Modeling, Simulating and Control of free falling bomb using PID

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Abstract– A six-degree of freedom (6DOF) mathematical model for the free fall bomb (FFB) is a crucial factor for designing a control system. FFB is an unmanned vehicle fired from a fast-moving airplane on the way to the ground to follow the assigned target. It might also be referred to as an air-to-ground smart bomb. Because building a mathematical model saves time and effort in the domains of control and testing processes, a nonlinear simulation model of the FFB's dynamics should be built using an appropriate CAD tool such as MATLAB (Simulink). In this work, the FFB aerodynamic model is estimated using a semi-empirical technique USAF Missile-DATCOM. To control the attitude of an autonomous FFB, the mass inertia model is estimated from the CAD tool and experimental work, and the actuation model is identified using system identification to describe the servo's dynamics, then the dynamic model is built to describe the overall FFB system. PID controller is one of the best controller types that is widely used nowadays due to it simplicity, performance, and implementation. PID controller is designed for the FFB roll channel to stabilize the FFB's roll angle. The tracking performance of the designed controller is verified through different types of inputs, and the simulation results shows the superiority of the roll control system.

I. INTRODUCTION

The FFB physical system's modelling and simulation are frequently used as key tools to investigate, simulate, and evaluate complex engineering systems with a degree of accuracy necessary for design and execution [1]. To simulate the trajectory of the bomb, a 6DOF nonlinear dynamic model of the bomb was created. A 6-DoF complete simulation model with a high level of confidence allows designers and engineers to evaluate and investigate new air vehicle proto-types for an aerial vehicle, such as an Aeroplan. Formulating the 6 -DOF equations of motion for kinematic and dynamic models is the first step in creating a flight simulation model. The semi-empirical build-up method known as missile DAT-COM is frequently used to predict aerodynamic performance during the initial design and analysis. Missile DATCOM can estimate the aerodynamic coefficients and stability derivatives of the body based on the current flight as well as the body's geometrical configurations, the FFB's servo system is represented through a transfer function which is estimated from the system identification, System identification using parametric identification techniques has a specific model structure. The parameters are estimated using the observation of the input/output data. experiment is performed using the utilized servo and with rotary encoder as feedback to perform the identification experiment. To control the missile's trajectory actively with conventional control surfaces, the missile must first be stabilized in roll, it is difficult to maintain a constant path while it is rapidly spinning. There are a variety of payloads that require a roll-stabilized platform. The stabilization of a missile's roll presents many useful opportunities. Roll control benefits the stability of the missile's flight as well as enabling new payload objectives. During the typical launch of a missile, the vehicle can be driven to high roll rates, even with a mostly symmetric body, while avoiding dynamic instability whereby the missile would roll and pitch rapidly in a corkscrew path, leaving the missile short of its intended maximum altitude is critical, roll stabilization also opens the door to full rocket active control.

A control mechanism known as a proportional-integral-derivative controller (PID controller) is often employed in industrial control systems due to its simplicity, low cost, and easy for implementation. The difference between a desired roll input and a measured value from the navigation system is fed to the designed controller to periodically calculate the control output value [2]

This paper is constructed as the following in section II Constructing a model for the mass-inertia model, identifying the actuator model using an identification process and the aerodynamic model is estimated using DATCOM, section III the PID controller is designed for the system's roll channel to control the missile roll angle for keeping the system stable, section IV shows the experimental work with the simulation results. Finally, section V represents the conclusion and the future work.

II. MODELING

Modelling used to create a mathematical model that incorporates important physical model parameters. The mathematical model simulates the physical model and specifies the requirements for linearizing a nonlinear system. Utilize specific embedded systems, IMU sensors, and servomotors to implement the hardware. The FFB geometric and mass inertia model is generated, aerodynamic model is estimated, actuation model is considered as a first order transfer function with the predefined time delay, atmospheric model is built according to the international standard, are detailed in this section as follows:

A. Geometric mass of inertia model

All the geometric data is measured physically from FFB in the laboratory to fully acquire the geometric model.

The top view of the FFB case study and the geometric data is as shown in Fig.1 and Table I respectively.

Fig. 1 Geometric shape.

Table I Bomb diminution and geometric parameters

parameter	value
x_{cg}	0.161227 m
y_{cg}	0.049 m
z_{cg}	0.049 m
Body Length	0.275m
Body Diameter	0.098m
Mach	0.5
angle of attack α	-50510152025
mass	0.65 kg
I_{XX}	0.0002589804 kg.m^2
I_{YY}	0.0002586289 kg.m^2
I_{ZZ}	0.000550835 kg.m^2

$$I = \begin{bmatrix} I_{xx} \; I_{xy} \; I_{xz} \\ I_{yx} \; I_{yy} \; I_{yz} \\ I_{zx} \; I_{zy} \; I_{zz} \end{bmatrix} \quad (1)$$

The value of Ixy, Iyx, Izy and Iyz are equal to zero due to symmetric and the value of I_{XZ} and Izx are very small can be neglected compared with the value of Ixx, Iyy, and Izz

$$I = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \quad (2)$$

B. Aerodynamic modeling for the bomb

To formulate a 6DOF mathematical model of bomb, we define the following coordinate systems [1].

- $OX_bY_bZ_b$ Bomb-Fixed coordinate system with its origin at bomb centre of gravity (c.g.)
- $OX_aY_aZ_a$ Air-trajectory reference coordinate system.
- $OX_gY_gZ_g$ Earth-reference coordinate system.

The aerodynamic model's primary function is to compute the aerodynamic moments and forces experienced by the bomb during flight. In the six-degree-of-freedom equation that describes the motion of the bomb, the aerodynamic forces drag force, side force, and lift force are described in terms of dimensionless coefficients obtained from the Datcom. The stability derivative values of the bomb are often used to explain its dynamic properties [3] and [4] The resultant aerodynamic force acting at a point called centre of pressure and this point is usually not located at the centre of gravity of the vehicle. Datcom is a widely used semi-empirical datasheet component build-up method for the preliminary design and analysis of missile aerodynamics and performance [5].

The nonlinear differential 6-DOF equations of motion (EOM) for an aerial vehicle are utilised for modelling and simulation of the vehicle under investigation and have been driven by generic Newton-Euler translational and rotational dynamics to build up the dynamic model. The equations of motion are created based on the following assumptions to simplify the model [6].

- The vehicle is assumed as a rigid body.
-
- The rotation of the earth is ignored.
- The vehicle's mass, moments of inertia, and the location of the centre of mass are considered constant during any dynamic analysis.
- The vehicle is symmetric in the X-Z plane.

The complete set of six degree of freedom equations:

$$\dot{U} = \frac{-mg\sin(\theta) - 0.5\, C_x\, \rho v^2 S}{m} + rw - qw \quad (3)$$

$$\dot{V} = \frac{0.5\, C_y\, \rho v^2 S}{m} - ru \quad (4)$$

$$\dot{W} = \frac{-mg\cos(\theta) - 0.5\, C_{xz}\, \rho v^2 S}{m} + qu \quad (5)$$

$$\dot{q} = \frac{1}{I_{yy}}\, 0.5\, \rho v^2 SDC_m \quad (6)$$

$$\dot{r} = \frac{1}{I_{zz}}\, 0.5\, \rho v^2 SDC_n \quad (7)$$

$$\dot{\varphi} = r\tan(\theta) \quad (8)$$

$$\dot{\theta} = q \quad (9)$$

$$\dot{\psi} = \frac{1}{r\cos(\theta)} \quad (10)$$

$$\dot{X}_E = U\cos(\theta) - V\psi + W\sin(\theta) \quad (11)$$

$$\dot{Y}_E = U\cos(\theta) + V + W\,\psi \quad (12)$$

$$\dot{Z}_E = -U\sin(\theta) + W\cos(\theta) \qquad (13)$$

where (U, V, and W) are body axes velocity (p) Roll rate , (φ) Roll angle (q) Pitch rate, (θ) Pitch angle,(r)Yaw rate,(ψ) Yaw angle (X_E ,Y_E, Z_E)Position on Earth axes system.

The bomb is designed with this parameter with the Inventor software as shown in Fig.2.

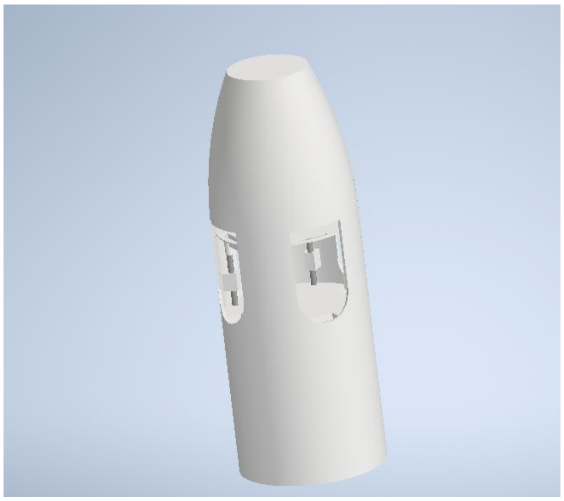

Fig. 2 Simulated bomb

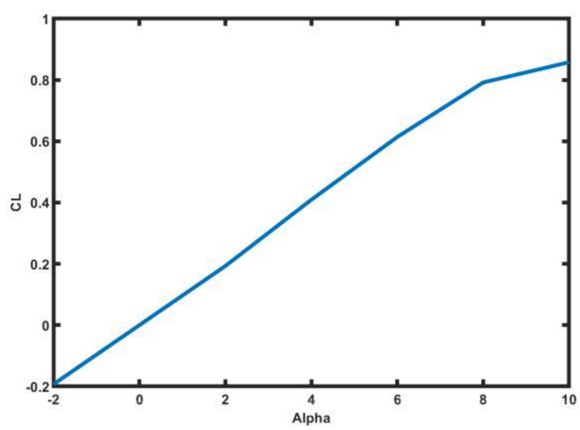

Fig. 3 C_L with Different values angle of attack

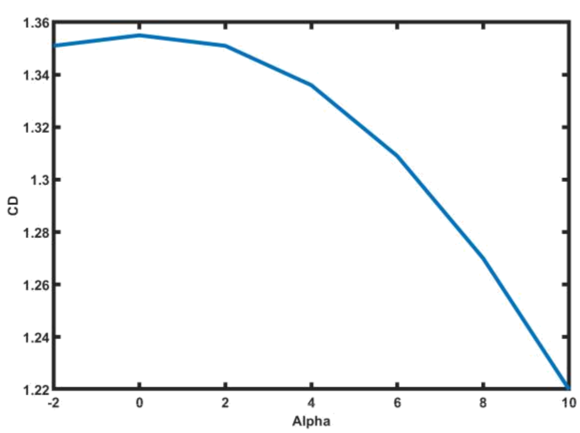

Fig. 4 C_D with Different values angle of attack

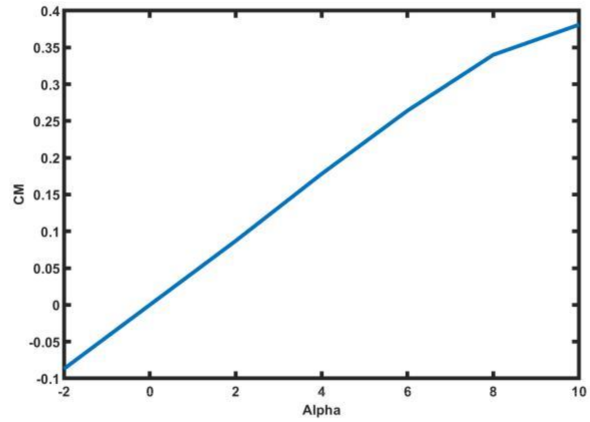

Fig. 5 C_M with Different values angle of attack

C. actuation model

First, the transfer functions must be defined for the used servo the modeling of this servo motor is done by the Arduino and potentiometer as a feedback as shown in Fig.9 begin with giving the system step input and get the step response as shown in Fig. 6 and the Matlab function system identification .this transfer function may be first order or second order we will choose the first order transfer function because it fit with 94 percent while the second order fit with 92% [7] then by giving multiple steps and track the output as shown in Fig.7 [8].

$$TF = \frac{K_a}{S+1} \qquad (14)$$

Then the obtained transfer function is:

$$TF = \frac{4.969}{S+4.549} \qquad (15)$$

By using Matlab for tuning the PID to adjust the rising time, settling time and the overshot.

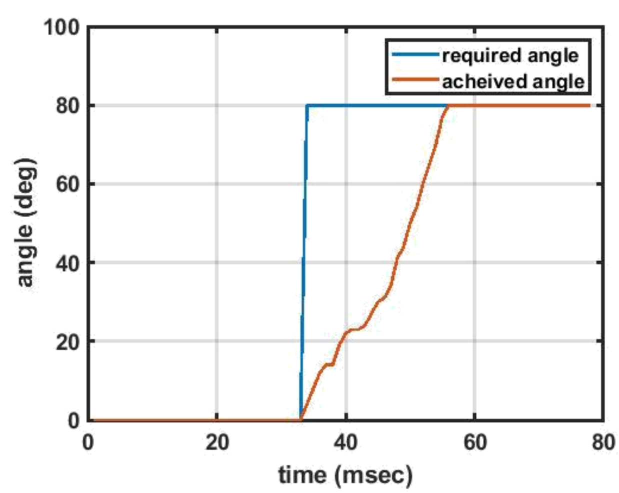

Fig. 6 Step response

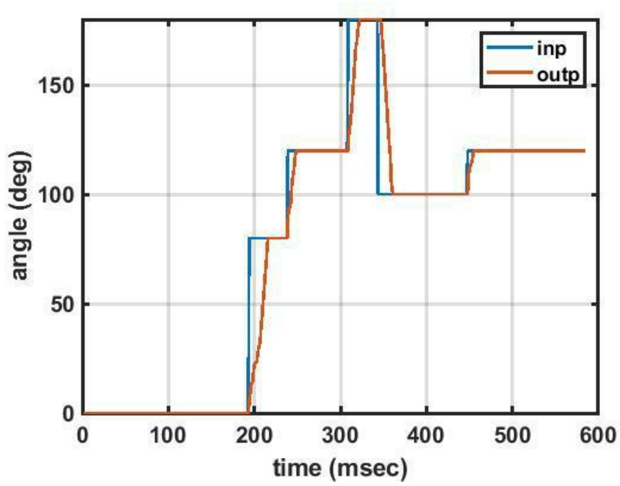

Fig. 7 Input output tracking response

D. Atmospheric model

The international standard atmosphere is used to model the atmospheric model as shown in the following equations:

$$P_H = P_o \left[\frac{T_H}{I_o}\right]^{\frac{-90}{R\frac{dt}{dh}}} \qquad (16)$$

$$P_o = P_o \left[\frac{I_H}{T_o}\right]^{\frac{-90}{R\frac{dt}{dh}}} \qquad (17)$$

III. DESIGNING PID CONTROLLER FOR THE PITCH, YAW, AND ROLL ATTITUDE

The FFB's attitude must be managed throughout its flight path in line with the movements required in relation to the inertial or reference frame. Controller is employed to do this. The Proportional-Integrator-Derivative (PID) controller is the most often used controller. The bomb is managed in this part by a conventional PID controller. A servo motor is used to control how the fins move [9]. The manual calculations indicated above are no longer often used in modern industrial facilities to tune loops as shown in Fig.5. Software for PID tuning and loop optimization is utilized to deliver repeatable outcomes. These computer program Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.

will compile the data, create process models, and offer the best optimization. Controlling the overall transfer function

of the system is the controller's primary goal of the system. [10]

The difference between an intended set point and a measured process variable is the error value e (t), which a PID controller continually calculates and uses to apply a proportional, integral, and derivative term-based correction. The controller adjusts a variable to reduce the error over time. [6].

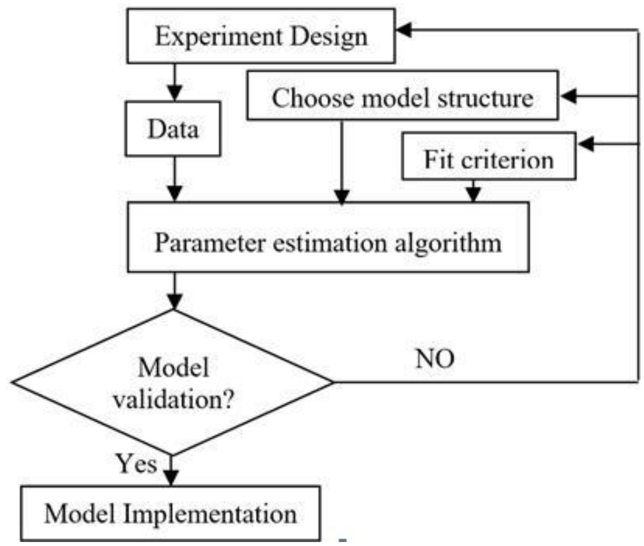

Fig. 8 System Identification procedure

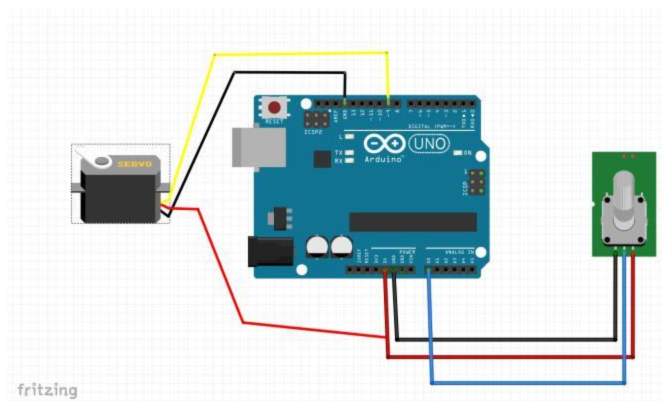

Fig. 9 System Identification hardware connection

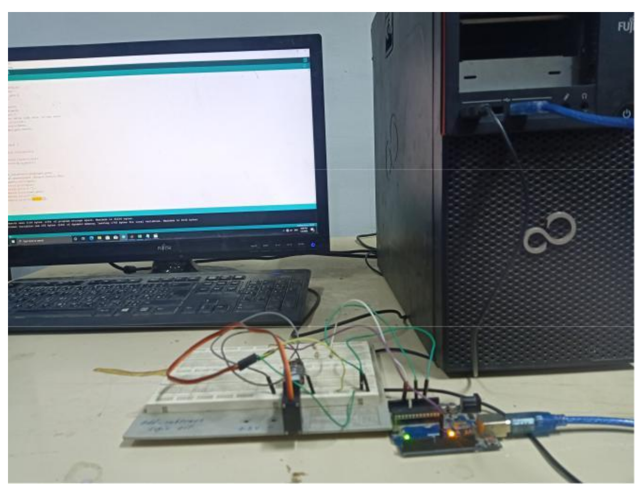
Fig. 10 Experiment setup

Fig. 11 System without controller

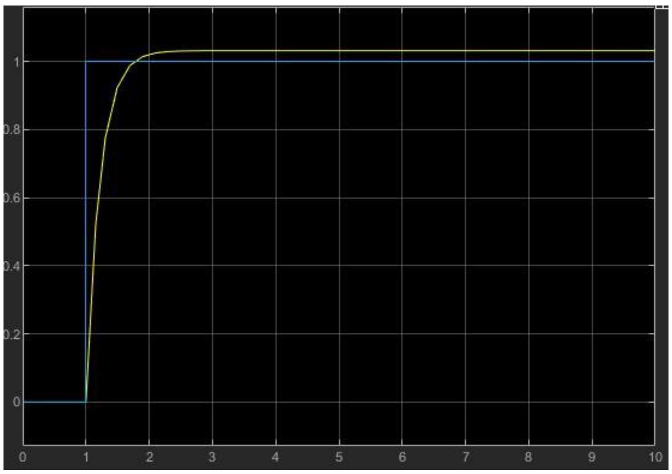

Fig.12 System response without controller

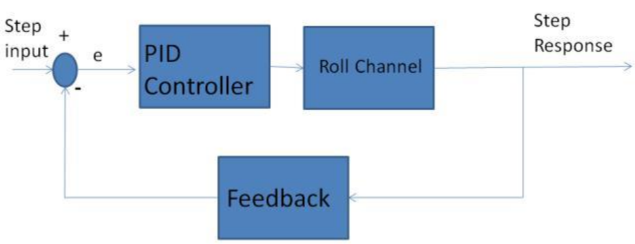

Fig.13 PID general structure

A PID controller may be used in many different situations since it just must comprehend the measured process variable. The three model parameters can be changed by a PID controller to suit certain process requirements. The degree of system oscillation, the amount that the system deviates from a fixed point, and the controller’s responsiveness to errors may all be used to describe the controller’s response. Adopting the PID algorithm does not guarantee optimal control or even system stability [11].

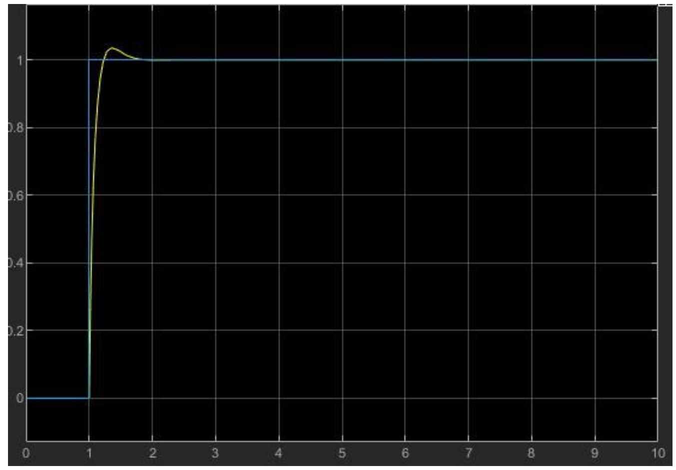

Fig.14 Step response with PID controller

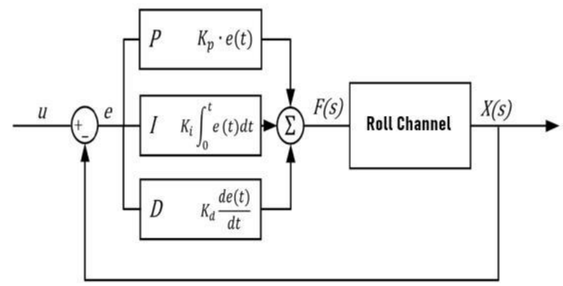

Fig. 15 PID algorithm structure

Table II The response before and after using the controller

	rising time(sec)	Overshoot (percent)	Steady state error
Before controller	0.8	1	0.2 deg
after controller	0.2	1.2	0 deg

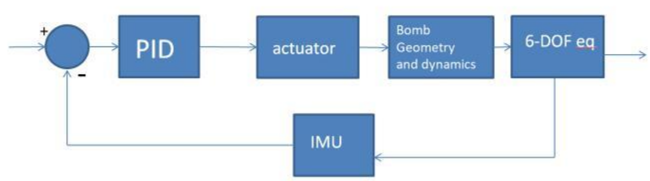

Fig.16 Overall system block diagram

IV. IMPLEMENTATION

As illustrated, implementation by converting all your software into actual hardware content to measure attitude, particularly roll angle, by attaching an MPU 6050 to a node MCU and controlling any roll movement, there is a wireless link between the node MCU and the computer.

implementation of PID by using Arduino by setting the value of the PID gains.

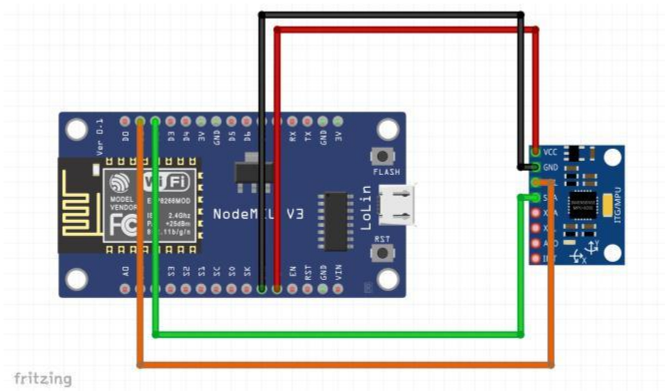

Fig.17 connection between node MCU and IMU

V. Conclusion

In this work, physics based modelling of a Free Falling Body is constructed ,geometric model is calculated experimentally in laboratory ,mass inertia model is estimated according to the CAD model ,semi empirical Datcom technique is used to estimate the aerodynamic coefficient and derivative ,the atmospheric model is represented using ISA ,after completing the 6DOF model, A control system is designed to stabilize the roll channel of Free Falling Body, a PID Structure is utilized ,the Performance of the controlled system is compared with the open loop system and the performance is accepted and the overshot also , increased rather in time by 60 percent the open loop and the steady state error is zero .

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The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g.” In this section, please acknowledge your faculty supervisor/advisor and any sponsor that helped finance your research and participation in conference.

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