**close all;**

**clc;**

**syms dtheta1 dtheta2 dtheta3 dtheta4 phi phi\_dot**

**syms theta theta\_dot**

**syms psi psi\_dot x x\_dot y y\_dot z z\_dot**

**syms omega1 omega2 omega3 omega4**

**syms Ix Iy Iz g m kt2 kq a1 a2 a3 a4 a5 b1 b2 b3**

**syms thetafix vi1 vi2 vi3 vi4 k2 R**

**%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%**

**Ix=4.856\*10^(-3);**

**Iy=4.856\*10^(-3);**

**Iz=8.801\*10^(-3);**

**l=0.225; %% arm length**

**Jr=3.357\*10^(-6); %% Rotor Inertia**

**a1=(Iy-Iz)/Ix;**

**a2=Jr/Ix;**

**a3=(Iz-Ix)/Iy;**

**a4=Jr/Iy;**

**a5=(Ix-Iy)/Iz;**

**b1=l/Ix;**

**b2=(l)/Iy;**

**b3=1/Iz;**

**%Mass**

**m=.468;**

**g=9.81;**

**%Aerodynamic force and Moment constant**

**kt=2.98\*10^(-6);**

**kq=1.14\*10^(-7);**

**%{**

**omega=sqrt(m\*g/(4\*kt));**

**omega4 = omega, omega3 = omega4, omega2 = omega3, omega1 = omega2 ;**

**%}**

**%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%**

**% state vectors**

**u = [omega1; omega2;omega3;omega4];**

**x = [phi;phi\_dot;theta;theta\_dot;**

**psi;psi\_dot;x;x\_dot;y;y\_dot;z;z\_dot;vi1;vi2;vi3;vi4];**

**y = [phi;phi\_dot;theta;theta\_dot;**

**psi;psi\_dot;x;x\_dot;y;y\_dot;z;z\_dot];**

**T1=k2\*omega1^(2)\*((thetafix/3) -vi1/(2\*omega1\*R));**

**T2=k2\*omega2^(2)\*((thetafix/3) -vi2/(2\*omega2\*R));**

**T3=k2\*omega3^(2)\*((thetafix/3) -vi3/(2\*omega3\*R));**

**T4=k2\*omega4^(2)\*((thetafix/3) -vi4/(2\*omega4\*R));**

**% non-linear system**

**F1=phi\_dot;**

**F2=(theta\_dot\*psi\_dot\*a1)-(theta\_dot\*(omega1-omega2+omega3-omega4)\*a2)+(b1\*(T1-T3));**

**F3=theta\_dot;**

**F4=(phi\_dot\*psi\_dot\*a3)+(phi\_dot\*(omega1-omega2+omega3-omega4)\*a4)+(b2\*(T4-T2));**

**F5=psi\_dot;**

**F6=phi\_dot\*theta\_dot\*a5 + b3\*kq\*(T1-T2+T3-T4);**

**F7=x\_dot;**

**F8=(-(T1+T2+T3+T4)/m)\*(cos(phi)\*sin(theta)\*cos(psi)+sin(phi)\*sin(psi));**

**F9=y\_dot;**

**F10=(-(T1+T2+T3+T4)/m)\*(cos(phi)\*sin(psi)\*sin(theta)-cos(psi)\*sin(phi));**

**F11=z\_dot;**

**F12=(g)-( (T1+T2+T3+T4)/m )\*cos(phi)\*cos(theta);**

**F=[F1;F2;F3;F4;F5;F6;F7;F8;F9;F10;F11;F12];**

**A.symbolic = jacobian(F, x);**

**B.symbolic = jacobian(F, u);**

**A.symbolic=subs(A.symbolic,sym('phi'),0);**

**A.symbolic=subs(A.symbolic,sym('phi\_dot'),0);**

**A.symbolic=subs(A.symbolic,sym('theta'),0);**

**A.symbolic=subs(A.symbolic,sym('theta\_dot'),0);**

**A.symbolic=subs(A.symbolic,sym('psi'),0);**

**A.symbolic=subs(A.symbolic,sym('psi\_dot'),0);**

**A.symbolic=subs(A.symbolic,sym('x'),0);**

**A.symbolic=subs(A.symbolic,sym('x\_dot'),0);**

**A.symbolic=subs(A.symbolic,sym('y'),0);**

**A.symbolic=subs(A.symbolic,sym('y\_dot'),0);**

**A.symbolic=subs(A.symbolic,sym('z'),0);**

**A.symbolic=subs(A.symbolic,sym('z\_dot'),0);**

**A.symbolic=subs(A.symbolic,sym('R'),.125);**

**A.symbolic=subs(A.symbolic,sym('omega1'),620.610);**

**A.symbolic=subs(A.symbolic,sym('omega2'),620.610);**

**A.symbolic=subs(A.symbolic,sym('omega3'),620.610);**

**A.symbolic=subs(A.symbolic,sym('omega4'),620.610);**

**A.symbolic=subs(A.symbolic,sym('thetafix'),.1);**

**A.symbolic=subs(A.symbolic,sym('k2'),(.923\*10^(-5)));**

**A.symbolic=subs(A.symbolic,sym('vi1'),0.3068);**

**A.symbolic=subs(A.symbolic,sym('vi2'),0.3068);**

**A.symbolic=subs(A.symbolic,sym('vi3'),0.3068);**

**A.symbolic=subs(A.symbolic,sym('vi4'),0.3068);**

**A=eval(A.symbolic);**

**Z1=[0 0 0 0 0 0 0 0 0 0 0 0 -128.8 0 0 0];**

**Z2=[0 0 0 0 0 0 0 0 0 0 0 0 0 -128.8 0 0];**

**Z3=[0 0 0 0 0 0 0 0 0 0 0 0 0 0 -128.8 0];**

**Z4=[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -128.8 ];**

**A=[A;Z1;Z2;Z3;Z4];**

**B.symbolic=subs(B.symbolic,sym('phi'),0);**

**B.symbolic=subs(B.symbolic,sym('phi\_dot'),0);**

**B.symbolic=subs(B.symbolic,sym('theta'),0);**

**B.symbolic=subs(B.symbolic,sym('theta\_dot'),0);**

**B.symbolic=subs(B.symbolic,sym('psi'),0);**

**B.symbolic=subs(B.symbolic,sym('psi\_dot'),0);**

**B.symbolic=subs(B.symbolic,sym('x'),0);**

**B.symbolic=subs(B.symbolic,sym('x\_dot'),0);**

**B.symbolic=subs(B.symbolic,sym('y'),0);**

**B.symbolic=subs(B.symbolic,sym('y\_dot'),0);**

**B.symbolic=subs(B.symbolic,sym('z'),0);**

**B.symbolic=subs(B.symbolic,sym('z\_dot'),0);**

**B.symbolic=subs(B.symbolic,sym('R'),.125);**

**B.symbolic=subs(B.symbolic,sym('omega1'),620.610);**

**B.symbolic=subs(B.symbolic,sym('omega2'),620.610);**

**B.symbolic=subs(B.symbolic,sym('omega3'),620.610);**

**B.symbolic=subs(B.symbolic,sym('omega4'),620.610);**

**B.symbolic=subs(B.symbolic,sym('thetafix'),.1);**

**B.symbolic=subs(B.symbolic,sym('k2'),(.923\*10^(-5)));**

**B.symbolic=subs(B.symbolic,sym('vi1'),0.3068);**

**B.symbolic=subs(B.symbolic,sym('vi2'),0.3068);**

**B.symbolic=subs(B.symbolic,sym('vi3'),0.3068);**

**B.symbolic=subs(B.symbolic,sym('vi4'),0.3068);**

**B=eval(B.symbolic);**

**Z5=[.004856 0 0 0];**

**Z6=[0 .004856 0 0];**

**Z7=[0 0 .004856 0];**

**Z8=[0 0 0 .004856 ];**

**B=[B;Z5;Z6;Z7;Z8];**

**C=eye(16);**

**D=0;**

**%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%**

**sys\_ss = ss(A,B,C,D) co = ctrb(sys\_ss);**

**Controllability\_Matrix\_Rank = rank(co)**

**step(sys\_ss,'+');**

**hold on**

**%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%**

**Q = [ 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 ;**

**0 100 0 0 0 0 0 0 0 0 0 0 0 0 0 0;**

**0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0;**

**0 0 0 100 0 0 0 0 0 0 0 0 0 0 0 0;**

**0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0;**

**0 0 0 0 0 100 0 0 0 0 0 0 0 0 0 0;**

**0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0;**

**0 0 0 0 0 0 0 100 0 0 0 0 0 0 0 0;**

**0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0;**

**0 0 0 0 0 0 0 0 0 100 0 0 0 0 0 0;**

**0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0;**

**0 0 0 0 0 0 0 0 0 0 0 100 0 0 0 0;**

**0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0;**

**0 0 0 0 0 0 0 0 0 0 0 0 0 100 0 0;**

**0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0;**

**0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 100;**

**]; %% Controlling parameter**

**R1 = 1;**

**K = lqr(A,B,Q,R1)**

**AA = A-B\*K;**

**BB = B;**

**CC= C;**

**DD= D;**

**sys\_cl = ss(AA,BB,CC,DD);**

**step(sys\_ss,'\*');**

**eig\_new=eig(sys\_cl)**

**eig\_old=eig(sys\_ss)**

**step(sys\_cl);**

**%{**

**non-linear system, y(t) = g(x,u,t)**

**G = [G1; G2; G3; G4];**

**%}**

**% compute jacobian**

**%{**

**VALUES USED:**

**1) To find thetafix:**

**Thrust=ct\*rho \*A \*(R\*omega)^(2)=kt\*omega^(2) ,ct from BEMT=sigma aby2 \* theta by3**

**-lambdai/2 where lambdai=root ctby2,**

**kt experimentally found out. Omega also nominal value. thus equating these**

**we get thetafix**

**2)to findk2**

**Thrust=k2\*ct\*omega^(2)**

**3)to find inflow (vi)**

**vi= root(ct/2)\*R\*omega**

**%}**