

Visualizing the Flight Test Data and its Simulation

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Abstract - To build a 3D virtual model of an aircraft by modelling in the MATLAB Simulink. The Simulink model consists of the circuit model of aircraft containing its design parameters nested in the model containing input for control deflections and atmospheric variables. Mean Sea Level Conditions used here, with the assumption of aircraft flying near sea level. The first aim was to generate the graphs of changes in translational velocities, rotational velocities and Euler angles with respect to time, corresponding to a cruising aircraft with specified deflection of a single control surface for an interval of 5 seconds after which the control surface was brought back to original configuration. The results of the graphs were compared with the results of an ideal case obtained from solving the equation of motion of an aircraft. The database of information regarding the changing parameters acts as a feed to the circuitry containing the virtual model. 'Aeroblk_HL20' was the virtual aircraft used for animation. The values of aircraft orientation parameters after computation goes to 'Aeroblk_HL20' which changes its attitude and position accordingly. The position of the aircraft has been tracked using non-inertial North-East-Down system in which the origin was fixed at the Centre of Gravity of aircraft and its axes were oriented along the geodetic directions as defined by the earth surface. The behaviour of aircraft in animation was in accordance with the ideal values obtained from graphs for the given condition. This verification thus proves the efficiency of the virtual tool built. This tool bridges the gap between the myriad of aircraft orientation data and the simulation of an aircraft in flight.

Key Words: MATLAB, Simulation, Orientation of aircraft, Control system, Virtual model

1. INTRODUCTION

On December 17, 1903, Wright brothers invented aircraft controls making fixed-wing powered flight possible. Their fundamental breakthrough was the invention of three-axis control, enabling the pilot to control the aircraft and maintain its equilibrium. With the advancement and development in aircraft sector it becomes mandatory for control engineers to investigate the stability of the aircraft. Aircraft and missiles are usually equipped with a control system to provide stability, disturbances rejection and reference signal tracking. The motion of an aircraft in free flight is extremely complicated. The control theory for the

same has two approaches [1]. The first approach is based on frequency response methods, the root locus technique, transfer functions, and Laplace transforms. This approach to control theory is sometimes called classical or conventional control theory. A major feature of these analysis methods is their adaptability to simple graphical procedures. With the advent of high-speed digital computers, control system analysis methods are developed based on the state-space formulation of the system. These analysis techniques, developed since the 1960s, are commonly called modern control theory [2]. With the state-space formulation and usage of graphic tools, it becomes easier to simulate an aircraft in flight and also to keep a check on the control parameters of the aircraft. Such abilities are crucial in the design and working of automatic flight controller and working of autopilot. Sperry brothers are the designers of the first automatic flight controller. This invention changed the whole aircraft manufacturing sector and also boost the invention of other technologies like, aerodynamics, structures, materials, population and flight control [3]. As per the objective of this paper, a simple simulation tool is designed as the base for converting numeric data into virtual model. This basic tool, upon further modification can be helpful in understanding and designing of Flight Control Systems. Ambitious aircraft programs and tough competition between manufacturers helps strive towards Flight Control System (FCSs), to provide improved and efficient performance [4]. Generally, aircraft contains three translation motions (vertical, horizontal and transverse) and three rotational motions (pitch, yaw and roll) by controlling aileron, rudder and elevator. To reduce the complexity of analysis, the aircraft is usually assumed as a rigid body and aircraft's motion consist of a small deviation from its equilibrium flight condition [5]

1.1 Aircraft Orientations

An aircraft in flight is free to rotate about the three axes, namely, vertical, lateral and longitudinal. The moments about these axes are called yaw, pitch and roll respectively. These axes move with vehicle and rotate relative to the earth along with the aircraft. The yaw axis passes through C.G. of aircraft and is perpendicular to the wings and fuselage reference line. It is directed towards the bottom of the aircraft. A positive yawing motion moves the nose of the aircraft to the right. The pitch axis or transverse or lateral axis passes through

C.G. of aircraft and is directed to the right, parallel to a line drawn from wingtip to wingtip. A positive pitching motion raises the nose of the aircraft and lowers the tail. The roll axis or longitudinal axis passes through C.G. and is directed forward, parallel to the fuselage reference line. An angular displacement about this axis is called bank. A positive rolling motion lifts the left wing and lowers the right wing. These moments about principle axes are generated by the deflection of three primary control surfaces, which vary the pressure distribution over the surface, thus varying the net force about aircraft's C.G.

1.2 Forces and Coefficients

The principle forces acting on an aircraft in flight are Lift force, Drag force and the moments due to the same. Lift can be defined as the normal component of the resultant force that is responsible for flying of the aircraft. The drag force is the horizontal component of the resultant force, opposite to the direction of motion, that provides resistance to the motion of aircraft in air. The lift and drag forces act through the aerodynamic centre of the aircraft. The engine forces provide forward thrust to the aircraft. These forces generate moments about C.G., whose magnitude is dictated by the magnitude of the respective forces and their distance from the C.G.

Lift force coefficient

$$C_L = \frac{L}{qS}$$

; L = lift force

q = dynamic pressure

S = Surface area

Drag force coefficient

$$C_D = C_{D,0} + \frac{C_L^2}{\pi e AR}$$

; $C_{D,0}$ = zero lift drag coefficient

e = Oswald's efficiency factor

AR = Aspect Ratio

Moment coefficient

$$C_m = \frac{M}{qSc}$$

; M = moment force

q = dynamic pressure

S = Surface area

c = chord of the wing

2. MATLABCODE FORMULATION

MATLAB is a programming and numeric computing environment used by millions of engineers and scientists to analyse data, develop algorithms, and create models. MATLAB provides professionally developed toolboxes for signal and image processing, control systems, wireless communications, computational finance, robotics, deep learning and AI and more. MATLAB combines a desktop environment tuned for iterative analysis and design processes with a high-level programming language that expresses matrix and array mathematics directly. The aircraft model used under this project is a 6-DOF RCAM (Research Civil Aviation Model) [1]. The aim is to model the state vectors and control vectors of this aircraft as well as the change in them in the form of state derivatives. There are 12 state vectors and 5 control vectors. The state vectors consist of 3 translational velocities, 3 rotational velocities, 3 Euler angles and 3 directions (i.e., position North, position East, position Down). The control vectors are deflections in Aileron, Elevator, Rudder, throttle-1 and throttle-2. The maximum deflections of control surfaces and throttle is set which also limits the values of control vectors. The maximum and minimum deflection for aileron is +25 and -25, for elevator it is +10 and -25, for rudder it is +30 and -30, for both throttles it is 0.5 and 10 respectively.

3. SIMULINK MODEL

A multi-domain modelling and simulation environment for engineers and scientists who design controls, wireless, and other dynamic systems. With Simulink, you can design and simulate systems before moving to hardware, and you can explore and implement new designs without having to write C, C++, or HDL code. Simulink is the platform for Model-Based Design that supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems.

Key capabilities include:

- A graphical editor for modelling all components of a system.
- A library of prebuilt blocks for modelling algorithms and physical systems.
- Large-scale modelling blocks for creating reusable system components and libraries.
- A simulation engine with ODE solvers for verifying that all parts of system work together.

- Visualization tools for analysing and comparing results from multiple simulations.

The complete Simulink model used is as below in Fig -1 and Fig -2:

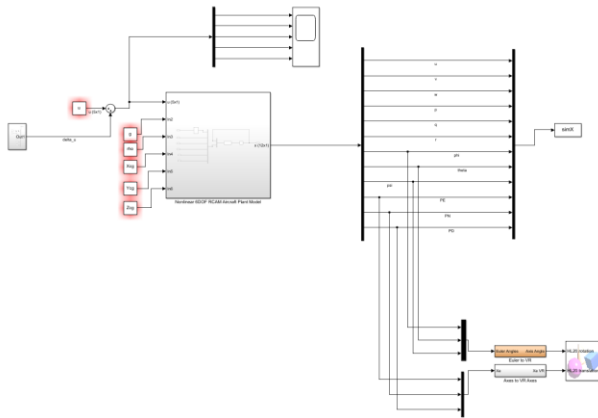


Fig -1: Complete simulation model

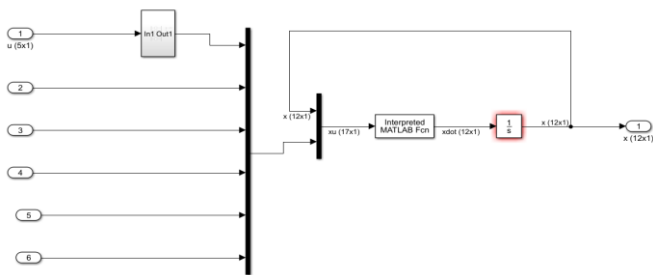


Fig -2: Nonlinear 6-Degree of Freedom RCAM Aircraft Plant Model Block

Rotation of parameters in body frame to aircraft carried North, East and Down frame by suitable Euler angles help in determining position of aircraft w.r.t earth. Aircrafts use a coordinate system of axes which has its origin as the Centre of Gravity of the aircraft. Two slightly different alignments of these axes are used depending on the situation: "body fixed axes" and "stability axes". Body fixed axes defined and fixed relative to the body of the vehicle as follows:

- X-body axis is along the vehicle body and is positive towards the normal direction of motion.
- Y-body axis is at right angle to X-body axis and is oriented along the wing. The Y-axis is usually positive to the right side of vehicle.
- Z-body axis is perpendicular to wing-body (XY) plane and usually points downwards.

Aircraft operates at constant "trim" Angle of Attack. The angle of the nose (the X Axis) does not align with the

direction of the oncoming air. The difference in these directions is the Angle of Attack. So, parameters are defined in terms of a slightly modified axis system called "stability axes". The stability axis system is used to get the X axis aligned with the oncoming flow direction. Essentially, the body axis system is rotated about the Y body axis by the trim Angle of Attack and then "re-fixed" to the body of the aircraft. Engine forces for both the engines calculated initially using the Newton's Second law according to the throttle setting and then it defined in the body axis system.

The final input into the MATLAB created function involves calculation of the translational, rotational velocities and the Euler angles. The first 9 state vectors calculated as follows:

$$\begin{bmatrix} x'_1 \\ x'_2 \\ x'_3 \end{bmatrix} = \begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix} = \left(\frac{1}{m} \right) \times \overline{F_b} - \overline{\omega_{b/e}} \times \overline{V_b}$$

; where F_b is the summation of gravity force, engine forces and aerodynamic forces.

$$\begin{bmatrix} x'_4 \\ x'_5 \\ x'_6 \end{bmatrix} = \begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = I_b^{-1} \times (\overline{M_{CG}} - \overline{\omega_{b/e}} \times I_b \overline{\omega_{b/e}})$$

; where M_{CG} is the summation of moment about CG due to engine and aerodynamic moments about CG. I_b is the inertia matrix.

$$\begin{bmatrix} x'_7 \\ x'_8 \\ x'_9 \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & S\phi t\theta & c\phi t\theta \\ 0 & c\phi & -S\phi \\ 0 & S\phi / c\theta & c\phi / c\theta \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix}^b$$

4. Result

The aircraft flying at a speed of 85 m/s with all control surface deflections at zero. The throttles set at minimum condition required for flying for RCAM model. The initial position of aircraft according to [PN, PE, PD] is kept at [-12000, -1000, -4000]. The '.m' file is run for a time period of 60 seconds and the results are generated as shown in Fig -3. The aircraft flying at a speed of 85 m/s. The deflection for rudder and elevator is kept at zero while the ailerons deflected at time t=30 seconds for about 2 seconds by an angle of 5 degrees and then brought back to normal. The throttles set at minimum condition required for flying for RCAM model. The initial position of aircraft according to [PN, PE, PD] is kept at [-12000, -1000, -4000]

The '.m' file is run for a time period of 60 seconds and the results are generated as shown in Fig -4.

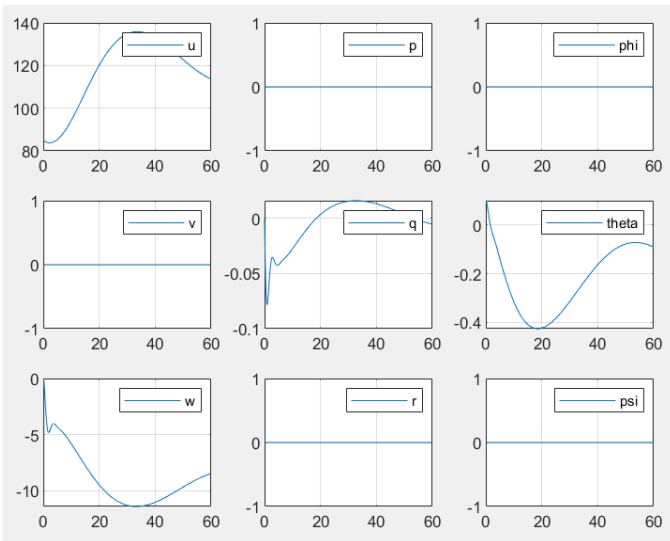


Fig -3 State vector Vs Time (Test-1)

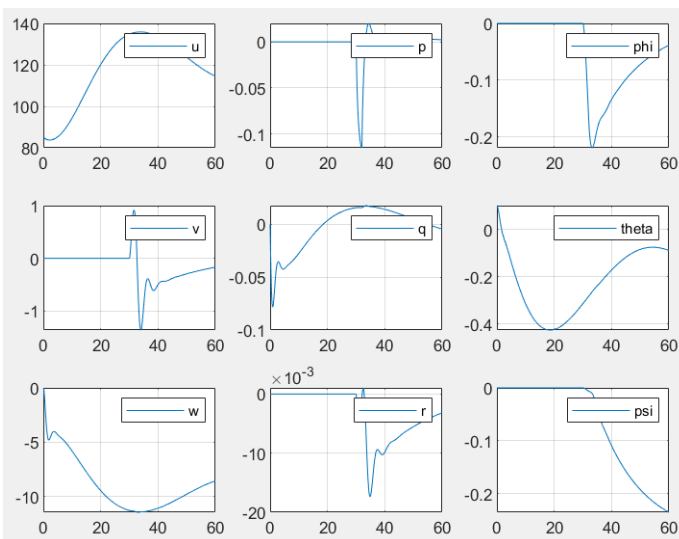


Fig -4 State vector Vs Time (Test-2)

The virtual model of aircraft with position and direction indicated in bottom right corner as shown in Fig -4. This model was taken from the inbuilt model of "aeroblk_HL20" present in the MATLAB environment. Aerodynamic force coefficient matrix formed which consists of 3 elements namely, roll coefficient, pitch coefficient and yaw coefficient. Moment and forces considered along body axis and about the aerodynamic centre of aircraft. The aerodynamic forces are calculated from the respective force coefficients. These forces are primarily in stability axis system. They are converted into the body axis system by rotating them by specific angles. Aircraft operates at a constant "trim" Angle of Attack. The angle of the nose (the X Axis) does not align with the direction of the oncoming air. The difference in these directions is the Angle of Attack. So, parameters are defined

in terms of a slightly modified axis system called "stability axes".



Fig -4 Virtual model of aircraft

5. CONCLUSIONS

The results from graphical representation of various coordinates and angles from the scope used in the block diagram of Simulink. Deflecting the aileron control and got the graphical representation for different variables. Upon deflecting the aileron by 5 degrees, there is a peak observed in the graph indicating rotation about x axis i.e., the value of 'p'. After deflecting it the dip observed. This shows that the aircraft has undergone rolling which is shown by changes in the graphs of 'p' and 'phi'. The graphs obtained from the virtual model in the MATLAB Simulink are in accordance with the actual results obtained from the aircraft flying with ideal condition. This proves the efficiency of the model developed. This model helps in better understanding of control & navigation of aircrafts and missiles by the usage of 3-dimensional model view. It acts as a bridge between the theoretical understanding and the practical application. Even though this model is based upon the ideal conditions of atmosphere, modelled for sea level conditions, it can be further modified to simulate the real-life problem with the data available from Flight Data Recorder and by usage of atmospheric modelling.

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