State Variables and Input Variables on Linearization Processes

Variable	Value
X_u	$-0.0042(2u)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)+0.0455\left(\frac{-w}{V_a^2}\right)(\cos\alpha)(2u)$ $-0.0078q^2\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)-0.0204(2u)\left(\frac{-w}{V_a^2}\right)^2(-\sin\alpha)$ $+0.2275(2u)\left(\frac{-w}{V_a^2}\right)^2(\cos\alpha)-0.0025(2u)(u_3)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)$ $+0.02824(2u)(u_3)\left(\frac{-w}{V_a^2}\right)(\cos\alpha)$ $-0.1236(2u)\left(\frac{-2\alpha w}{V_a^2}\right)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)$ $-0.0019(2u)(u_3)^2\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)-0.0009(2u)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)\lvert u_3\rvert$ $-0.0051q\left(\frac{u}{V_a}\right)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)+0.0573q\left(\frac{u}{V_a}\right)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)$ $-0.0623q\left(\frac{u}{V_a}\right)\left(\frac{-w}{V_a^2}\right)^2(-\sin\alpha)$ $-0.0077q\left(\frac{u}{V_a}\right)(u_3)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)$ $-0.0307(2u)\left(\frac{-w}{V_a^2}\right)^2(u_3)(-\sin\alpha)$
X_w	$-q-0.0042\,(2w)\left(\frac{u}{V_a^2}\right)(-\sin\alpha)+0.0455\left(\frac{u}{V_a^2}\right)(\cos\alpha)(2w)-0.0078q^2\left(\frac{u}{V_a^2}\right)(-\sin\alpha)$ $-0.0204(2w)\left(\frac{u}{V_a^2}\right)^2(-\sin\alpha)+0.2275(2w)\left(\frac{u}{V_a^2}\right)(\cos\alpha)$ $-0.0025(2w)(u_3)\left(\frac{u}{V_a^2}\right)(-\sin\alpha)+0.0282(2w)(u_3)\left(\frac{u}{V_a^2}\right)(\cos\alpha)$ $-0.1236(2w)\left(\frac{2\alpha u}{V_a^2}\right)\left(\frac{u}{V_a^2}\right)(-\sin\alpha)-0.0019(2w)(u_3)^2\left(\frac{u}{V_a^2}\right)(-\sin\alpha)$ $-0.0009(2w)\left(\frac{u}{V_a^2}\right)(-\sin\alpha)\lvert u_3\rvert-0.0051q\left(\frac{w}{V_a}\right)\left(\frac{u}{V_a^2}\right)(-\sin\alpha)$ $-0.0573q\left(\frac{w}{V_a}\right)\left(\frac{u}{V_a^2}\right)(\cos\alpha)-0.0623q\left(\frac{w}{V_a}\right)\left(\frac{u}{V_a^2}\right)^2(-\sin\alpha)$ $-0.0077q\left(\frac{w}{V_a}\right)(u_3)\left(\frac{u}{V_a^2}\right)(-\sin\alpha)-0.0307(2w)\left(\frac{u}{V_a^2}\right)^2(u_3)(-\sin\alpha)$
X_q	$-w-0.0078(2q)(\cos\alpha)-0.0051V_a(\cos\alpha)+0.0573V_a(\sin\alpha)$ $-0.0623V_a\alpha(\cos\alpha)-0.0077V_a(u_3)(\cos\alpha)$

Variable	Value
Z_u	$q - 0.0078q^2\left(\frac{-w}{V_a^2}\right)(\cos\alpha) - 0.0455(2u)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha) - 0.0042(2u)\left(\frac{-w}{V_a^2}\right)(\cos\alpha)$ $-0.2275(2u)\left(\frac{-w}{V_a^2}\right)^2(-\sin\alpha) - 0.0204(2u)\left(\frac{-w}{V_a^2}\right)^2(\cos\alpha)$ $-0.0282(2u)(u_3)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha) - 0.0025(2u)(u_3)\left(\frac{-w}{V_a^2}\right)(\cos\alpha)$ $-0.1236(2u)\left(\frac{-2\alpha w}{V_a^2}\right)\left(\frac{-w}{V_a^2}\right)(\cos\alpha) - 0.0019(2u)(u_3)^2\left(\frac{-w}{V_a^2}\right)(\cos\alpha)$ $-0.0009(2u)\left(\frac{-w}{V_a^2}\right)(\cos\alpha)\lvert u_3\rvert - 0.0573q\left(\frac{u}{V_a}\right)\left(\frac{-w}{V_a^2}\right)(-\sin\alpha)$ $-0.0051q\left(\frac{u}{V_a}\right)\left(\frac{-w}{V_a^2}\right)(\cos\alpha) - 0.0623q\left(\frac{u}{V_a}\right)\left(\frac{-w}{V_a^2}\right)^2(\cos\alpha)$ $-0.0077q\left(\frac{u}{V_a}\right)(u_3)\left(\frac{-w}{V_a^2}\right)(\cos\alpha) - 0.0307(2u)(u_3)\left(\frac{-w}{V_a^2}\right)^2(\cos\alpha)$
Z_w	$-0.0078q^2\left(\frac{u}{V_a^2}\right)(\cos\alpha) - 0.0455(2w)\left(\frac{u}{V_a^2}\right)(-\sin\alpha) - 0.0042(2w)\left(\frac{u}{V_a^2}\right)(\cos\alpha)$ $-0.2275(2w)\left(\frac{u}{V_a^2}\right)^2(-\sin\alpha) - 0.0204(2w)\left(\frac{u}{V_a^2}\right)^2(\cos\alpha)$ $-0.0282(2w)(u_3)\left(\frac{u}{V_a^2}\right)(-\sin\alpha) - 0.0025(2w)(u_3)\left(\frac{u}{V_a^2}\right)(\cos\alpha)$ $-0.01236(2w)\left(\frac{2\alpha u}{V_a^2}\right)\left(\frac{u}{V_a^2}\right)(\cos\alpha) - 0.0019(2w)(u_3)^2\left(\frac{u}{V_a^2}\right)(\cos\alpha)$ $-0.0009(2w)\left(\frac{u}{V_a^2}\right)(\cos\alpha)\lvert u_3\rvert - 0.0573q\left(\frac{w}{V_a}\right)\left(\frac{u}{V_a^2}\right)(-\sin\alpha)$ $-0.0051q\left(\frac{w}{V_a}\right)\left(\frac{u}{V_a^2}\right)(\cos\alpha) - 0.6223q\left(\frac{w}{V_a}\right)\left(\frac{u}{V_a^2}\right)^2(\cos\alpha)$ $-0.0077q\left(\frac{w}{V_a}\right)(u_3)\left(\frac{u}{V_a^2}\right)(\cos\alpha) - 0.0307(2w)(u_3)\left(\frac{u}{V_a^2}\right)^2(\cos\alpha)$
Z_q	$u - 0.0078(2q)(\sin\alpha) - 0.0573V_a(\cos\alpha) - 0.0051V_a(\sin\alpha)$ $-0.0623V_a\alpha(\sin\alpha) - 0.0077V_a(u_3)(\sin\alpha)$
M_u	$-0.3232q\left(\frac{u}{V_a}\right) - 0.2110(2u)\left(\frac{-w}{V_a^2}\right) - 0.2190(2u)(u_3) + 0.0009(2u)$
M_w	$-0.3232q\left(\frac{w}{V_a}\right) - 0.2110(2w)\left(\frac{u}{V_a^2}\right) - 0.2190(2w)(u_3) + 0.0009(2w)$
M_q	$-0.3232V_a$
X_{dt}	$-u(\sin\theta) + w(\cos\theta)$
Z_{dt}	$-w(\sin\theta) - u(\cos\theta)$
X_{u1}	$0.3333(\cos u_5)$

Variable Value

Variabel	Nilai
X_{u3}	$-0.0025(V_a^2)(\cos\alpha) + 0.0282(V_a^2)(\sin\alpha) - 0.0019(V_a^2)(2u_3)(\cos\alpha)$ $-0.0009(V_a^2)(\cos\alpha) - 0.0077q(V_a)(\cos\alpha) - 0.0307\alpha(V_a^2)(\cos\alpha)$
X_{u5}	$0.3333(u_1)(-\sin u_5)$
Z_{u1}	$-0.3333(\sin u_5)$
Z_{u3}	$-0.0282(V_a^2)(\cos\alpha) - 0.0025(V_a^2)(\sin\alpha) - 0.0019(V_a^2)(2u_3)(\sin\alpha)$ $-0.0009(V_a^2)(\sin\alpha) - 0.0077q(V_a)(\sin\alpha) - 0.0307\alpha(V_a^2)(\sin\alpha)$
Z_{u5}	$-0.3333(u_1)(\cos u_5)$
M_{u1}	$0.6335(\sin u_5)$
M_{u3}	$-0.219(V_a^2)$
M_{u5}	$0.6335(u_1)(\cos u_5)$

Modelling in Matlab

```
function XDOT = NACA9412(X,U,Condition_Signal)

%States
u = X(1); %u
w = X(2); %w
q = X(3); %q
theta = X(4); %theta
x_i = X(5); %x
z_i = X(6); %z
plot_r12 = X(7);

%Inputs
u1 = U(1); % front rotors speed
u2 = U(2); % rear rotors speed
u3 = U(3); % Deflection angle elevator
u4 = U(4); % Moment Pitch
u5 = U(5); % Tilt angle rotor

% --- CONSTANTS ---
%Physical Parameters
m = 6; % Kg
S = 0.55; % m^2
c = 0.282; % m
b = 2; % m
Iy = 0.7893;% kg . m^2
KT = 0.1142;% kg . m
KQ = 0.007048;% kg . m^2
rho = 1.2133;% kg . m^3
g = 10; % m . s^2
Kd = 0.1328;
```

```
%Aerodynamic Parameters
CL0 = 0.81857;
CLalpha = 4.09127;
CLde = 0.50787;
CLq = 7.31097;
CLcdmin = 0.4806;

CDmin = 0.06047;
CDde = 0.016043;

CM0 = 0.00763;
CMalpha = -1.76966;
CMde = -1.83747;
CMq = -19.22663;

%Alpha angle of attack
alpha = atan2(w,u);

Va = sqrt(u^2 + w^2);

%Dynamic Pressure
Q = 0.5*rho*(Va^2)*S;

%Aerodynamic Force and Moment
CL = CL0 + CLalpha*alpha + CLq *q*c/(2*Va) + CLde*u3;
CD = CDmin + Kd *((CL-CLcdmin)^2) + CDde *abs(u3);
CM = CM0 + CMalpha*alpha + CMq *q*c/(2*Va) + CMde*u3;

%Aerodynaminc Moment
Ma = Q*c*CM;

%Rotors Force and Moment
%Front Rotors
% r12x = cos(u3)*KT*(u1^2);
% r12z = sin(u3)*KT*(u1^2);
% M12  = 0.25*cos(u3)*KT*(u1^2);

r12x = cospi(u5)*u1;
r12z = sinpi(u5)*u1;
M12  = 0.25*sinpi(u5)*u1;

r34x = cospi(1/2)*u2;
r34z = sinpi(1/2)*u2;
M34  = -0.5*sinpi(1/2)*u2;

Rx = 2*(r12x + r34x);
Rz = -2*(r12z + r34z);
Mr = 2*(M12 + M34);

%Gravity Effect
Gx = -sin(theta)*m*g;
Gz = cos(theta)*m*g;

Cx = Q*(CL*sin(alpha)-CD*cos(alpha));
Cz = Q*(-CL*cos(alpha)-CD*sin(alpha));

Fx = Gx + Rx;
```

```
Fz = Gz + Rz;

Mtot = Mr + Ma;

if Condition_Signal == 1 %Cruise condition
    Mtot = Mr + Ma;
    Fx = Gx + Rx + Cx;
    Fz = Gz + Rz + Cz;

elseif Condition_Signal == 2 %Transition condition
Mtot = u4;
Fx = Gx + Rx;
Fz = Gz + Rz;
theta_min = 0.05;
theta_max = -0.05;

if theta >= theta_max
theta = theta_max;
elseif theta <= theta_min
theta = theta_min;
end

elseif Condition_Signal == 3 %VTOL Condition
Mtot = u4;
Fx = Gx + Rx;
Fz = Gz + Rz;
End

udot = -q*w + Fx/m;
wdot = q*u + Fz/m;
qdot = (1/Iy)*(Mtot);
thetadot = q;
xdot = u*cospi(theta/180) + w*sinpi(theta/180);
zdot = -u*sinpi(theta/180) + w*cospi(theta/180);

if zdot == 0 %Condition airplane on ground

udot = 0;
wdot = 0;
qdot = 0;
thetadot = 0;

end

XDOT = [udot
wdot
qdot
thetadot
xdot
zdot
alpha];
```

Simulink Diagram in Matlab