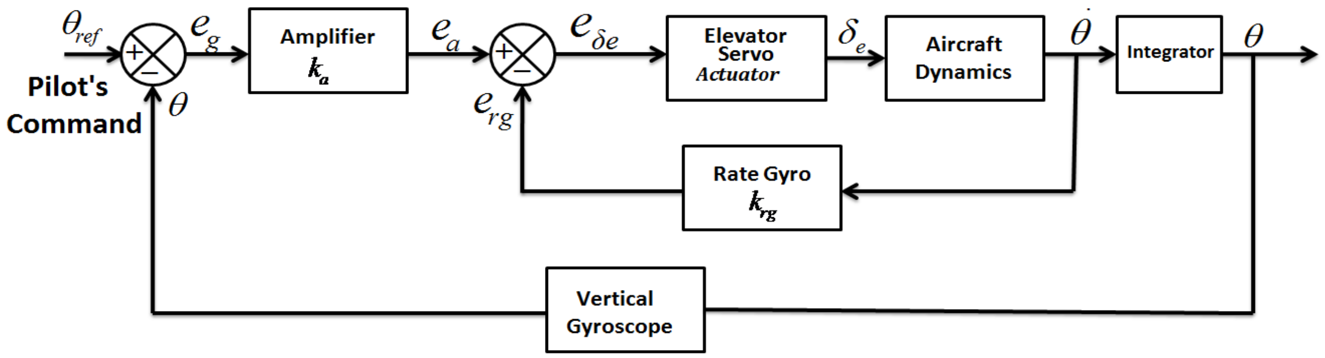


Figure.1 Block Diagram for A General Aviation Aircraft Control System with pitch rate feedback

II. MODELING OF GENERAL AVIATION AIRCRAFT WITH OFFLINE PID CONTROLLERS

A. *Closed loop/Ultimate cycle methods*

Ultimate cycle methods are also called as closed loop/Ultimate Gain methods. In 1942 Ziegler and Nichols published a paper [3] where they explained two methods for tuning the parameters of P-, PI- and PID controllers. These two methods are the Ziegler-Nichols' closed loop method, and the Ziegler-Nichols' open loop method. Based on this Ziegler-Nichols' controller methods a number of tuning techniques were implemented. Few of the Ultimate cycle methods applied in this paper are taken from reference [9]. The Sustained Oscillations getting from the system is shown in figure.2. Also figure.3 shows the Tyreus-Luyben MATLAB/Simulink model of the system designed with closed loop tuning method. This logic uses the critical gain (K_C) and period of sustained oscillations (T_C) and designs the PID controller for the general aviation aircraft.

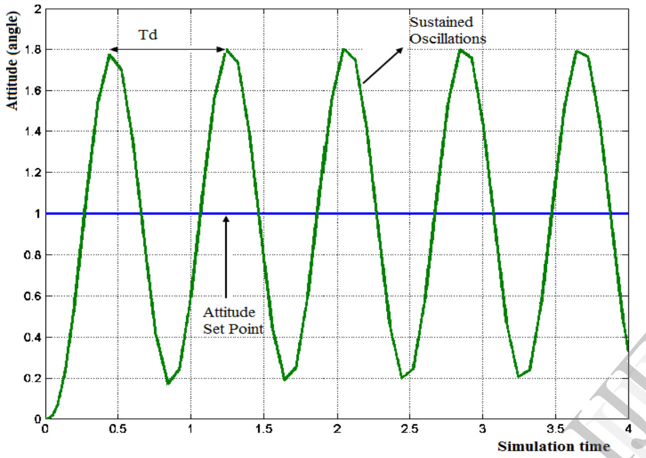


Figure.2 Closed Loop Ultimate Cycles

B. *Closed loop peak overshoot/under shoot Methods:*

The PID controller gain methods used in this paper are [5, 6, 7]

- Damped cycling
- Good Gain
- Set Point Overshoot

The procedural steps to apply these methods are

Step-1: Design the system with proportional controller (P) Only with unity feedback.

Step-2: Adjust the proportional controller gain until one overshoot and one undershoot is observed in the response which is shown in figure. 4

Step-3: Note the values of time period between the first peak overshoot and first under shoot (T_{OU}), peak time (t_P), time period between first peak overshoot, peak output change (Δy_p), first minimum undershoot (Δy_u), set point change(Δy_s) and second overshoot (P_d), overshoot, and undershoot from the figure.4

Step-4: Calculate the PID gain parameters based on the method considered from the reference [6].

Figure.5 shows the entire MATLAB/Simulink model for overshoot/undershoot methods comparison model.

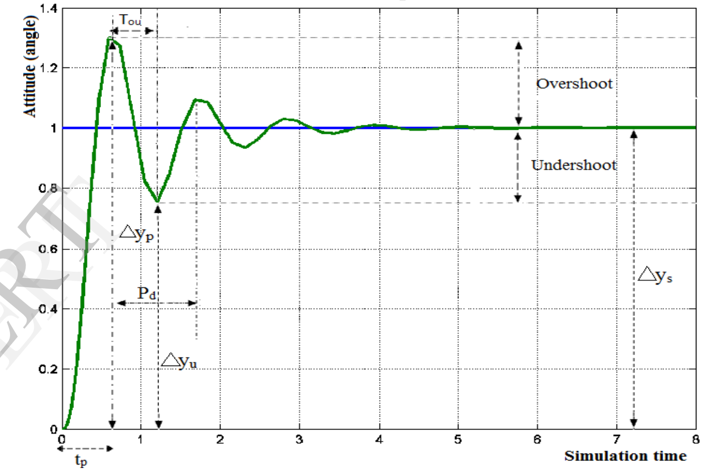


Figure.4 Overshoot and undershoot

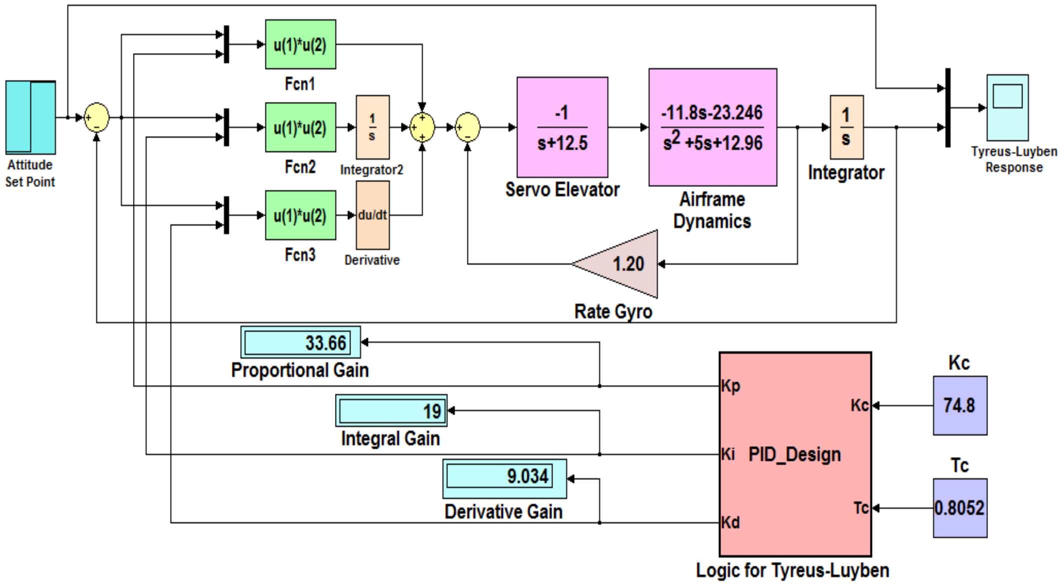


Figure.3 MATLAB/Simulink model for the system designed with Tyreus-Luyben PID controller

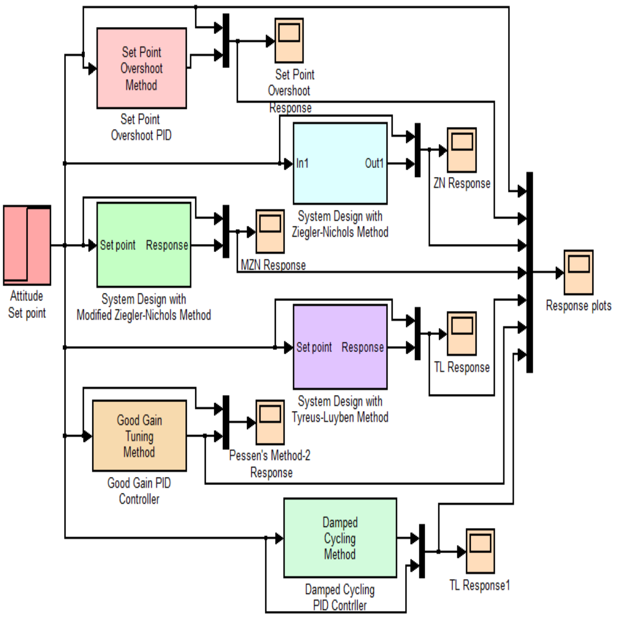


Figure.5 Combined Model for ultimate cycle methods and Overshoot/Undershoot PID Tuning methods

The Proportional gain, Integral time, Integral gain, Derivative time, Derivative gain are listed in table.1.

TABLE.1 PID VALUES FOR CLOSED LOOP METHODS

S. No	Method Name	K_P	T_I	K_I	T_D	K_D
1.	Tyreus-Luyben	24.68	0.402	61.3	0.268	6.625
2.	Good Gain	25.28	0.909	27.81	0.227	5.743
3.	Damped cycling	18.96	0.471	40.23	0.117	2.233
4.	Set Point Overshoot	17.09	1.459	11.71	0.067	0.161

C. Disadvantage of the offline tuning PID controllers:

Amongst the all offline closed loop control methods proposed above Tyreus-Luyben and Good Gain PID controller tuning methods gives better output response but whenever the disturbance occurred in the system the response is degrades as shown in the figure.12. To overcome this problem it is required to design a controller such that it should generate appropriate PID gains for the system for various kinds of disturbances. It is achieved by intelligent concepts like Fuzzy Controller. The following sections discuss the designing of Fuzzy Logic PID controller for better disturbance rejection.

III. PROPOSED FUZZY-PID CONTROLLER FOR DISTURBANCE REJECTION:

The fuzzy theory [12, 13] represents linguistic constructs (in mathematics usually take numerical values) such as ‘many’, ‘medium’, ‘often’, ‘low’, ‘few’. In general, the fuzzy logic enables human reasoning capabilities by providing an inference structure

A. Proposed Fuzzy-PID Controller Design:

The following are the steps for obtaining fuzzy rules according to disturbance effects

1. Consider the closed loop control system without any controller
2. Apply step input, observe the response and note down the error value.
3. Tune the system to get better response with best PID controller gains and note down PID gain values.
4. Now apply small disturbance at possible instances in real time, for this control system disturbance is considered at airframe dynamics.
5. Observe the response and note own the error value at this time which will be different from the previous error value and repeat step 3.
6. Now increase the disturbance and repeat steps 2 & 3
7. Repeat step 6 for all possible disturbance effects.
8. Finally note down these error values and PID gains for different disturbance effects.
9. Now create fuzzy rules with error and PID gains in such a way that system should not be affected for any kind of disturbances.

The following methods shows adaptive corrections can be made by fuzzy logic controller,

$$K_p = K_p^{'} + \Delta K_p \qquad (4.1)$$

$$K_i = K_i^{'} + \Delta K_i \qquad (4.2)$$

$$Kd = K_d^{'} + \Delta K_d \qquad (4.3)$$

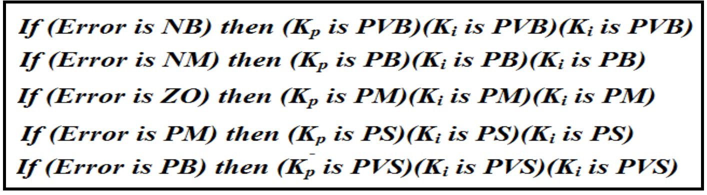
Here Kp’, Ki’, and Kd’ refer to the preceding value of the PID parameters whereas Kp, Ki, and Kd refer to the latest corrected values of the parameters after a suitable tuning step was completed.

B. Fuzzy decision rules for fuzzy like PID controller

A single-input and three-output fuzzy controller [45] is formed and the membership functions and fuzzy rules are determined. The membership function of the language variables “Error”, K_p, K_i and K_d are having different ranges and their plots are as follows.

Here to represent ‘error’ for fuzzy rules the set of linguistic values (NB, NM, ZO, PM, PB) stand for “negative big”, ”negative medium”, ”zero”, ”positive medium” and “positive big” are used and to represent Kp, Ki, and Kd for fuzzy rules the set of linguistic values (PVS, PS, PM, PB, PVB) stand for “positive very small ”, “positive small”, “positive medium”, “positive big” and “positive very big” are used.

The following rules shown in figure.7 gives the decision taken by fuzzy logic controller


If (Error is NB) then (K_p is PVB)(K_i is PVB)(K_i is PVB)

If (Error is NM) then (K_p is PB)(K_i is PB)(K_i is PB)

If (Error is ZO) then (K_p is PM)(K_i is PM)(K_i is PM)

If (Error is PM) then (K_p is PS)(K_i is PS)(K_i is PS)

If (Error is PB) then (K_p is PVS)(K_i is PVS)(K_i is PVS)

Figure.7 Decision table for Proposed Method

Here the linguistic variables for error was taken from quantization -12.5 to 12.5 and hence NB=-12.5 to -7.5, NM=-7.5 to -3.5, ZO=-3.5 to 3.5, PM=3.5 to 7.5 and PB=7.5 to 12.5 were considered. Similarly for the proportional gain in the quantization range from 176 to 38 and hence PVB=176 to 140, PB=140 to 104, PM=104 to 77, PS=77 to 48, and PVS=48 to 38, and for the integral gain in the quantization range from 29.5 to 19.01 and hence PVB=29.5 to 27.5, PB=27.5 to 26, PM=26 to 19.7, PS=19.7 to 19.01, and PVS=19.01 to 19.03 and for the derivative gain the quantization range taken from

30 to 24.7 and hence PVB=30 to 24.7, PB=24.7 to 20, PM=20 to 13.7, PS=13.7 to 9.3, and PVS=9.3 to 19.03 were considered.

A Mamdani fuzzy system with single input and three output FIS editor is shown in below figure.8 and the consequent figure.9 shows MATLAB/SIMULINK Model for the proposed controller designed with these Fuzzy Rules.

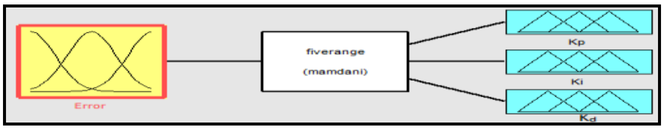


Figure.8 Mamdani fuzzy System for Fuzzy-PID

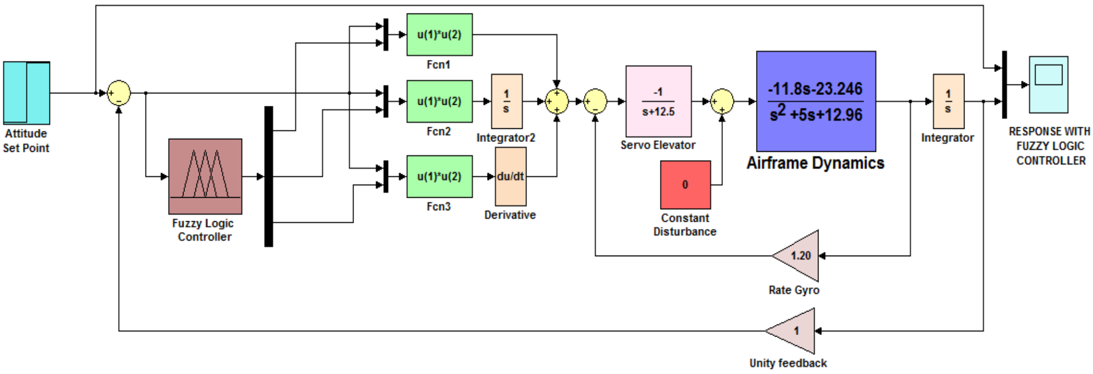


Figure.9 MATLAB/Simulink model for the system designed with FUZZY PID controller

IV. SIMULATION RESULTS

The comparison response of the system designed with closed loop/ultimate cycle methods and peak overshoot/under shoot PID control tuning methods are shown in Figure.10. Amongst all the responses, Tyreus-Luyben method gave good response with better time domain specifications.

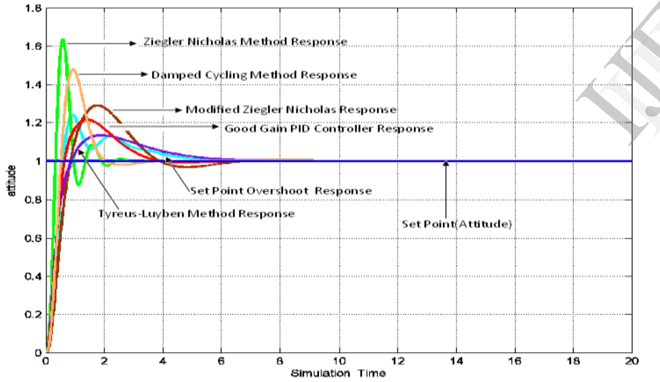


Figure.10 Combined responses of the system with ultimate cycle and overshoot PID tuning methods

Figure.11 shows response of the system with Tyreus-Luyben PID controller with and without disturbance It can be found from this figure for 50% of process disturbance the output response is degraded.

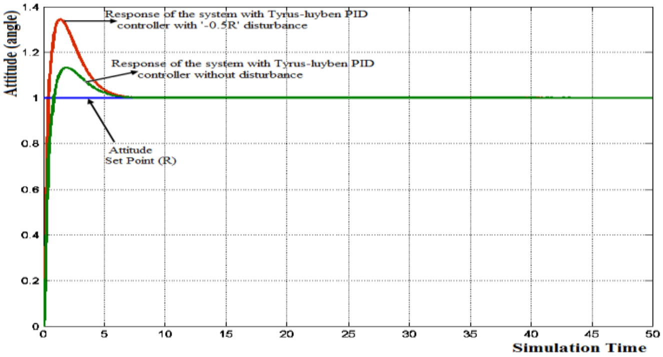


Figure.11 Comparison response of Tureus-Luyben PID tuning with and without disturbance

FUZZY-PID is making an effort at decreasing this peak overshoot along with better time domain specifications. Which can be evident from the figure.12 shows the Comparison response of Tyreus-Luyben and FUZZY PID with 50% disturbance from set point. However with offline PID controlling techniques rejects disturbances at feed forward, feedback and output disturbances except for process disturbance.

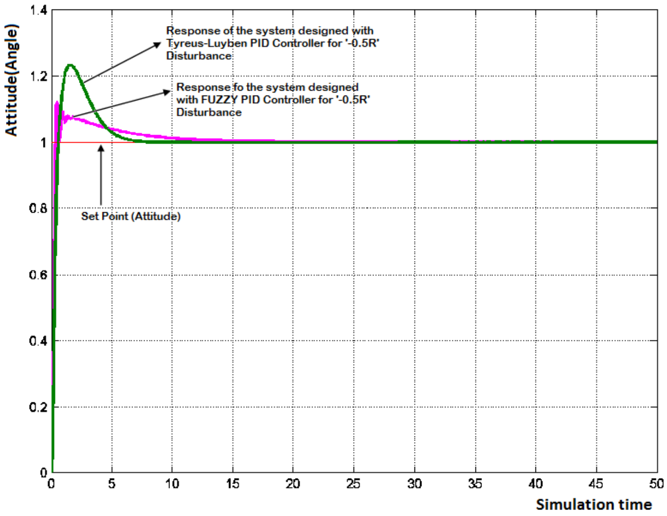


Figure.12 Comparison response of Tyreus-Luyben and FUZZY PID with 50% disturbance from set point

Figure.13 shows the comparison response of system with different step disturbances applied in the presence of FUZZY-PID controller. It is evident from figures.8 and 9 the response of the system reaches the set point very quickly for any kind of disturbances.

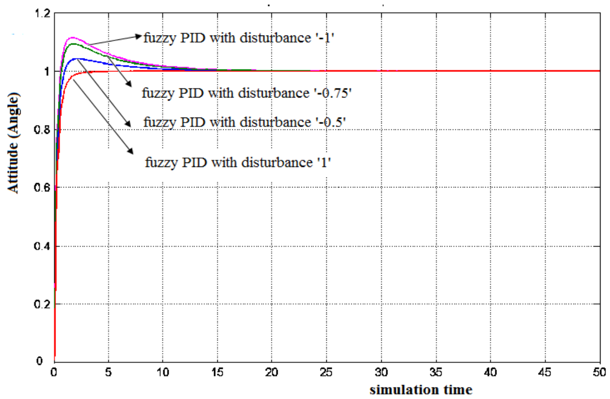


Figure.13 Response of the system with different types of disturbances applied in the presence of FUZZY-PID controller

The time domain specifications [8] of the system designed with FUZZY-PID controller and Tyreus-Luyben PID controller with different disturbances lists in table.2 and from this table it is apparent that peak overshoot of Tyreus-Luyben controller from ultimate cycle methods is 13.28% and for FUZZY-PID is 5.62% from setpoint, All the methods are giving transient behavior is smooth for positive disturbances but for FUZZY-PID it will be smooth for both positive and negetive disturbances

TABLE: COMPARISON OF TIME DOMAIN PERFORMANCE PARAMETERS FOR DIFFERENT DISTURBANCES IN THE PRESENCE OF FUZZY-PID CONTROLLER

Applied Disturbance	***Time Domain Specifications***	**Controller Used**		
		Tyreus Luyben PID Controller	***Fuzzy Logic PID Controller***	***Improvement in parameters***
With the disturbance of '-1'	*Delay Time (T_d) in Sec*	0.2425	0.1415	0.101
	Rise Time (T_r) in Sec	0.2727	0.145	0.1277
	Settling Time (T_s) in Sec	4.882	7.8093	-2.9273
	Peak Overshoot (M_P) in %	34.64	13.07	21.57
	Transient Behavior	Oscillatory	Smooth	Improved
	% Steady state Error (E_{SS})	Zero	Zero	
With the disturbance of '-0.75'	*Delay Time (T_d) in Sec*	0.2538	0.1735	0.0803
	Rise Time (T_r) in Sec	0.3136	0.19	0.1236
	Settling Time (T_s) in Sec	5.0679	5.19	-0.1221
	Peak Overshoot (M_P) in %	28.77	10.76	18.01
	Transient Behavior	Oscillatory	Smooth	Improved
	% Steady state Error (E_{SS})	Zero	Zero	0
With the disturbance of '-0.5'	*Delay Time (T_d) in Sec*	0.2715	0.1787	0.0928
	Rise Time (T_r) in Sec	0.3589	0.2036	0.1553
	Settling Time (T_s) in Sec	5.9841	6.0837	-3.7884
	Peak Overshoot (M_P) in %	23.26	8.55	11.34
	Transient Behavior	Smooth	Smooth	-
	% Steady state Error (E_{SS})	Zero	Zero	0
With the disturbance of '0'	*Delay Time (T_d) in Sec*	0.3158	0.1894	0.1624
	Rise Time (T_r) in Sec	0.5327	0.2361	0.2966
	Settling Time (T_s) in Sec	5,865	6.4284	-0.5634
	Peak Overshoot (M_P) in %	13.28	5.62	7.66
	Transient Behavior	Smooth	Smooth	-
	% Steady state Error (E_{SS})	Zero	Zero	0

V. CONCLUSION

Hence, in this paper at first the conventional offline PID controller techniques like ultimate cycle/ Overshoot-undershoot methods are used for controlling attitude of the Longitudinal Autopilot. For this a General Aviation aircraft selected as an example. From these techniques Tyreus-Luyben method is selected as a finest PID controller with better time domain specifications, but whenever a negative maximum disturbance occurred for the process disturbance at airframe dynamics the response of the system is degraded with a peak overshoot of 34.64 in order to suppress the peak overshoot and to improve other time domain specifications and to get quick response FUZZY LOGIC-PID controller is designed for disturbance rejection. The performance of the system is verified by applying different step input disturbances as the percentage of input. The peak overshoot now reduces to 13.07%. However future scope area concluded is the settling time for negative disturbances are increasing, to overcome this use of adaptive fuzzy and artificial neural networks are preferred. Also this study can applied to different aircrafts like business aircraft, jet aircraft and missile aircraft.

Hence, it is concluded that the FUZZY LOGIC PID controller is the finest controller than conventional offline PID controlling techniques for controlling airframe dynamics for better process disturbance rejection.

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