SARDAR VALLABHBHAI PATEL INSTITUTE OF TECHNOLOGY

AERONAUTICAL DEPARTMENT

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SUMMER INTERNSHIP (3170001)
MINI-PROJECT

“BEAVER FLIGHT SIMULATOR”

SUBMITTED TO:
AERONAUTICAL DEPARTMENT (SVIT-VASAD)

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1. ABSTRACT

This project will simulate the aircraft in real time with given conditions and we can see the aircrafts motion and reacts as we change the control of aircraft via slider or joystick.
Flight simulators are currently used to train prospective pilots who will fly aircrafts and will also help to study students of aeronautical and aerospace students. However, the flight
Simulator usually need more space, more budgets, and another things so that the simulator can be operated as similar as possible to a real aircraft and can gain real experience.it can happen in low budget and can simulate in any given laptop with correct software. These can happen with the help of software Matlab & Simulink which then integrate with Flight gear. In the given below document, all information of these project is given.

2. INTRODUCTION

In this project, the process of creating the simulator with the above-mentioned software for the 'beaver dhc2' aircraft. A flexible environment for the analysis of aircraft dynamics and control will be developed. This environment uses the power and flexibility of the simulation and system analysis programs SIMULINK and MATLAB.

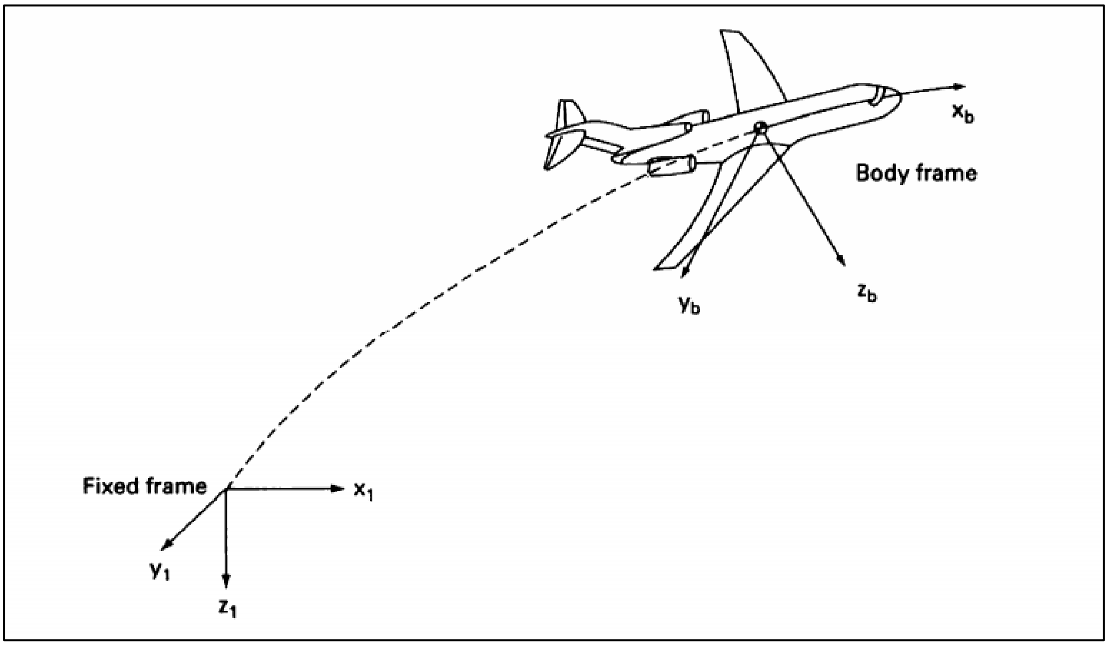
The proper understanding about all the equations of the aircraft on which the aircraft flies and these simulation can be repeated with other aircrafts also. You need to change the coefficients and trim steady level flight conditions.

An understanding of the dynamic characteristics of an airplane is important in accessing its handling or flying qualities as well as for designing autopilots. An airplane can be considered to be dynamically stable if after being disturbed from its equilibrium flight condition the ensuing motion diminishes with time. The stability can be understand by the simulating the aircraft by applying proper damping to the aircraft.

Next section will give a problem definition and discuss the aircraft equations of motion and the approach taken to solve these equations. 4^{th} section will obtain results and solution of the equations to obtain the aircraft states. Section 5 & 6 will discuss the graphical simulator designed using SIMULINK and FlightGear.

3. DEFINING EQUATIONS

The detailed explanation of the given equations and theory can be seen in references books given at last. I have tried to shorten and clarify as much as possible. So, before developing the equations of motion, we need to define our system of axes, Figure 1 shows the two sets of coordinate systems used, the body axis system attached to the aircraft and the inertial axis system that is fixed to the Earth.



The rigid body motion equations (force and moments) to describe the motion of the aircraft, obtained from newton's second law:

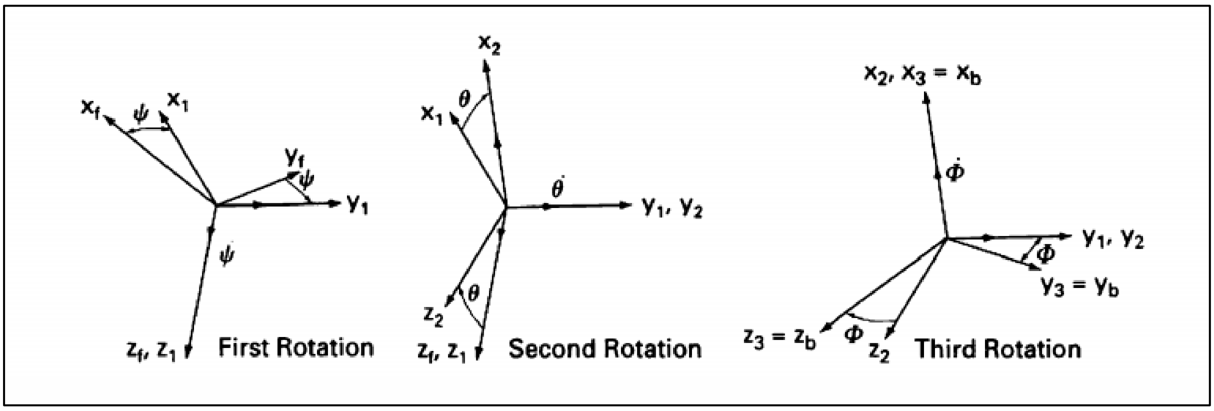
$\Sigma F = d/dt\ (mV)$

$\Sigma M = d/dt\ (H)$

These are vector equations, where Fx, Fy, Fz, and u, v, w are the components of the force and velocity along the x, y, and z axes, respectively. The force components are composed of contributions due to the aerodynamic, propulsive, and gravitational forces acting on the airplane.

While, L, M, N and Hx, Hy, Hz, are the components of the moment and moment of momentum along the x, y, and z axes, respectively.

The orientation and position of the airplane can be defined in terms of a fixed frame of reference as shown in Figure 2, The orientation of the airplane can be described by three consecutive rotations, whose order is important. The angular rotations are called the Euler angles.



Here we know the position and orientation, but in respect to equations can be found out in detail in the reference books and pdf given at last of the document.

All 12 equations are given below in form of images are as follow:

$$F_x - mg\sin(\theta) = m(\dot{u} + qw - rv)$$
$$F_y + mg\cos(\theta)\sin(\phi) = m(\dot{v} + ru - pw)$$
$$F_z + mg\cos(\theta)\cos(\phi) = m(\dot{w} + pv - qu)$$

$$L = I_x\dot{p}_i - I_{xz}\dot{r} + qr(I_z - I_y) - I_{xz}pq$$
$$M = I_y\dot{q} + qr(I_x - I_z) + I_{xz}(p^2 - r^2)$$
$$N = I_{xz}\dot{p}_i + I_z\dot{r} + qp(I_y - I_z) - I_{xz}rq$$

$$\begin{bmatrix} \frac{dx}{dt} \\ \frac{dy}{dt} \\ \frac{dz}{dt} \end{bmatrix} = \begin{bmatrix} C_\theta C_\psi & S_\Phi S_\theta C_\psi - C_\Phi S_\psi & C_\Phi S_\theta C_\psi + S_\Phi S_\psi \\ C_\theta S_\psi & S_\Phi S_\theta S_\psi + C_\Phi C_\psi & C_\Phi S_\theta S_\psi - S_\Phi C_\psi \\ -S_\theta & S_\theta C_\theta & C_\Phi C_\theta \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

$$\begin{bmatrix} \dot{\Phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & S_\Phi \tan\theta & C_\Phi \tan\theta \\ 0 & C_\Phi & -S_\Phi \\ 0 & S_\Phi \sec\theta & C_\Phi \sec\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

These are 12 non-linear ordinary differential equations in twelve variables, which represent the state vector of the aircraft $[p,q,r,u,v,w,\varphi,\theta,\psi,x,y,z]$.

These 12 vectors give the specific location and orientation of aircraft.

p- Angular rate of roll
q- Angular rate of pitch
r- Angular rate of yaw
u- Velocity along X-axis
v- Velocity along Y-axis
w-Velocity along Z-axis
φ- Roll angle
θ- Pitch angle
ψ- Yaw angle
x- X-coordinate of aircraft
y- Y-coordinate of aircraft
z- Z-coordinate of aircraft

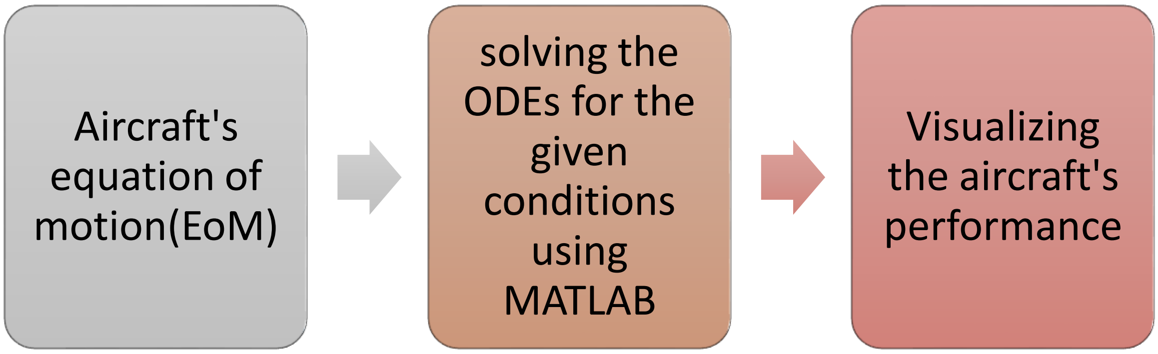
For any aircraft at given altitude there are trimming conditions for the stable flight which depends on the coefficients and obtained by various experiments and deep analytics of aircraft. For the beaver aircraft state vector at the trimming point is given in the following table: (velocity are in m/s and angles are in radians)

State	Value	State	Value
V	35	x	0
Alpha	0.211	y	0
Beta	-0.026	z	0
p	0	δe	-0.093
q	0	δa	0.009624
r	0	δr	-0.0495
ϕ	0.191	δf	0
θ	0	n	1800
ψ	0	pz	20

There are 12 equations which we have to solve and then the output answers we need to give as an input in flight gear to simulate the aircraft. So to solve these equation we will use inbuilt command for ode equations (ode45 solver).

These function uses range-kutta method to solve the equation in 4 to 5 orders at given interval of time. These function is called ode45 function which is for nonstiff problem type and medium order of accuracy. About these function you can find it more on these given link: https://in.mathworks.com/help/matlab/ref/ode45.html

Our MATLAB code presented in this report, will implement the most critical parts of the Beaver aircraft model, which are the aerodynamic model, engine model, atmosphere and air data model.by the given ode45 function we obtain the aircraft states and their deviation from the trimmed point during an interval of time. The following flow chart describes the sequence of the project.


Aircraft's equation of motion(EoM)
solving the ODEs for the given conditions using MATLAB
Visualizing the aircraft's performance

4. CALCULATIONS

In order to solve the twelve ordinary differential equations using the Rung-Kutta method in MATLAB by the “ode45” function, it is required that the time rate of each variable be explicit ly defined, which means that we need to decouple any coupled equations to get each variable’s time rate defined in terms of the other variables. To do this, we used the MALTAB Symbolic Toolbox and solved the coupled $L\ and\ N$ moment equations for $p\ and\ r$ and we obtained the following decoupled equations.

$$\dot{p} = \frac{I_z L + I_{xz} N + I_{xz}^2 qr - I_z^2 qr - I_{xz} I_y pq + 2 I_{xz} I_z pq + I_y I_z qr}{I_{xz}^2 + I_x I_z}$$

$$\dot{r} = -\frac{I_{xz} L - I_x N + I_{xz}^2 pq + I_x I_y pq - I_x I_z pq - I_x I_{xz} qr + I_{xz} I_y qr - I_{xz} I_z qr}{I_{xz}^2 + I_x I_z}$$

So for solving all the 12 equations we need aircraft’s data which is very important as all the equations are depending on the coefficients of beaver aircraft. Thanks to the thesis pdf of beaver aircraft where all the data is given. Thesis of aircraft will be given in the references.

Manufacturer	De Havilland Aircraft of Canada Ltd.
Serial no.	1244
Type of aircraft	Single engine, high-wing, seven seat, all-metal aircraft
Wing span b	14.63 m
Wing area S	23.23 m^2
Mean aerodynamic chord $\overline{c}$	1.5875 m
Wing sweep	$0°$
Wing dihedral	$1°$
Wing profile	NACA 64 A 416
Fuselage length	9.22 m
Max. take-off weight	22800 N
Empty weight	14970 N
Engine	Pratt and Whitney Wasp Jr. R-985
Max. power	450 Hp at $n = 2300$ RPM, $p_z = 26'' Hg$
Propeller	Hamilton Standard, two-bladed metal regulator propeller
Diameter of the propeller	2.59 m
Total contents of fuel tanks	521 l
Contents fuselage front tank	131 l
Contents fuselage center tank	131 l
Contents fuselage rear tank	95 l
Contents wing tanks	2 x 82 l
Most forward admissible c.g. position	17.36% $\overline{c}$ at 16989 N; 29.92% $\overline{c}$ at 22800 N
Most backward admissible c.g. position	40.24% $\overline{c}$

$x_{c.g.}$	$=$	0.5996	$[m]$	in F_M
$y_{c.g.}$	$=$	0.0	$[m]$	in F_M
$z_{c.g.}$	$=$	-0.8851	$[m]$	in F_M
I_x	$=$	5368.39	$[kg\,m^2]$	in F_R
I_y	$=$	6928.93	$[kg\,m^2]$	in F_R
I_z	$=$	11158.75	$[kg\,m^2]$	in F_R
J_{xy}	$=$	0.0	$[kg\,m^2]$	in F_R
J_{xz}	$=$	117.64	$[kg\,m^2]$	in F_R
J_{yz}	$=$	0.0	$[kg\,m^2]$	in F_R
m	$=$	2288.231	$[kg]$	
h	$=$	1828.8	$[m]$	$(= 6000\ [ft])$
ρ	$=$	1.024	$[kg\,m^{-3}]$	

For finding the forces from 3 axes we will need coefficients from 3 axis. So formula for all the coefficients are given below:

Aerodynamic force and moment coefficients measured in the body-fixed reference frame:

$$
\begin{aligned}
C_{X_a} &= C_{X_0} + C_{X_\alpha}\alpha + C_{X_{\alpha^2}}\alpha^2 + C_{X_{\alpha^3}}\alpha^3 + C_{X_q}\frac{q\bar{c}}{V} + C_{X_{\delta_r}}\delta_r + C_{X_{\delta_f}}\delta_f + C_{X_{\alpha\delta_f}}\alpha\delta_f \\
C_{Y_a}^{*} &= C_{Y_0} + C_{Y_\beta}\beta + C_{Y_p}\frac{p\,b}{2V} + C_{Y_r}\frac{rb}{2V} + C_{Y_{\delta_a}}\delta_a + C_{Y_{\delta_r}}\delta_r + C_{Y_{\delta_r\alpha}}\delta_r\alpha \\
C_{Z_a} &= C_{Z_0} + C_{Z_\alpha}\alpha + C_{Z_{\alpha^3}}\alpha^3 + C_{Z_q}\frac{q\bar{c}}{V} + C_{Z_{\delta_e}}\delta_e + C_{Z_{\delta_e\beta^2}}\delta_e\beta^2 + C_{Z_{\delta_f}}\delta_f + C_{Z_{\alpha\delta_f}}\alpha\delta_f \\
C_{l_a} &= C_{l_0} + C_{l_\beta}\beta + C_{l_p}\frac{p\,b}{2V} + C_{l_r}\frac{rb}{2V} + C_{l_{\delta_a}}\delta_a + C_{l_{\delta_r}}\delta_r + C_{l_{\delta_a\alpha}}\delta_a\alpha \\
C_{m_a} &= C_{m_0} + C_{m_\alpha}\alpha + C_{m_{\alpha^2}}\alpha^2 + C_{m_q}\frac{q\bar{c}}{V} + C_{m_{\delta_e}}\delta_e + C_{m_{\beta^2}}\beta^2 + C_{m_r}\frac{rb}{2V} + C_{m_{\delta_f}}\delta_f \\
C_{n_a} &= C_{n_0} + C_{n_\beta}\beta + C_{n_p}\frac{p\,b}{2V} + C_{n_r}\frac{rb}{2V} + C_{n_{\delta_a}}\delta_a + C_{n_{\delta_r}}\delta_r + C_{n_q}\frac{q\bar{c}}{V} + C_{n_{\beta^3}}\beta^3
\end{aligned}
$$

C_X		C_Y		C_Z	
parameter	value	parameter	value	parameter	value
0	-0.03554	0	-0.002226	0	-0.05504
α	0.002920	β	-0.7678	α	-5.578
α^2	5.459	$\frac{pb}{2V}$	-0.1240	α^3	3.442
α^3	-5.162	$\frac{rb}{2V}$	0.3666	$\frac{q\bar{c}}{V}$	-2.988
$\frac{q\bar{c}}{V}$	-0.6748	δ_a	-0.02956	δ_e	-0.3980
δ_r	0.03412	δ_r	0.1158	$\delta_e\beta^2$	-15.93
δ_f	-0.09447	$\delta_r\alpha$	0.5238	δ_f	-1.377
$\alpha\delta_f$	1.106	$\frac{\dot{\beta}b}{2V}$	-0.1600	$\alpha\delta_f$	-1.261

C_l		C_m		C_n	
parameter	value	parameter	value	parameter	value
0	0.0005910	0	0.09448	0	-0.003117
β	-0.06180	α	-0.6028	β	0.006719
$\frac{pb}{2V}$	-0.5045	α^2	-2.140	$\frac{pb}{2V}$	-0.1585
$\frac{rb}{2V}$	0.1695	$\frac{q\bar{c}}{V}$	-15.56	$\frac{rb}{2V}$	-0.1112
δ_a	-0.09917	δ_e	-1.921	δ_a	-0.003872
δ_r	0.006934	β^2	0.6921	δ_r	-0.08265
$\delta_a\alpha$	-0.08269	$\frac{rb}{2V}$	-0.3118	$\frac{q\bar{c}}{V}$	0.1595
		δ_f	0.4072	β^3	0.1373

C_X		C_Y		C_Z	
parameter	value	parameter	value	parameter	value
dpt	0.1161	$-$	$-$	dpt	-0.1563
$\alpha \cdot dpt^2$	0.1453				

C_l		C_m		C_n	
parameter	value	parameter	value	parameter	value
$\alpha^2 \cdot dpt$	-0.01406	dpt	-0.07895	dpt^3	-0.003026

$$dpt \equiv \frac{\Delta p_t}{\frac{1}{2}\rho V^2} = C_1 + C_2 \frac{P}{\frac{1}{2}\rho V^3} \quad \text{with:} \quad \begin{cases} C_1 & = \quad 0.08696 \\ C_2 & = \quad 191.18 \end{cases}$$

Calculations for the engine power as output of one of the forces of the axes is as follow:

- Engine power P, $[N m\, s^{-1}]$:

$$P = 0.7355\left\{-326.5 + \left(0.00412(p_z + 7.4)(n + 2010) + (408.0 - 0.0965n)\left(1.0 - \frac{\rho}{\rho_0}\right)\right)\right\}$$

As there are all the variables available so we store them in .mat file named “dhc2_vars.mat” and before running any script of this project we will load all the variables so we don’t have to specify each variable separately every time.

So equation of the 3 forces and 3 moments are as given:

Equations

- Dimensional forces, $[N]$:

$$\begin{aligned} X_a &= C_{X_a}\; q_{dyn}\, S \\ Y_a &= C_{Y_a}\; q_{dyn}\, S \\ Z_a &= C_{Z_a}\; q_{dyn}\, S \end{aligned}$$

- Dimensional moments, $[Nm]$:

$$\begin{aligned} L_a &= C_{l_a}\; q_{dyn}\, S\, b \\ M_a &= C_{m_a}\; q_{dyn}\, S\, \overline{c} \\ N_a &= C_{n_a}\; q_{dyn}\, S\, b \end{aligned}$$

For the steady level flight trim conditions:

```
Input vector (trimmed):

                u =  -9.3083e-002
                      9.6242e-003
                     -4.9506e-002
                                0
                      1.8000e+003
                      2.0000e+001
```

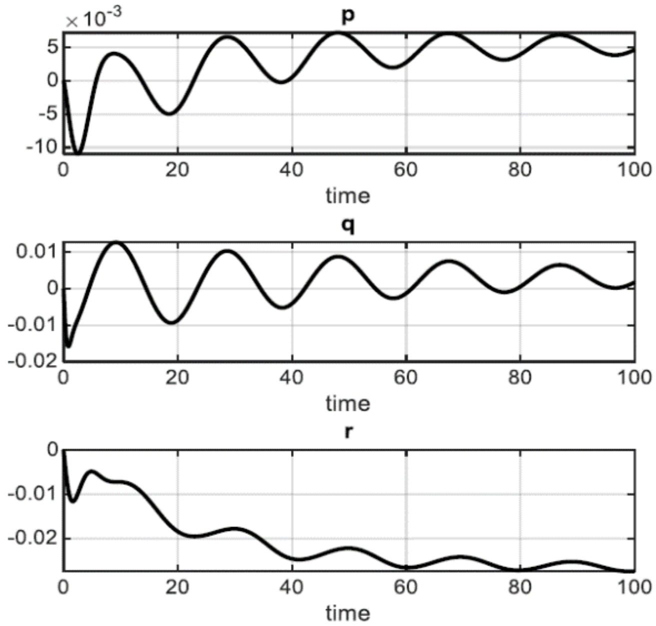
Here 6 different trim conditions are for the elevator, aileron, rudder, flap, rpm, manifold pressure respectively are given as a constant conditions for the aircraft simulation for a steady level flight.

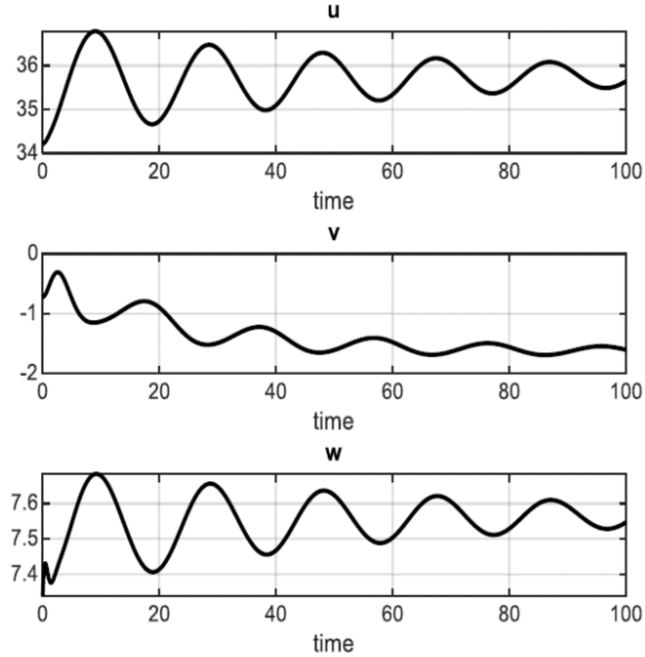
After we change the given conditions of trimmed the alpha and beta (angle of attack and slideslip angle) also changes and due to which the vector velocity along 3 axis also changes as

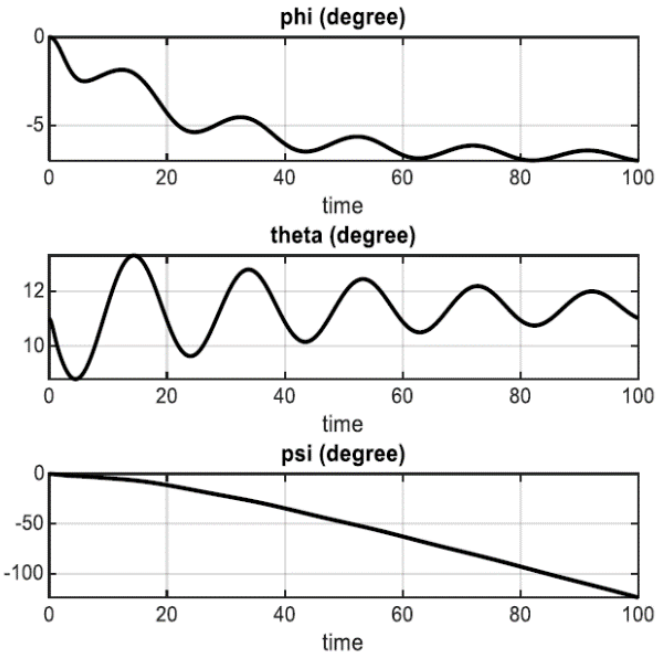
$$\begin{aligned} u &= V\cos\alpha\cos\beta \\ v &= V\sin\beta \\ w &= V\sin\alpha\cos\beta \end{aligned}$$

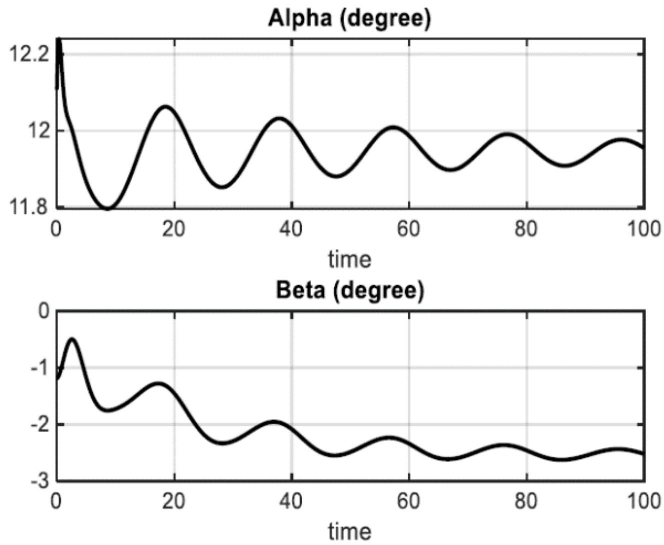
5. RESULTS

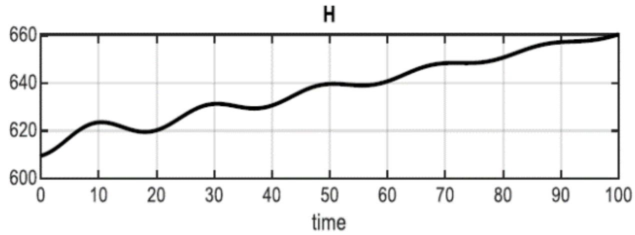
Solving the 12 non-linear ordinary differential equations at the given trim conditions for a time span of 100 $seconds$ resulted the following results.

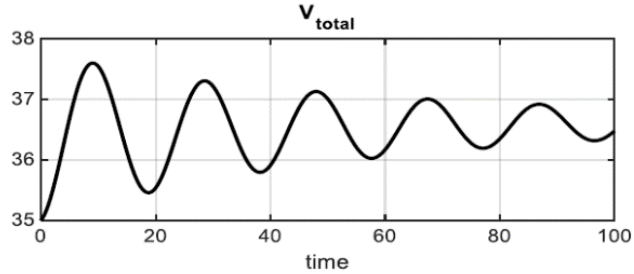




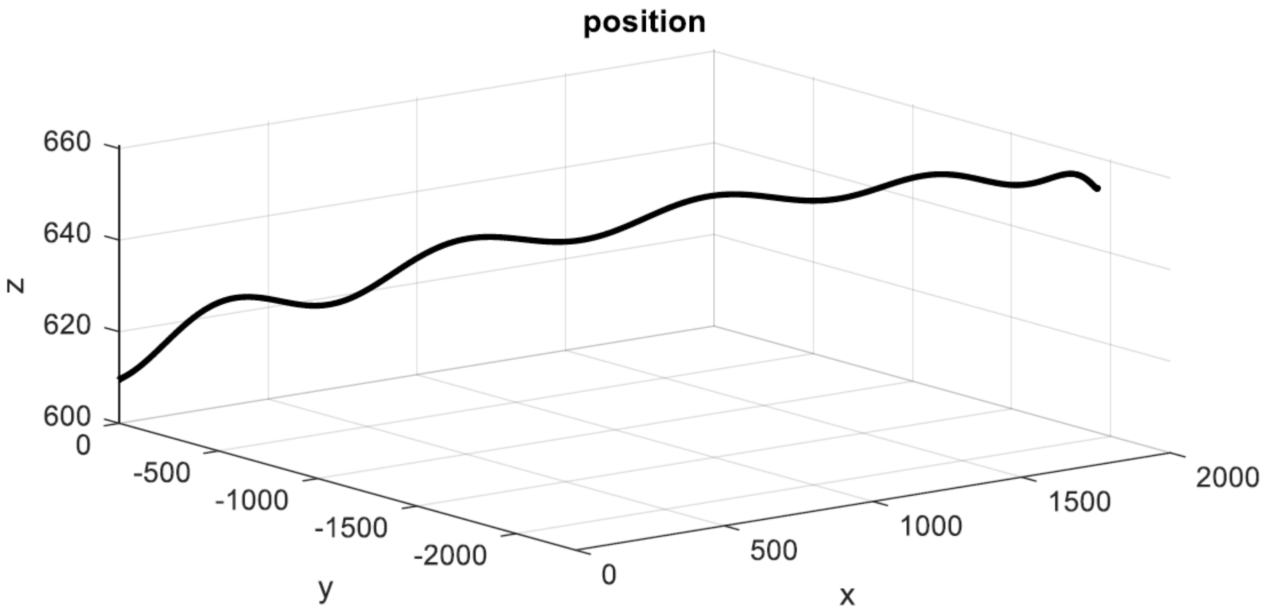








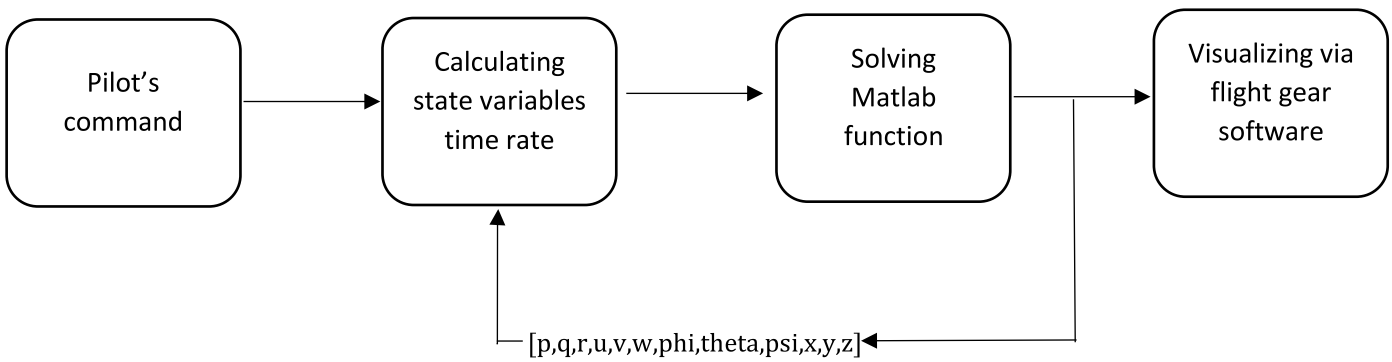
The aircraft clearly appears to be oscillating about its trim state, and the results appear to be reasonable. The order of magnitude of the velocities is as expected, as for our case; the x velocity (around 35m/s) component must have the largest value, while the y-component have the lowest change in value with time. In addition, the p, q, $and\ r$ values appear to be oscillating about zero, which is expected during the trim state. The open loop response of the position state in the three directions, is obtained by integrating the velocity components, and plotted to show the aircraft motion during time. Below given figure shows the position of the beaver aircraft in space. The aircraft's position plot also clearly suggests that the results are valid, as it shows a typical aircraft's motion for a trim state.



6. SIMULINK AND FLIGHT GEAR

We have done all the important part of the simulator. In the computer language it is called back end part which means the work going inside the system. Now front end is only remaining which is easy part so we wanted to visualize and simulate the aircraft performance in real-time. Hence, we created a Simulink model based on the same MATLAB function we created earlier which calculated the time rates of the state variables where we used a simple “integrator” block to calculate the variables in real-time during simulation. You can understand these with the block diagram shown below:

Now the flight data created by the Matlab function is inserted as 6-DoF in inbuilt flight gear function of aerospace blockset in Simulink library.



7. SIMULINK AND MATLAB CODE

Matlab Main script Code (FlightScript.m)

```
close all
clear all
clc

format shortG

V = 35;
alpha = 2.1131e-001;
beta = -2.0667e-002;
z = 2000*0.3048;
x = 0; y = 0;

u = V*cos(alpha)*cos(beta);
v = V*sin(beta);
w = V*sin(alpha)*cos(beta);
phi = 0; theta = 1.9190e-001; psi = 0;
q = 0; r = 0; p = 0;

IC = [p; q; r; phi; theta; psi; u; v; w; x; y; z];

tspan =[0 100];

[t,sol] = ode45(@(t,sol) odefun5(t,sol), tspan, IC);

figure(1)
plot3(sol(:,10), sol(:,11), sol(:,12), 'k', 'LineWidth', 2)
xlabel('x'); ylabel('y'); zlabel('z');
title('position')
grid on

figure(2)
subplot(311)
plot(t, sol(:,4).*180/pi, 'k', 'LineWidth', 1.5)
title('phi (degree)'); xlabel('time'); grid on
subplot(312)
plot(t, sol(:,5).*180/pi, 'k', 'LineWidth', 1.5)
title('theta (degree)'); xlabel('time'); grid on
subplot(313)
plot(t, sol(:,6).*180/pi, 'k', 'LineWidth', 1.5)
title('psi (degree)'); xlabel('time'); grid on

figure(3)
```

```
subplot(211)
plot(t, atan2(sol(:,9),sol(:,7)).*180./pi, 'k', 'LineWidth', 1.5)
title('Alpha (degree)'); xlabel('time'); grid on
subplot(212)
V_ = sqrt(sol(:,7).^2 + sol(:,8).^2 + sol(:,9).^2);
plot(t, asin(sol(:,8)./V_).*180./pi, 'k', 'LineWidth', 1.5)
title('Beta (degree)'); xlabel('time'); grid on

figure(4)
subplot(311)
plot(t, sol(:,1), 'k', 'LineWidth', 1.5)
title('p'); xlabel('time'); grid on
subplot(312)
plot(t, sol(:,2), 'k', 'LineWidth', 1.5)
title('q'); xlabel('time'); grid on
subplot(313)
plot(t, sol(:,3), 'k', 'LineWidth', 1.5)
title('r'); xlabel('time'); grid on

figure(5)
subplot(311)
plot(t, sol(:,7), 'k', 'LineWidth', 1.5)
title('u'); xlabel('time'); grid on
subplot(312)
plot(t, sol(:,8), 'k', 'LineWidth', 1.5)
title('v'); xlabel('time'); grid on
subplot(313)
plot(t, sol(:,9), 'k', 'LineWidth', 1.5)
title('w'); xlabel('time'); grid on

figure(6)
plot(t, sqrt(sol(:,7).^2 + sol(:,8).^2 + sol(:,9).^2), 'k', 'LineWidth', 1.5)
title('V_{total}'); xlabel('time'); grid on

figure(7)
plot(t, sol(:,12), 'k', 'LineWidth', 1.5)
title('H'); xlabel('time'); grid on
```

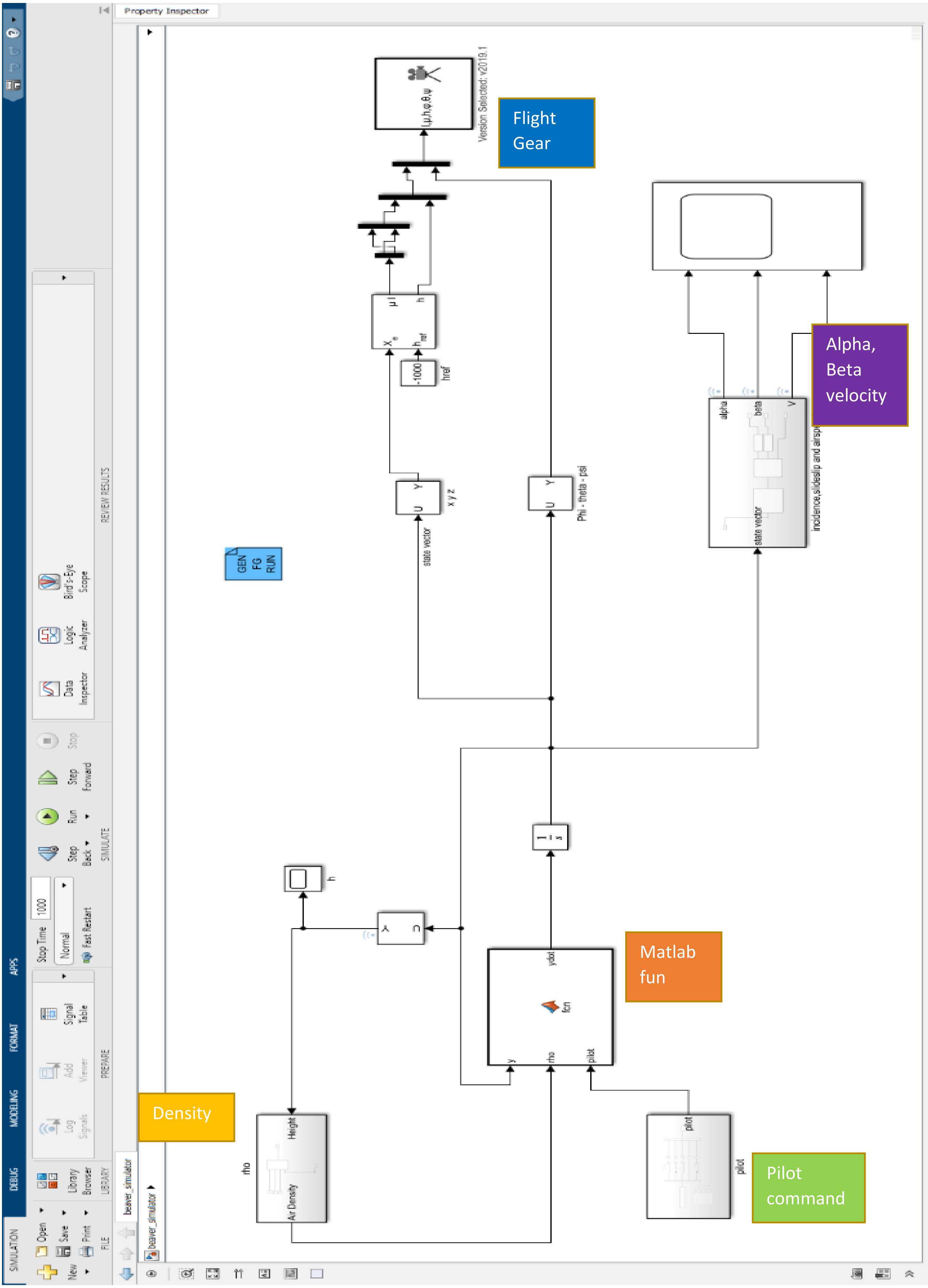
odefun5.m

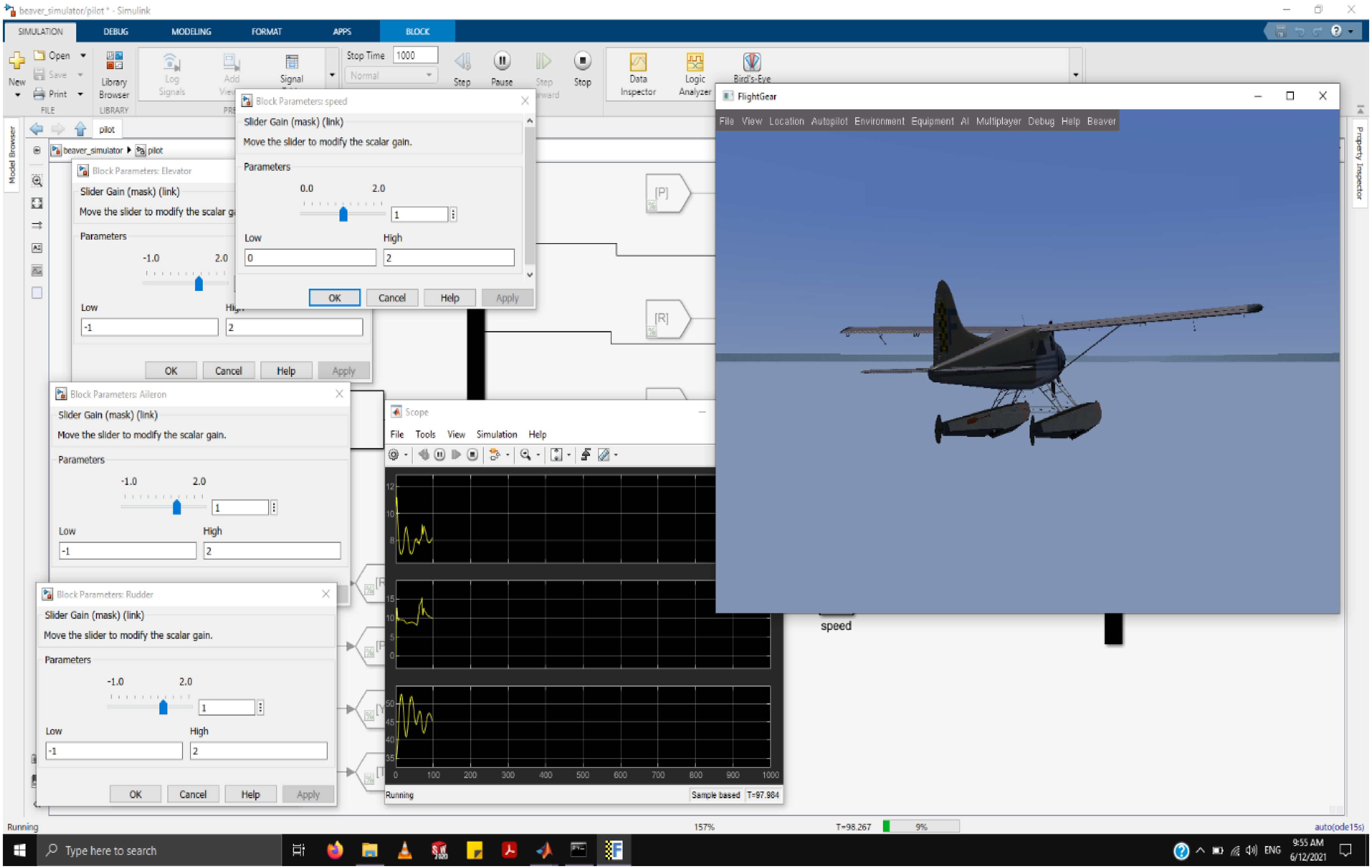
```
function [ ydot ] = odefun5( t,y )
```

```
load('dhc2_vars.mat')

Ix = 5368.39; Iy = 6.92893e3; Iz = 11158.75;
Ixy = 0; Ixz = 1.1764e2; Iyz = 0;
m = 2288.231; g = 9.81;

Delv = -9.3083e-002;
Dail = 9.6242e-003;
Drud = -4.9242e-002;
Dflap = 0;
n = 1800;
Pz = 20;

p = y(1); q = y(2); r = y(3); phi = y(4); theta = y(5); psi = y(6);
u = y(7); v = y(8); w = y(9); xe = y(10); ye = y(11); z = y(12);

V = sqrt(u^2 + v^2 + w^2);
alpha = atan2(w,u);
beta = asin(v/V);

rho = 1.225*exp(-g*(z)/287.05/(288-0.0065*(z)));
P = 0.7355*(-326.5+(0.00412*(Pz+7.4)*(n+2010)+(408-0.0965*n)*(1-rho/1.225)));
dpt = 0.08696+191.18*(P*2/rho/V^3);
qdyn = 0.5*rho*V^2;

Cx = Cx0 + Cx_alpha*alpha + Cx_alpha2*alpha^2 + Cx_alpha3*alpha^3 +
Cx_q*q*beaver_c/V...
     + Cx_dr*Drud + Cx_df*Dflap + Cx_df_alpha*alpha*Dflap...
     + Cx_dpt*dpt + Cx_dpt2_alpha*dpt^2*alpha;

Cy = Cy0 + Cy_beta*beta + Cy_p*p*beaver_b/2/V + Cy_r*r*beaver_b/2/V...
     + Cy_da*Dail + Cy_dr*Drud + Cy_dr_alpha*alpha*Drud;

Cz = Cz0 + Cz_alpha*alpha + Cz_alpha3*alpha^3 + Cz_q*q*beaver_c/V +
Cz_de*Delv...
     + Cz_de_beta*Delv*beta^2 + Cz_df*Dflap...
     + Cz_df_alpha*alpha*Dflap + Cz_dpt*dpt;

Cl = Cl0 + Cl_beta*beta + Cl_p*p*beaver_b/2/V + Cl_r*r*beaver_b/2/V...
     + Cl_da*Dail+Cl_dr*Drud...
     + Cl_da_alpha*alpha*Dail + Cl_alpha2_dpt*alpha^2*dpt;

Cm = Cm0 + Cm_alpha*alpha + Cm_alpha2*alpha^2 + Cm_q*q*beaver_c/V...
     + Cm_de*Delv + Cm_beta2*beta^2 + Cm_r*r*beaver_b/2/V + Cm_df*Dflap...
     + Cm_dpt*dpt;

Cn = Cn0 + Cn_beta*beta + Cn_p*p*beaver_b/2/V + Cn_r*r*beaver_b/2/V + Cn_da...
```

```
        *Dail + Cn_dr*Drud + Cn_q*q*beaver_c/V + Cn_beta3*beta^3 + Cn_dpt3*dpt^3;

    Fx = Cx*qdyn*beaver_S;
    Fy = Cy*qdyn*beaver_S;
    Fz = Cz*qdyn*beaver_S;
    L = Cl*qdyn*beaver_S*beaver_b;
    M = Cm*qdyn*beaver_S*beaver_c;
    N = Cn*qdyn*beaver_S*beaver_b;

    ydot(1) = (Iz*L + Ixz*N + Ixz^2*q*r - Iz^2*q*r - Ixz*Iy*p*q + 2*Ixz*Iz*p*q +
Iy*Iz*q*r)/(Ixz^2 + Ix*Iz);
    ydot(2) = (M - Ixz*p^2 + Ixz*r^2 - Ix*q*r + Iz*q*r)/Iy;
    ydot(3) = -(Ixz*L - Ix*N + Ixz^2*p*q + Ix*Iy*p*q - Ix*Iz*p*q - Ix*Ixz*q*r +
Ixz*Iy*q*r - Ixz*Iz*q*r)/(Ixz^2 + Ix*Iz);

    euler = [[1, sin(y(4))*tan(y(5)), cos(y(4))*tan(y(5))];...
             [0, cos(y(4)), -sin(y(4))];...
             [0, sin(y(4))*(1/cos(y(5))), cos(y(4))*(1/cos(y(5)))]] * ...
             [y(1); y(2); y(3)];

    ydot(4) = euler(1);
    ydot(5) = euler(2);
    ydot(6) = euler(3);

    ydot(7) = (Fx - g*m*sin(theta) - m*q*w + m*r*v)/m;
    ydot(8) = (Fy + m*p*w - m*r*u + g*m*cos(theta)*sin(phi))/m;
    ydot(9) = (Fz - m*p*v + m*q*u + g*m*cos(phi)*cos(theta))/m;

    C = [[cos(y(5))*cos(y(6)), sin(y(4))*sin(y(5))*cos(y(6))-(cos(y(4))*sin(y(6))),
cos(y(4))*sin(y(5))*cos(y(6))+(sin(y(4))*sin(y(6)))];
         [cos(y(5))*sin(y(6)), sin(y(4))*sin(y(5))*sin(y(6))+(cos(y(4))*cos(y(6))),
cos(y(4))*sin(y(5))*sin(y(6))-(sin(y(4))*cos(y(6)))];
         [-sin(y(5)), sin(y(4))*cos(y(5)), cos(y(4))*cos(y(5))]];

    Cmat = C * [y(7); y(8); y(9)];

    ydot(10) = Cmat(1);
    ydot(11) = Cmat(2);
    ydot(12) = Cmat(3);
    ydot = [ydot(1); ydot(2); ydot(3); ydot(4); ydot(5); ydot(6);...
            ydot(7); ydot(8); ydot(9); ydot(10); ydot(11); ydot(12)];
end
```

Simulink Model


Property Inspector
Flight Gear
GEN FG RUN
Alpha, Beta velocity
Matlab fun
Density
Pilot command



beaver_simulator/pilot * - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
BLOCK
Stop Time
1000
Step
Pause
Stop
Data Inspector
Logic Analyzer
Bird's-Eye
Block Parameters: speed
Slider Gain (mask) (link)
Move the slider to modify the scalar gain.
Parameters
0.0
2.0
Low
High
0
2
OK
Cancel
Help
Apply
Block Parameters: Elevator
Block Parameters: Aileron
Block Parameters: Rudder
FlightGear
File View Location Autopilot Environment Equipment AI Multiplayer Debug Help Beaver
Scope
File Tools View Simulation Help
Running
Sample based T=97.984
speed
T=98.267
9%
157%
auto(ode15s)
Type here to search
9:55 AM
6/12/2021

8. REFERENCES

[1] Robert C. Nelson. flight stability and automatic control. Second edition, United States, McGraw-Hill, INC., 1998.

[2] MSc-thesis - A SIMULINK environment for flight dynamics and control analysis: Application to the DHC-2 Beaver

[3] AE 430 - Stability and Control of Aerospace Vehicles

You can download the project from the given link:

https://drive.google.com/drive/folders/1IDIZmFdYA11NayJCcqlseE0kLqbvMeq5?usp=sharing

REPORT BY:
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