AIRCRAFT STABILITY AND CONTROL

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ABSTRACT: Aiming to develop an effective way of auto stabilizing controller for aircraft. The whole simulation is built on MATLAB Simulink aerospace blockset, where a non-linear model is built which is then linearized using a built-in control design function. It is then tuned using a PID controller and simulated to validate the function of the model. This simulation system plays an important role in designing and testing the control system and has made a good effect on validating the control law of the aircraft.

1.0 INTRODUCTION:

Aircraft designs incorporate various stability characteristics that are necessary for better flight performance. At cruise, it is difficult for aircraft to maintain uniform flight condition because of turbulence which makes controllability and manoeuvrability challenging for the pilot. By developing an efficient autonomous controller, we can make aircraft stable in any conditions.

2.0 APPROACH:

Mathematical equations which are the semi-physical model of the desired system also known as a mathematical model are the best way to approach a control design. Flight dynamic models are based on mathematical models of the motions of aircraft in its six degrees of freedom. The control of UAV can be achieved by controlling the rudder, elevator and ailerons. We use Euler angles in our system to represent the orientation of the aircraft. In our control system, we aim to stabilize moment rates which in turn control our body coordinates.

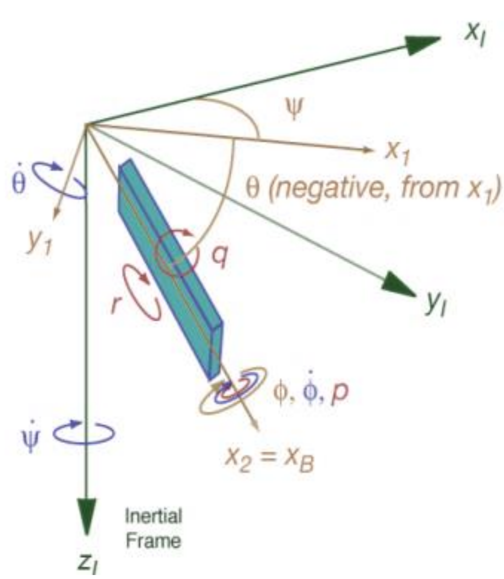


Fig 1: Inertial Frame

Here theta, psi, phi, p, q, r are pitch angle, roll angle, yaw angle, roll rate, pitch rate and yaw rate respectively. Moment rates are dependent on inertia and moment produced by control surfaces of aircraft.

Attitude

$$\varphi = p + q\sin(\varphi)\tan(\theta) + r\cos(\varphi)\tan(\theta)$$

$$\theta = q\cos(\varphi) - r\sin(\varphi) \qquad \text{….(1)}$$

$$\psi! = q\sin(\varphi)\cos(\theta) + r\cos(\varphi)\cos(\theta)$$

Angular velocities

$$p = (l +(I_{yy} - I_{zz})qr)/ I_{xx}$$

$$q = (m +(I_{zz} - I_{xx})pr)/ I_{yy} \quad \ldots(2)$$

$$r = (n +(I_{xx} - I_{yy})pq)/ I_{zz}$$

Linear velocity

$$u = (X - mg\sin(\theta)+ m(rv - qw))/m$$

$$v = (Y + mg\sin(\varphi)\cos(\theta)+ m(pw- ru))/m \quad \ldots(3)$$

$$w = (Z + mg\cos(\varphi)\cos(\theta)+ m(qu - pv))/m$$

Position

$$x = ((\cos\theta \cos\psi)u + (- \cos\varphi \sin\psi + \sin\varphi \sin\theta \cos\psi)v + (\sin\varphi \sin\psi + \cos\varphi \sin\theta \cos\psi)w)/m$$

$$y = ((\cos\theta \sin\psi)u + (\cos\varphi \cos\psi + \sin\varphi \sin\theta \sin\psi)v + (-\sin\varphi \cos\psi + \cos\varphi \sin\theta \sin\psi)w)/m \quad \ldots(4)$$

$$z = ((-\sin\theta)u + (\sin\varphi \cos\theta)v + (\cos\varphi \cos\theta)w)/m$$

Equation (1),(2),(3) and (4) describe the mathematical model of the aircraft. Since force and moment are derived from aerodynamic coefficients, the sum force and moment are not specified, because, for different aircraft, the coefficient is different. However, the 12 differential equations have formed the generic aircraft motion simulation process. Therefore, the model can be constructed by using the Matlab/Simulink with the obtained mathematical model.

3.0 MODELLING: The Airframe model is developed using an aerospace toolbox available in the Simulink library. Aerospace Toolbox provides standards-based tools and functions for analyzing the motion, mission, and environment of aerospace vehicles. For flight vehicles, we can import Data Compendium (DATCOM) files directly into MATLAB to represent vehicle aerodynamics. The aerodynamics can be combined with reference parameters to define aircraft configuration and dynamics for control design and flying qualities analysis. Initial parameters like a moment of inertia of aircraft, aircraft dimensions such as wingspan, surface position, CG position, aerodynamic coefficients are to be determined. Aerodynamic coefficients can directly be imported from an aerodynamic analysis software known as XFLR5.

3.1 Structure of simulation model

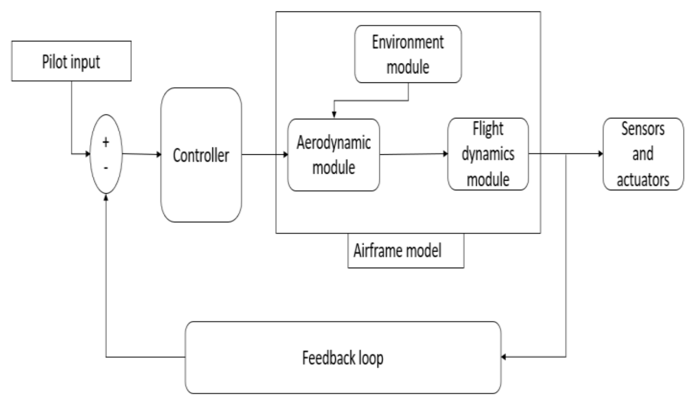
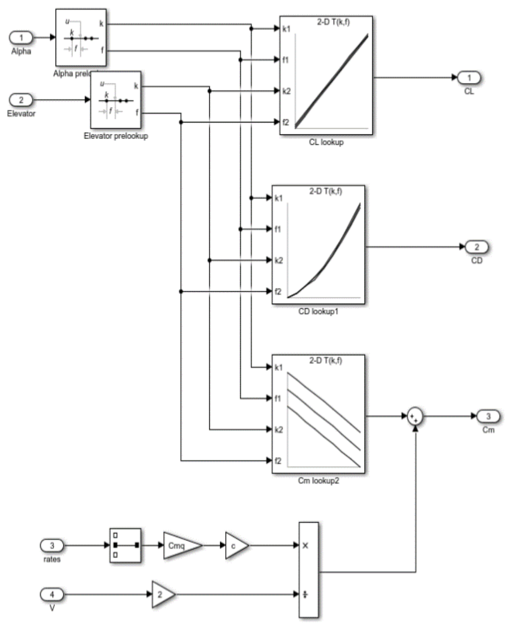


Fig 2: Block diagram of simulation model

The simulation model consists of an aerodynamic module that helps in calculating force and moment. While the flight dynamic module solves the equations and gives out state variables. These state variables are then sent to sensors, actuators and also controller through a feedback loop where the responses are tuned according to the desired input.

3.2 Aerodynamic model:



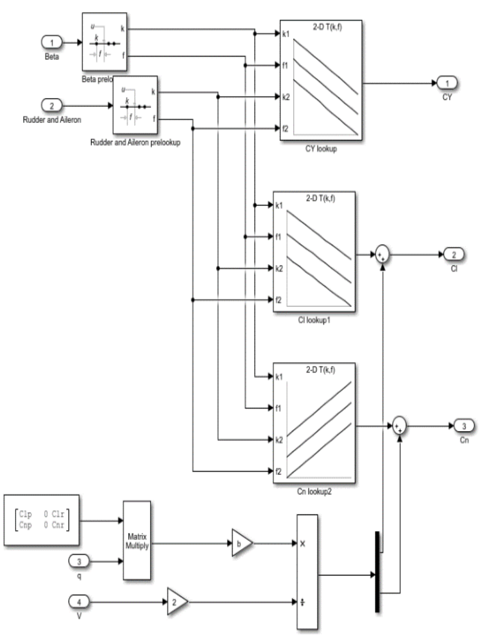


Fig 3. Longitudinal aerodynamic model
Fig 4. Lateral aerodynamic model

As discussed above aerodynamic coefficients for a varying angle of attack, sideslip angle, elevator, rudder and aileron angles are imported from aerodynamic analysis tools.

3.3 Environment model

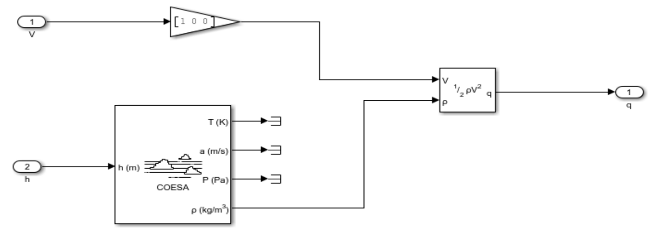


Fig 5. Environment module

COESA atmosphere model is chosen which is a US standard atmosphere. For the given altitude it defines the air density at that altitude.

3.4 Flight dynamics module:

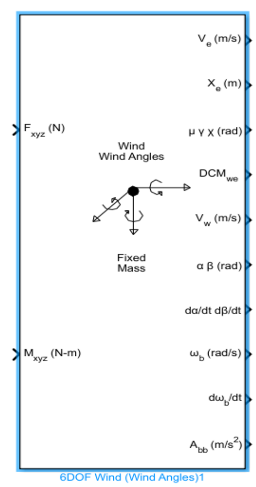


Fig 6: 6 DOF Flight dynamic module

This module integrates the 6 degrees of freedom equations of motion in the wind axis. It solves the 12 equations of motions. It receives forces and moments generated by the aerodynamic module and gives out state variables. The forces and moment generated by the aerodynamic module are in the x,y and z-direction. We have to assume certain initial conditions here such as altitude, initial velocity, initial orientation, mass, rotational inertia and body rotation rates.

3.5 Airframe model

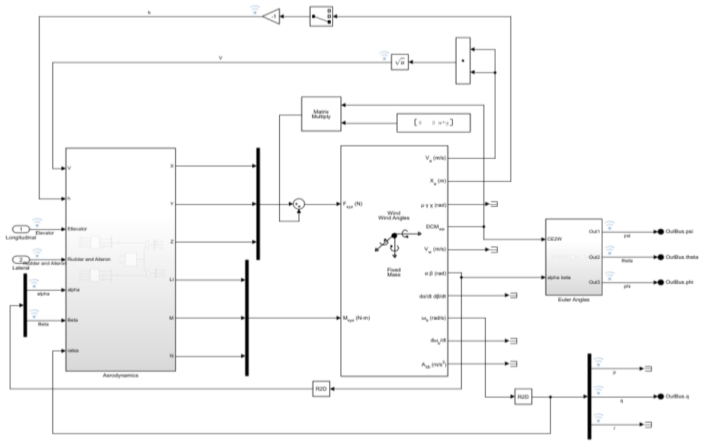


Fig 7: Airframe model

Later the aerodynamic module is connected to the flight dynamic module by connecting all the forces and moments generated in an aerodynamic module using mux. Wind angles are changed to Euler angles. Angular velocity is changed from radian to degree and demux is used to differentiate axes. Then the angle of attack and sideslip angle is fed back to an aerodynamic module from changing rad to deg. Velocity and position are also fed back to the aerodynamic module by converting it from vector to scalar quantity.

3.6 Controller: PID controller is used to controlling the longitudinal and lateral orientation of aircraft. While the feedback to the controller will be the orientation of the aircraft in the Euler angles.

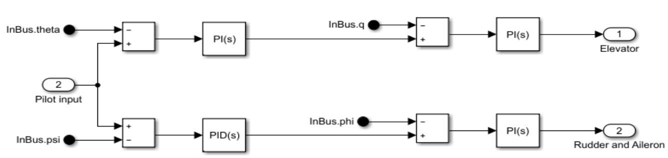


Fig 8: Controller

4.0 SIMULATION: Below is the overall model of the system. A unit step input for step time 5 seconds is given to the system. The bus signal contains the orientation angles of the aircraft.

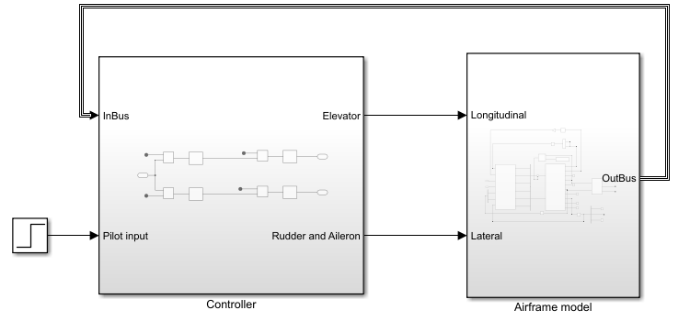


Fig 9. Main two Simulink block of the model

In order to verify the function of this autopilot system tests were carried out by using Matlab Simulink. The simulation tests are carried out with the aerodynamic coefficient which is obtained from aerodynamic analysis tools, the mass of the aircraft, the rotational inertia, etc. The following curves are given by taking one kind of aircraft as an example.

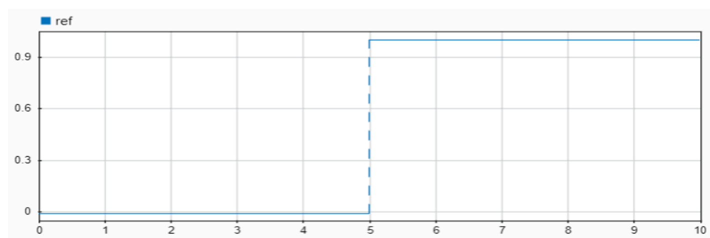


Fig 10: A unit step input

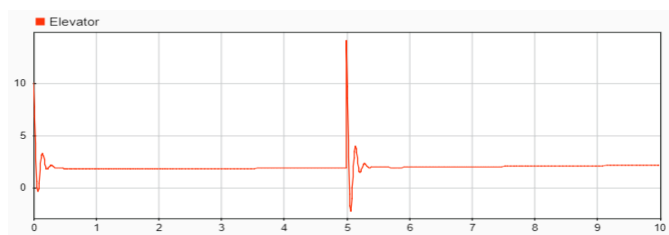


Fig 11: Response of elevator for unit change in pitch attitude

Fig 12 : Response for unit change in pitch attitude

The above results shown are the change in pitch attitude and elevator angle for a step unit input. When the flight reaches the required state, it auto stabilizes to that required pitch attitude.

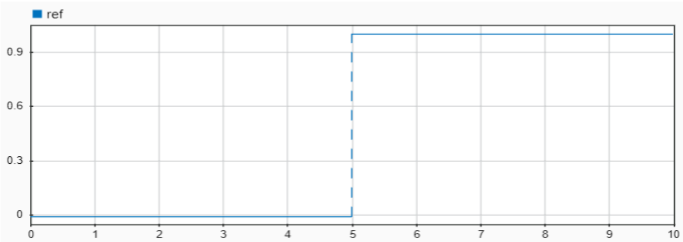


Fig 13: A unit step input

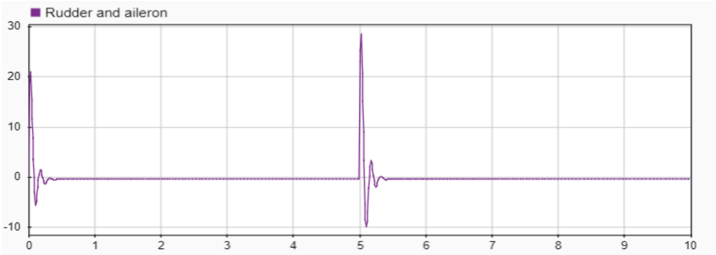


Fig 14: Response of rudder and aileron for unit change in pitch attitude

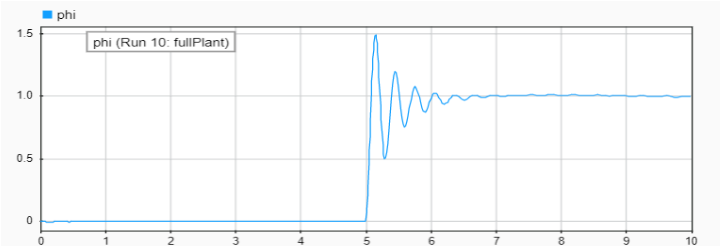


Fig 15: Response for unit change in yaw attitude

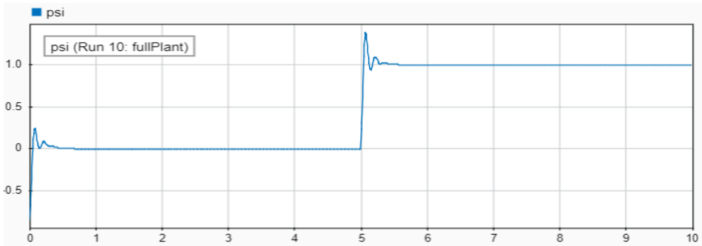


Fig 16: Response for unit change in roll attitude

The above results shown are the change in roll and yaw attitude as rudder and aileron angle changes for a step unit input. When the flight reaches the required state, it auto stabilizes to that required pitch attitude.

CONCLUSION AND FUTURE STUDY: A mathematical model is established of an aircraft in Matlab Simulink with the help of an aerospace blockset. Aerodynamic coefficients are taken from aerodynamics analysis tools while some of the initial parameters are assumed while developing the model. This model is then verified by running simulation and tuning the controller to get the best result out of it. Further study can be made by simulating with HIL (hardware in the loop). This simulation includes the electrical emulation of sensors and actuators.

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