Simulation of 6-DOF

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Abstract

6-DOF (Degrees of Freedom) is intended for simulation of Aerospace Vehicle dynamics and kinematics for testing and validating of Guidance, Navigation and Control. It is used to simulate all the three Translational and Rotational axes of the vehicle (The system is interfaced with MIU, INS and OBC).This system is useful for verification and validation of On-Board Computer Software. In aerospace vehicle, simulation S/W is the complete Model of the Plant and Algorithm (Navigation, Guidance, Control and Mission Sequence).This Model gives body rates and accelerations by 6DOF equations. Its inputs are thrust and control deflections. Forces and Moments are generated using Aerodynamic Force Coefficients and Moment Coefficients given by Aerodynamic Division.

Keywords- *6 degrees of freedom, Reaction control system, Fuel nozzle controller.*

I. INTRODUCTION

6 degrees of freedom has three rotations and three translations. Since a vehicle both translates and rotates through the air, two coordinate systems keep track of the vehicle. The first is known as fixed reference system referred to as a local level coordinate system. The local-level system is a standard, right-hand, three-axis coordinate system with the x-y plane representing the horizontal ground plane; the z-axis is positive down. This is a fixed system that does not translate or rotate.

The second coordinate system is fixed to the body of the vehicle, referred to as the body-fixed coordinate system. The x-axis is positive out of the nose of the vehicle; the y-axis is positive out the right hand side looking forward and the z-axis is positive looking down. The origin of the body- fixed coordinate system is located at the center of gravity of the vehicle. Its position is known with respect to the origin of the local body coordinate system. The altitude of the vehicle is obtained relative to the local-level coordinate system orientation through three rotations known as Euler angles. Direction cosines (or quaternion's) keep track of the Euler angles (or attitude) of the vehicle (the attitude of the body-fixed coordinate system) relative to the local level coordinate system.

II. RELATED WORK

The main factors taken into account of simulation are Body Rates (angular rates), Accelerations and Quaternion's.

The non real time simulation for aerospace vehicle consists of model and algorithm. Model consists of 6 DOF equations, actuator model and flexibility model. Algorithm consists of navigation, guidance and control routines. The simulation gives whether aerospace vehicle (6Dof) will follow the desired trajectory (from algorithm).Parameters like body rates, accelerations, control deflections and control rates are observed and analyzed. Navigation system gives aerospace vehicle position, Altitude is taken from the incremental angles and velocities are generated from rates and accelerations. Guidance compares these positions and velocities with desired trajectory positions and velocities, and generates the required lateral accelerations in Y and Z-axes of body frame. The controller takes Guidance output i.e. lateral accelerations as its input and generates the required actuator deflections to steer the aerospace vehicle in the required path.

III. GENERAL IDEA

Stage1 (S1) is the initial stage or the boost phase in the aerospace vehicle. In Stage1 FNC and RCS controllers are used. The algorithms for both the controllers will be different. This stage is the launch of the aerospace vehicle. Aerospace vehicles move relatively slowly through the lower atmosphere to minimize air resistance, and gather speed as they rise into thinner air and then into space. As the aerospace vehicle leaves the lower atmosphere, it tips in the direction of the target and gains speed. If the vehicle is being launched to maximum range, it will tip at an angle of 45 degrees, half of its energy going to gain height (and therefore time aloft), the other to gain distance. If the aerospace vehicle has stages, the lower ones will drop off after they have burned their fuel, and lighten the load. At a designated point in space, the last engines shutoff or burns out. The time between launch and engine burn out ranges from less than one minute to over five. Engine burn out ends up the Boost phase.

Stage2 (s2) is the second stage in the aerospace vehicle. In the stage2 also FNC and RCS controllers are used. In this stage ignition of the propulsion or fuel starts.

Payload stage is the final stage in the aerospace vehicles. The terminal Phase begins as the first air molecules begin to slow down and then to heat and to burn up the thin decoys and the remains of the aerospace vehicle. The air slows and heats the warheads too. The range of the aerospace vehicle determines the angle at which warheads fall onto the target. Warheads from the longest range aerospace vehicles arrive at shallow angles of little more than twenty degrees, while shorter range ones can come in at 45 degrees.

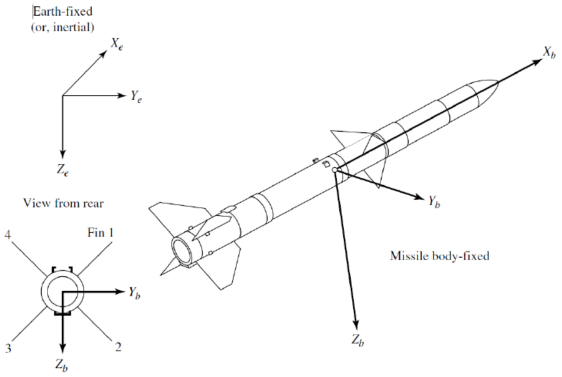


Fig.1. Orientation of the aerospace vehicle axes with respect to the Earth-fixed axes.

Translation and rotation of a rigid body may be expressed mathematically by the following equations:
Translation: $\Sigma (Z) = ma$
Rotation: $\Sigma \tau = d/dt\,(r\,mV)$

IV. PROPOSED SYSTEM

In aerospace vehicles, two other common coordinate systems are used. These coordinate systems are

A. *Launch Centered Inertial*:

This system is inertial fixed and is centered at launch site at the instant of launch. In this system, the x-axis is commonly taken to be in the horizontal plane and in the direction of launch, the positive z-axis vertical, and the y-axis completing the right-handed coordinate system.

B. *Launch Centered Earth-Fixed*:

This is an Earth-fixed coordinate system, having the same orientation as the inertial coordinate system (1). This system is advantageous in gimbaled inertial platforms in that it is not necessary to remove the Earth rate torque signal from the gyroscopes at launch.

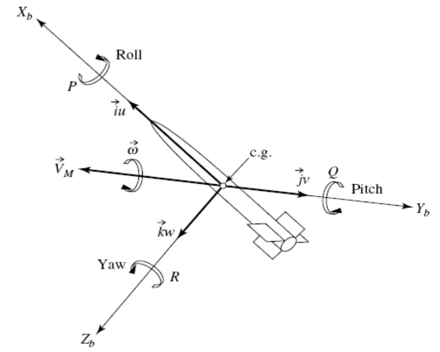
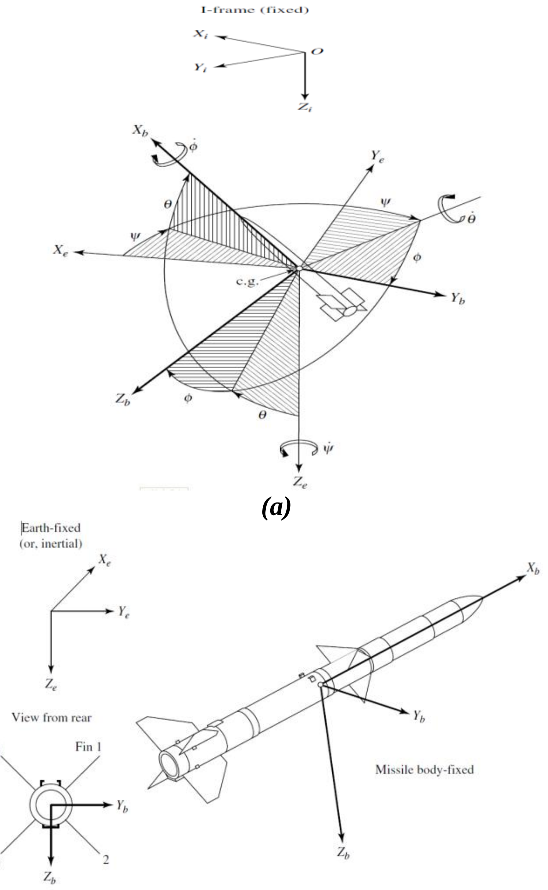


Fig 2. Representation of Missile's Six Degree of Freedom



(a)

(b)

Fig.3. Orientation of the missile axes with respect to the Earth-fixed axes.

C. *Design*:

The inputs to the 6-DoF simulation are Thrust, Atmosphere, Aerodynamic, wind, force etc. The outputs of the simulation are Accelerations and Body Rates. These outputs Accelerations and Body Rates are given as inputs to the navigation part.

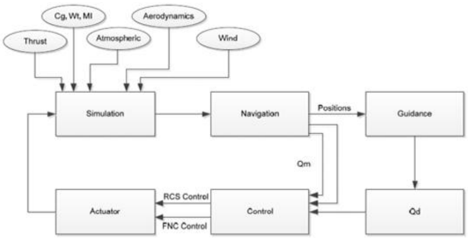


Fig. 4.Six DOF Block Diagram

D. *Overview*:

The modules associated with 6DoFmodeling are:

- Perturbation Module
- Environmental Module (Atmospheric Module)
- Aerodynamics Module
- Wind Module
- Thrust Module
    - Thrust mass module
    - Thrust-xyz Module
- MI & CG Module
- Force Module
- Moment Module

1) Perturbation Model: The core element of the model is a nonlinear representation of the rigid body dynamics of the airframe.

2) ISA Atmosphere Model block:

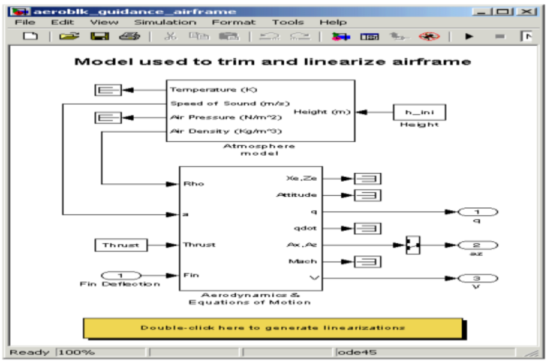


Fig.5.ISA Atmosphere Model

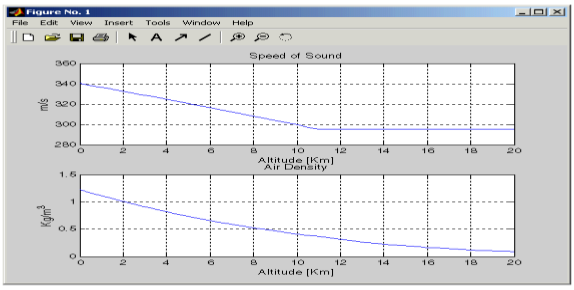


Fig.5. Variation of speed of sound and air density with respect to altitude

3) Aerodynamic module: Aerodynamics & Equations of Motion Subsystem: The Aerodynamics & Equations of Motion subsystem generates the forces and moments applied to the aerospace vehicle in the body axes and integrates the equations of motion that define the linear and angular motion of the airframe block.

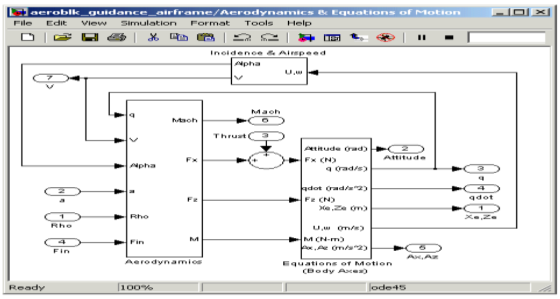


Fig.6.Aerodynamic Model

4) Wind Model: In simulations, tables represent winds as a function of altitude, direction, and magnitude. In six-DOF simulation winds alter the incidence angles and thus change the aerodynamic forces and moments.

Fig.6. Input and Output Model for Wind

Input:

H_t - Altitude (km)

Outputs:

Wind EW - Wind East/West

Wind NS - Wind North/South

Wind VE - Wind Vertical East

5). Thrust Model:

a) Thrust Mass:

This unit takes ambient pressure and location of Centre of gravity in body frame as input, and computes propulsive Forces in body frame.

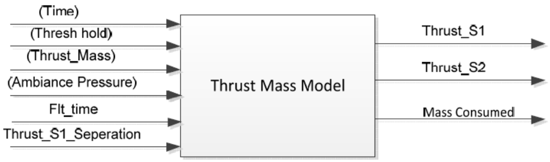


Fig.7. Input and Output Model for Thrust Model

Inputs:

t - Time

Thrust-Phase-Mass - Thrust Phase S1, S2

Thr - Thresh hold

Ambience Pressure - Ambience Pressure

Flt-time - Flight Time

T_S1_Sep - Thrust Stage1 Separation

Outputs:
Thrust_S1 - Thrust Stage1
Thrust_S2 - Thrust Stage2
Wt - Mass Consumed

b) Thrust XYZ: Thrust-XYZ unit takes the input of stage1 and stage2 of thrust and actuator input commands and gives the Thrust-X, Thrust-Y, Thrust-Z outputs.

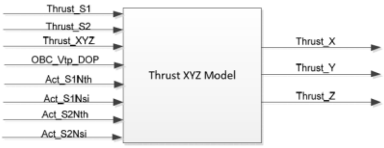


Fig.8. Input and Output Model for Thrust XYZ

Inputs:

Thrust_S1 - Thrust Stage1
Thrust_S2 - Thrust Stage2

Outputs :
Thrust-X - Thrust X
Thrust-Y - Thrust Y
Thrust-Z - Thrust Z

6) MI&CG Model:

This unit computes the aerospace vehicle mass, location of Centre of gravity along each body axes (X_{cg}, Y_{cg}, Z_{cg}) and moments of inertia about each body axes (I_{xx}, I_{yy}, I_{zz}). The parameters are computed by using one
Dimensional linear interpolation, from the stored data tables as a function of time

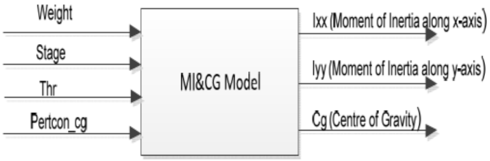


Fig.9. Input and Output Model for MI and CG

Inputs:

W_t	- Weight
Stage	- S1, S2, PL
Thr	- Thresh hold
Preston-cg	- Perturbation constant of Centre of gravity

Outputs

I_{xx}	-Moment of Inertia along x-axis
I_{yy}	-Moment of Inertia along Y-axis
I_{zz}	-Moment of Inertia along Z-axis
C_g	-Centre of Gravity

7) FORCE MODULE:

The aerodynamic forces depend on external shape and size (represented by length l), atmospheric density ρ, and pressure p, the linear velocity of the airframe.

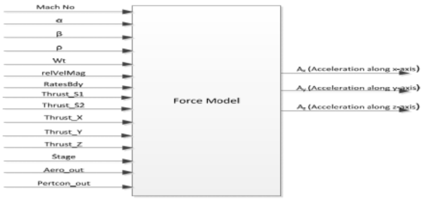


Fig.10. Input and Output Model for Force

Inputs:
M - Mach No.
α - Angle of Attack
β - Side Slip Angle
ρ - Density
Wt - Weight
Rel.Vel.Mag - Relative Velocity Magnitude
Outputs
A_x-Acceleration along x-axis
A_y- Acceleration along y-axis
A_z- Acceleration along z-axis

VIII. Moment Model:

This model takes the output of all the models (e.g. Mass, MI-CG, Thrust, aerodynamic co-efficient) and computes the incremental angles and incremental velocities**.**

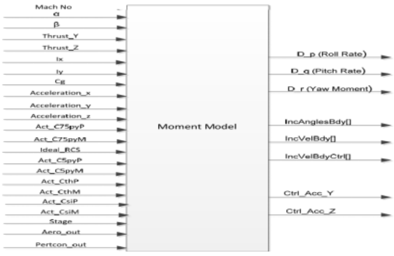


Fig.10. Input and Output Model for Moment

Inputs:
M - Mach No.
α - Angle of Attack
β - Side Slip Angle
Thrust-Y
Thrust-Z
Cg - Centre of gravity
Outputs:
Dp - Body axes roll rate
Dq - Body axes Pitch rate
Dr - Body axes Yaw rate

V. SIMULATION RESULTS

The outputs for the six-DOF Simulation are the accelerations and the Body Rates.

Acc-X:

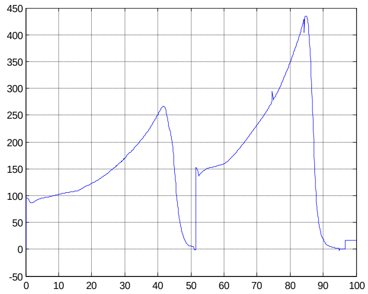


Fig.11. Output Graph for the Acceleration in X-direction

Acc-Y:

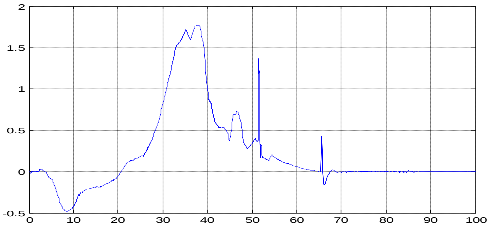


Fig.12. Output Graph for the Acceleration in Y-direction

Acc-Z:

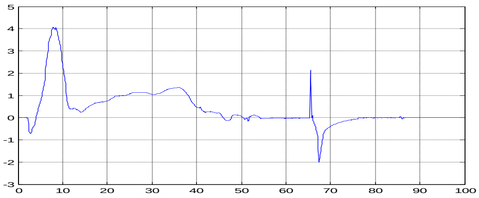


Fig.13.Output Graph for the Acceleration in Z-direction

The Body Rates are

Rate-X:

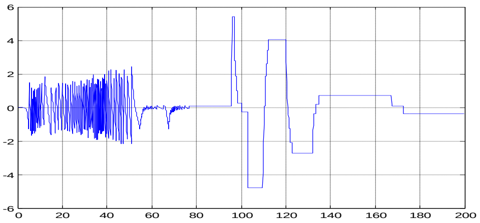


Fig.14. Output Graph for the Body Rate in X-direction

Rate-Y:

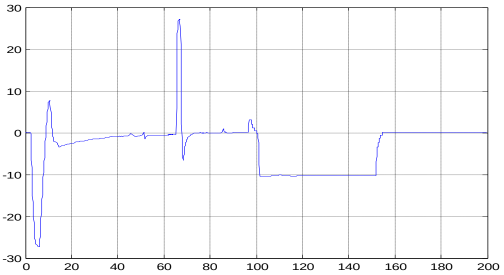


Fig.15.Output Graph for the Body Rate in Y-direction

Rate-Z:

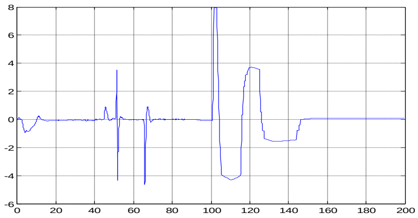


Fig.16. Output Graph for the Body Rate in Z-direction

VI. CONCLUSION

Simulation and modelling are essential to estimate the performance of any aerospace vehicle. It reduces the number of flight trails which are very costly (leading to financial involvement) .Here we implemented the 6dof simulation for the aerospace vehicle and we used 6dof as it validates all the necessary information required for the simulation.

REFERENCES

[1] Zarchan, Paul, Tactical and Strategic Aerospace vehicle Guidance, 3rd Edition, Volume 176, American Institute of Aeronautics and Astronautics, 1997.

[2] Nesline, F.W. and Nesline, M.L., "How Autopilot Requirements Constrain the Aerodynamic Design of Homing Aerospace vehicles," Conference Volume of 1984 American Control Conference, San Diego, CA, June 6-8, 1984.

[3] Stallard, D.V., "An Approach to Autopilot Design for Homing Interceptor Aerospace vehicles," AIAA- 91-2612-CP, AIAA Guidance and Control Conference, 1991.

[4] Washington, W. D., “Aerospace vehicle Aerodynamic Design Program,” 1980, 1990.

[5] Ashley, H., and Landahl, M., Aerodynamics of Wings and Bodies, Dover Publications Inc., NewYork, New York, 1965.

[6] Etkin, Bernard. Dynamics of Atmospheric Flight, John Wiley and Sons, 1972.

[7] Felio, D.A. and Duggan D.S. (1999). Autonomous Vehicle Guidance, Control andSimulation.14-18 June 1999 short course notes. The University of Kansas. 532 p.

[8] Aerospace vehicle Simulation Computer Program for AIM-7F, Volume III Analyst Manual(U), Joint Technical Coordination Group for Munitions Effectiveness, 61JTCG/ME-75-15-3, March 1979, CONFIDENTIAL.

[9] Etkin, Bernard (1967). Dynamics of flight, Stability and Control. 6th edition . JohnWiley & Sons, Inc., New-York. 519 p.

[10] Lestage, R., Lauzon, M., and Jeffrey, A. (2002). Automatic Tuning of Gain- ScheduledAutopilot for Computer Simulations. TR 2001-230. Defense R&D Canada-Valcartier, Canada. 47 p.