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# A Comparative Study on Flight Control Systems Design Using Conventional vs. Statistical Methods

**Engineering**

**KEYWORDS :** Flight Control Systems, Statistical methods, Monte Carlo simulation, Robust controller design, Matlab/Simulink, PID Controller

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## ABSTRACT

*Choice of controller design algorithm is always a challenge to the engineer, particularly in critical and dynamic systems such as fight controls. The usage of only conventional methods will not be sufficient in such critical systems design. Uncertainties, non linear disturbances, temperature variations etc… will cause variation in parameter values. In flight controls, sometimes these variations can cause huge impact on the response. In this scenario, statistical methods can be used to predict the effect on the response due to parameter variations. Statistical analysis will give the impact of a particular component on the response which can be used to increase the robustness of the system. An analog PID controller for controlling angle of an aileron is designed and the effect of parameter variations is studied using Monte Carlo simulation (MC). MC is used to vary the parameter value randomly within its probability distribution function. Since the variations are applied randomly uncertainty in the system is also taken into consideration. This paper compares the design considerations with respect to flight control systems using MC analysis and conventional methods such as Tyreus Luyben. This paper gives high level design methodology where both conventional and statistical methods can be combined to improve the controller design. The statistical analysis is done with help of Saber simulator tool. Here the effect of parameter variation on the overshoot of the response is studied. This result shows that the variations on the different dynamic characteristics using statistical methods.*

## I. Introduction

Primary control surfaces in a typical aircraft are elevators, rudders, and ailerons which control pitch, yaw, and roll motion of aircraft respectively. Flight control systems should provide smooth control and eliminate any erratic behavior.

There are many control system design methods and algorithms available. Because of increase in stability [2], improvement in disturbance rejection and reference tracking, closed loop systems are preferred for flight control scenarios. Proportional-integral-derivative (PID) controllers have been widely used in the industry due to the facts that they have simple structure and they assure an acceptable performance for the majority of the industrial processes [1]. PID technique can be used to design a good controller provided proper tuning methods are used.

## II. General Aviation Aircraft Control System

The basic closed loop control system for flight control surfaces is given in figure 1.

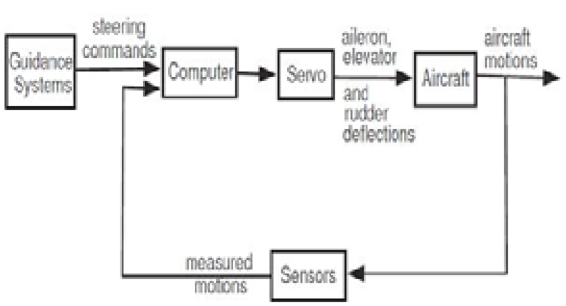


**Figure 1.general closed loop control system for flight controls**

A general aileron angle control system is given in figure1 and figure 2 [3-4]. All the transfer functions are calculated using short period approximation method.

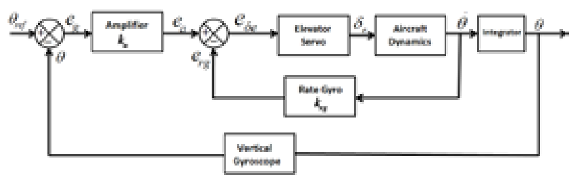


**Figure.2 General Aileron angle control system**

The transfer function of the General Aviation Aircraft [3-4] is given in equation (1).

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

The Aileron servo to deflect the aerodynamic control surfaces here considered it as an electric motor. $\delta_e$ is elevator deflection angle, $k_a$ is elevator servo gain, $e_g$ is input error voltage, $\tau_s$ is Servo motor time constant. For a typical servo motor $\tau_s$ fall in the range 0.05-0.25s the transfer function for servo elevator [4, 9] is given by equation (2).

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

This control system is modeled in MATLAB/Simulink and corresponding Monte Carlo simulations are done in Saber simulator.

## III. Modeling Aileron Control System

All the analyses discussed in this paper are carried out in MATLAB/Simulink given in figure 3 and Saber Simulator tool.

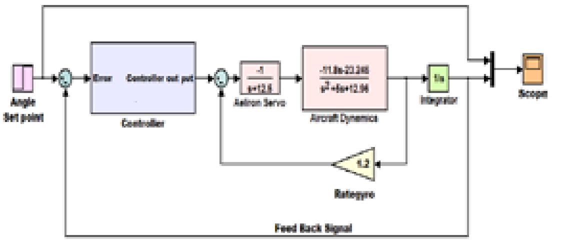


**Figure.3 MATLAB/Simulink model for the system designed with Ziegler-Nicholas PID controller**

### IV. Controller Design Using Conventional Tuning Techniques.

In this paper Tyreus Luyben tuning technique is used to design the PID controller design [6-7]. An analog PID controller is designed based on the gains obtained by using Tyreus Luyben method. Among different conventional tuning techniques, Tyreus Luyben will give optimal response [4]. These techniques may be able to eliminate different types of disturbances but effect of parameter variations on the controller response due to non linear disturbances, uncertainties, temperature variations etc will not be considered while designing of controller.

An analog PID controller is designed using the gains obtained from Tyreus Luyben method, figure 4.

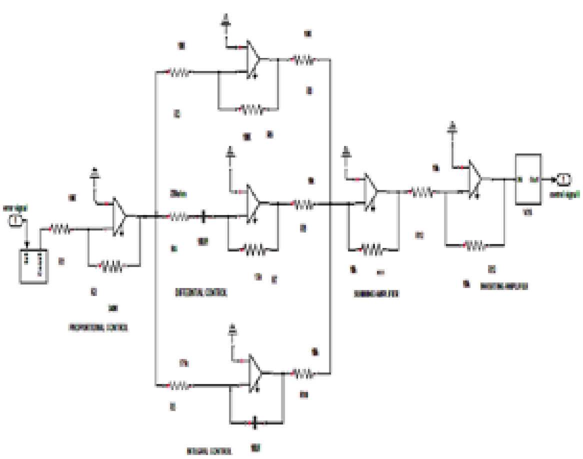

**Figure 4 Analog PID controller using Tyreus Luyben method in Matlab/Simulink**

### V. Need for Statistical Methods in Flight Control system design

Parameter variations should be considered at the design phase of controller itself especially in dynamic systems like aircrafts where different temperature conditions and non linear disturbances drastically affect the parameter values. Optimal values for parameters and their tolerances should be maintained. But maintaining very accurate parameter values, their tolerances and other specifications is not always easy.

Hence the controller must be robust so that any parameter variations will not change the response of controller.Statistical methods like Monte Carlo simulations play major role in designing robust systems.

### VI. Controller design using statistical methods

A high level design methodology for the controller design using Monte Carlo simulation is given in figure 5.

Monte Carlo methods are a broad class of computational algorithms that rely on random sampling to obtain numerical results (ref: wiki) [5, 8]. Since they will also consider the flaws in the designs parameter variations or any other uncertainties they are more suitable for designing robust systems.

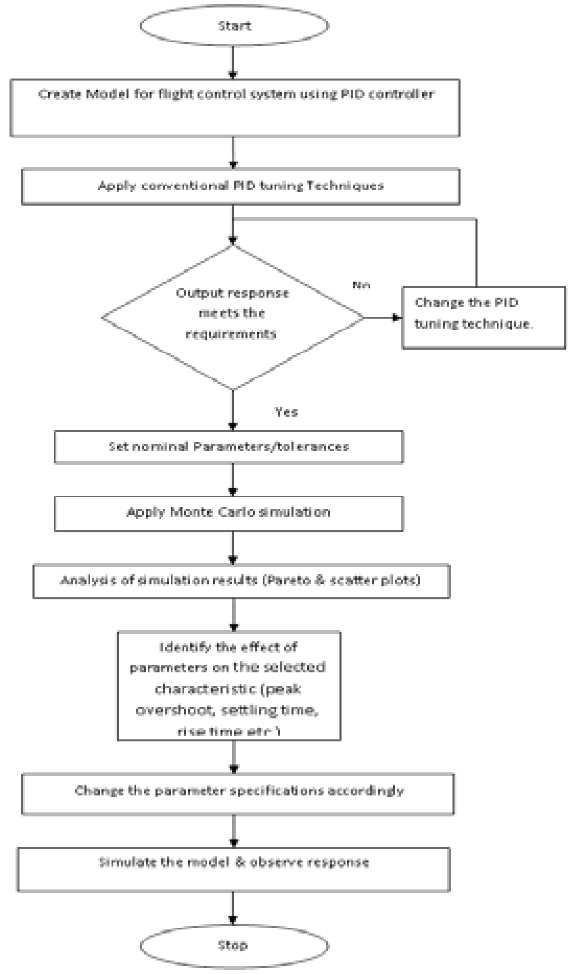


**Figure.5 Controller Design using Statistical methods**

### VII. Comparison Between Conventional and Statistical Methods

Table1 gives the comparison between conventional and statistical methods with respect to different design considerations.

**Table 1. Comparisons between Conventional and Statistical Methods**

| Design considerations | Design using conventional methods | Design using statistical methods |
|---|---|---|
| Computation time | less | more |
| Accuracy | less | more |
| Reliability | less | more |
| Robustness | less | more |
| Aging affect of parameters | Not considered | Considered |
| Parameter variation due to temperature change | Not considered | Considered |
| Uncertainty prediction | Not taken into account | Taken into account |
| Sensitivity analysis | No | Yes |
| Complexity | No | Yes |
| Design optimization | Yes | Comparatively More |
| Drift | Not considered | Considered |
| Flaws in model design | Not covered | Covered |
| Coverage of Worst case scenarios | No | No |

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| | | |
|---|---|---|
| Disturbance rejection | same | Almost Same |
| Response time (settling time) | same | Improved |

### VIII. Discussions

- Monte Carlo simulations involves many iterations which sometimes may take hours of time where as the conventional methods may take less time. Though in some scenarios like IC designs etc manual designing may take longer than that for Monte Carlo simulations. Parallel computing or distributive computing can be used to decrease the computation time drastically.
- Monte Carlo simulations can also be used to compute the interdependency of inputs which influences the output accuracy in real time.
- Conventional methods will not consider the parameter variation due to aging affects, climatic variations or drift in the parameters which are very common in avionics. Statistical methods along with above will also consider uncertainty i.e. faults in the models etc.
- Statistical methods not only will predict the uncertainty in the system but also with how much probability the uncertainty may occur quantitatively so that the engineer can modify the model as per the requirements [5].
- Sensitivity analysis can be done for conventional methods by using manual tuning of parameters but as the circuit become complex statistical methods will serve more since they give output is how much sensitive with respect to each input.
- Design optimization: In systems like flight controls at some times very accurate components with very low tolerance bands are needed. Since Statistical methods provide which parameter has how much affect on output in terms of variance, accuracy can be compromised for less variant parameters so it can compensate the cost used for high variant parameters.
- Neither statistical nor conventional methodologies will consider the system behavior at worst case scenarios like catastrophic effects etc. So it is engineer's responsibility to take defensive measures while designing the system.

### IX. Simulation Results

The response of the system using Tyreus Luyben method for 1V set point is given in figure 6.Here the analysis is done with respect to peak overshoot of the response.

**A. Monte Carlo results with 10% tolerance limits:**

The Monte Carlo simulation results with 10% tolerance for each component are given in figure 7. The tolerance limits of each component in the nominal design are set to 10 % initially. The frequency of occurrence for different overshoot values over 100 runs is given in figure8.

In figure.10 the main effect histogram shows the % change in the percentage of overshoot per % change in the parameter. The R**2 histogram gives the % change in overshoot as a measure of each parameter.

Clearly from figure 10 components r5 and r9 has most effect on peak overshoot. Capacitor C4 has least effect on the overshoot.

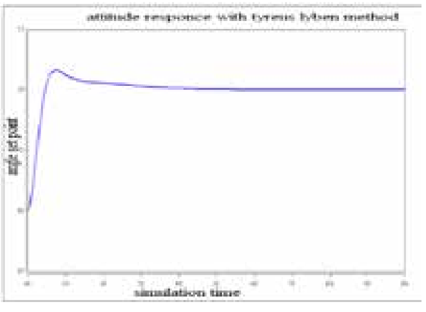


**Figure.6 Aileron angle response using Tyreus Luyben method**

**B. Monte Carlo results with 5% tolerance limits:**

Now the tolerance for r5 and r9 are changed to 5% and the Monte Carlo simulations are performed for 100 runs. The Monte Carlo simulation results for 5% tolerance for r5 and r9 shown in figure 11.

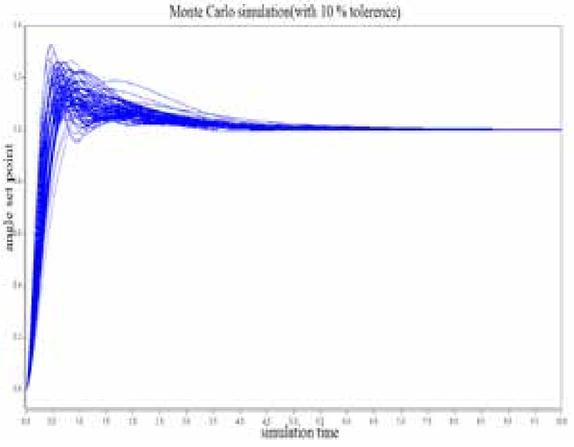


**Figure.7 Monte Carlo results (for 10% tolerance range)**

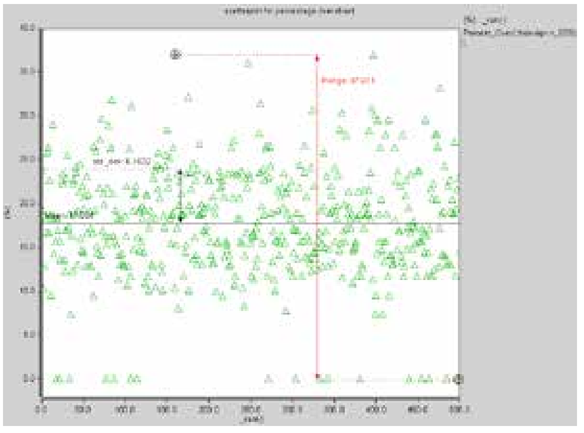

**Figure.8 scatter plot for percentage change in peak overshoot (for 10% tolerance range)**

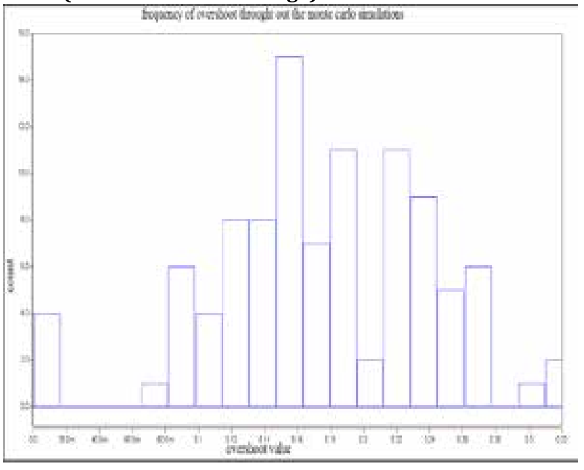


**Figure.9 no of occurrences of overshoot value (for 10% tolerance range)**

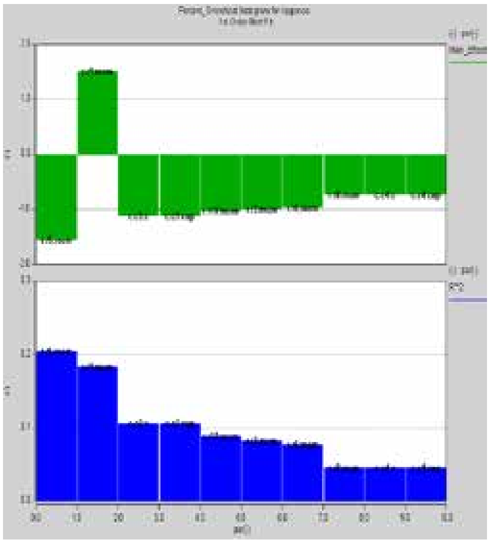

**Figure.10 Pareto analysis plots (for 10% tolerance range)**

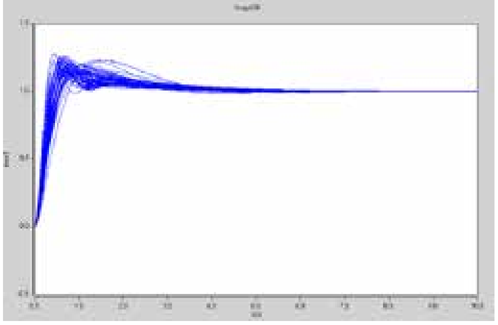

**Figure.11 Monte Carlo results after modifications for tolerance range**

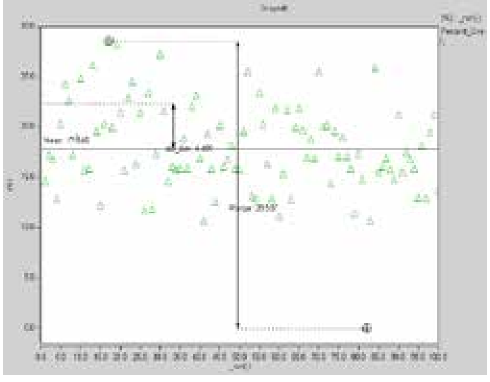

**Figure.12 scatter plot for percentage change in peak overshoot (after modification for tolerance)**

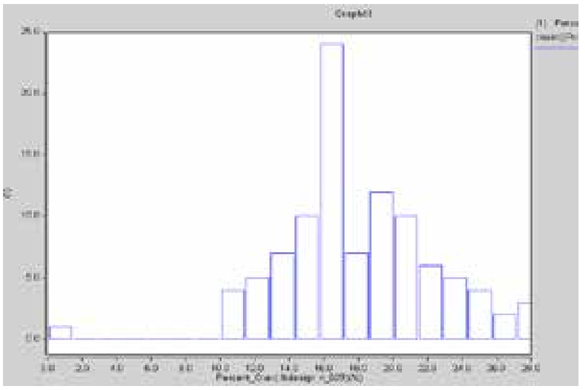

**Figure.13 no of occurrences of overshoot value (after modification of tolerance range)**

**Table 2. Comparisons between Conventional and Statistical Methods**

| Trial | % Tolerance | | | | | | M | S.D. | R |
|---|---|---|---|---|---|---|---|---|---|
| | r5 | r9 | c3 | r6 | r8 | c4 | | | |
| 1 | 10 | 10 | 10 | 10 | 10 | 10 | 17.804 | 6.1532 | 37.011 |
| 2 | 5 | 5 | 10 | 10 | 10 | 10 | 17.845 | 4.491 | 28.587 |
| 3 | 5 | 5 | 5 | 5 | 5 | 5 | 16.853 | 3.8804 | 23.523 |
| 4 | 1 | 1 | 10 | 10 | 10 | 10 | 17.201 | 4.0129 | 23.523 |
| 5 | 1 | 1 | 1 | 1 | 1 | 1 | 16.853 | 3.831 | 23.651 |

The scatter plot for the percentage change in peak overshoot is given in figure 12.The histogram after modification is given in figure 13.

Mean % overshoot (M), standard deviation of % overshoot (SD), range of %overshoot variation (R) for different trails are given in table 2. For each trail tolerance values for components are varied and clearly from trail 1 to trail 2 considerable variations are observed in standard deviation and range. For trials 3, 4, 5 not much variation is there.

Hence for r5 and r9 tolerances can be made to 5 % and others can be taken as 10 % which can reduce the cost.

## X. Conclusion

The comparison of conventional and statistical methods design considerations for flight controls is discussed. From results it is clear that system can be made more robust and compromising tolerances for parameters having least effect can achieve cost reduction and design optimization.

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