Appendix

Position_Matrix function

```
function
[Position]=Position_Matrix(phi1_dot_initial,
phi2_dot_initial,phi3_dot_initial,phi4_dot_i
nitial,T,rate1,rate2,rate3,rate4,Orientation
_Initial,Position_Initial,Rate_of_Change_R_I
nitial,Linear_Velocity_Initial)

if T>0;
dt=0.0005;
phi1_dot(1)=phi1_dot_initial;
phi2_dot(1)=phi2_dot_initial;
phi3_dot(1)=phi3_dot_initial;
phi4_dot(1)=phi4_dot_initial;
i=2;
for time=dt:dt:T
    phi1_dot(i)=phi1_dot(i-1)+rate1*dt;
    phi2_dot(i)=phi2_dot(i-1)-rate2*dt;
    phi3_dot(i)=phi3_dot(i-1)+rate3*dt;
    phi4_dot(i)=phi4_dot(i-1)-rate4*dt;
    i=i+1;
end;

l=0.315; %in meters
k1=5.86465*10^(-3);
k2=5.86465*10^(-3);
[a m]=size(phi1_dot);
for n=1:m
    F_alpha(n)=-
k1*((abs(phi1_dot(n))*phi1_dot(n))+(abs(phi2
_dot(n))*phi2_dot(n))+(abs(phi3_dot(n))*phi3
_dot(n))+(abs(phi4_dot(n))*phi4_dot(n)));

F_beta(n)=l*k2*((abs(phi3_dot(n))*phi3_dot(n
))-(abs(phi1_dot(n))*phi1_dot(n)));

F_theta(n)=l*k2*((abs(phi4_dot(n))*phi4_dot(
n))-(abs(phi2_dot(n))*phi2_dot(n)));
end


Rate_of_Change_R(:,:,1)=Rate_of_Change_R_Ini
tial;
alpha(1)=Rate_of_Change_R(1,1,1);
%alpha_initial
beta(1)=Rate_of_Change_R(1,2,1);
%beta_initial
theta(1)=Rate_of_Change_R(1,3,1);
%theta_initial
Ixx=0.0887; %in kg*m^2
Iyy=0.0887; %in kg*m^2
Izz=0.6062; %in kg*m^2
for k=2:m
    alpha(k)=alpha(k-1)+((F_alpha(k-
1)+F_alpha(k))/Izz)*dt/2;
    beta(k)=beta(k-1)+((F_beta(k-
1)+F_beta(k))/Iyy)*dt/2;
    theta(k)=theta(k-1)+((F_theta(k-
1)+F_theta(k))/Ixx)*dt/2;
    Rate_of_Change_R(:,:,k)=[alpha(k)
beta(k) theta(k)];

end;

R(:,:,1)=Orientation_Initial;
id=[1 0 0; 0 1 0; 0 0 1];
for index=2:m

v_norm=sqrt((alpha(index)*dt)^2+(beta(index)
*dt)^2+(theta(index)*dt)^2);
    v_matrix=[0 -alpha(index)*dt
beta(index)*dt; alpha(index)*dt 0 -
theta(index)*dt; -beta(index)*dt
theta(index)*dt 0];
    if v_matrix==[0 0 0; 0 0 0; 0 0 0]
        exp_v_at_identity=id;
        R(:,:,index)=R(:,:,index-
1)*exp_v_at_identity;
    else

exp_v_at_identity=id+(sin(v_norm)/v_norm)*v_
matrix+((1-
cos(v_norm))/v_norm^2)*(v_matrix)^2;
        R(:,:,index)=R(:,:,index-
1)*exp_v_at_identity;
    end;

end;


M=1.815; %in kg
g=9.8; %in m/s^2
for index_1=1:m

F_xb(index_1)=k2*dot(R(:,3,index_1),id(:,1))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)));

F_yb(index_1)=k2*dot(R(:,3,index_1),id(:,2))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)));

F_zb(index_1)=k2*dot(R(:,3,index_1),id(:,3))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)))-M*g;

end;


Linear_Velocity(:,:,1)=Linear_Velocity_Initi
al;
x_dot(1)=Linear_Velocity(1,1,1);
y_dot(1)=Linear_Velocity(1,2,1);
z_dot(1)=Linear_Velocity(1,3,1);
for index_2=2:m
    x_dot(index_2)=x_dot(index_2-
1)+(1/M)*(F_xb(index_2-
1)+F_xb(index_2))*dt/2;
    y_dot(index_2)=y_dot(index_2-
1)+(1/M)*(F_yb(index_2-
1)+F_yb(index_2))*dt/2;
    z_dot(index_2)=z_dot(index_2-
1)+(1/M)*(F_zb(index_2-
1)+F_zb(index_2))*dt/2;

Linear_Velocity(:,:,index_2)=[x_dot(index_2)
y_dot(index_2) z_dot(index_2)];
end;



Position(:,:,1)=Position_Initial;
x(1)=Position(1,1,1);
y(1)=Position(1,2,1);
z(1)=Position(1,3,1);
```

```
for index_3=2:m
    x(index_3)=x(index_3-1)+(x_dot(index_3-
1)+x_dot(index_3))*dt/2;
    y(index_3)=y(index_3-1)+(y_dot(index_3-
1)+y_dot(index_3))*dt/2;
    z(index_3)=z(index_3-1)+(z_dot(index_3-
1)+z_dot(index_3))*dt/2;
    Position(:,:,index_3)=[x(index_3)
y(index_3) z(index_3)];

end;
elseif T == 0
    [Position]=Position_Initial;
end
```

Linear_Velocity_Matrix function

```
function
[Linear_Velocity]=Linear_Velocity_Matrix(phi
1_dot_initial,phi2_dot_initial,phi3_dot_init
ial,phi4_dot_initial,T,rate1,rate2,rate3,rat
e4,Orientation_Initial,Position_Initial,Rate
_of_Change_R_Initial,Linear_Velocity_Initial
)
if T>0;
dt=0.0005;
phi1_dot(1)=phi1_dot_initial;
phi2_dot(1)=phi2_dot_initial;
phi3_dot(1)=phi3_dot_initial;
phi4_dot(1)=phi4_dot_initial;
i=2;
for time=dt:dt:T
    phi1_dot(i)=phi1_dot(i-1)+rate1*dt;
    phi2_dot(i)=phi2_dot(i-1)-rate2*dt;
    phi3_dot(i)=phi3_dot(i-1)+rate3*dt;
    phi4_dot(i)=phi4_dot(i-1)-rate4*dt;
    i=i+1;
end;

l=0.315; %in meters
k1=5.86465*10^(-3);
k2=5.86465*10^(-3);
[a m]=size(phi1_dot);
for n=1:m
    F_alpha(n)=-
k1*((abs(phi1_dot(n))*phi1_dot(n))+(abs(phi2
_dot(n))*phi2_dot(n))+(abs(phi3_dot(n))*phi3
_dot(n))+(abs(phi4_dot(n))*phi4_dot(n)));

F_beta(n)=l*k2*((abs(phi3_dot(n))*phi3_dot(n
))-(abs(phi1_dot(n))*phi1_dot(n)));

F_theta(n)=l*k2*((abs(phi4_dot(n))*phi4_dot(
n))-(abs(phi2_dot(n))*phi2_dot(n)));
end


Rate_of_Change_R(:,:,1)=Rate_of_Change_R_Ini
tial;
alpha(1)=Rate_of_Change_R(1,1,1);
%alpha_initial
beta(1)=Rate_of_Change_R(1,2,1);
%beta_initial
theta(1)=Rate_of_Change_R(1,3,1);
%theta_initial
Ixx=0.0887; %in kg*m^2
Iyy=0.0887; %in kg*m^2
Izz=0.6062; %in kg*m^2
for k=2:m
    alpha(k)=alpha(k-1)+((F_alpha(k-
1)+F_alpha(k))/Izz)*dt/2;
    beta(k)=beta(k-1)+((F_beta(k-
1)+F_beta(k))/Iyy)*dt/2;
    theta(k)=theta(k-1)+((F_theta(k-
1)+F_theta(k))/Ixx)*dt/2;
    Rate_of_Change_R(:,:,k)=[alpha(k)
beta(k) theta(k)];

end;



R(:,:,1)=Orientation_Initial;
id=[1 0 0; 0 1 0; 0 0 1];
for index=2:m

v_norm=sqrt((alpha(index)*dt)^2+(beta(index)
*dt)^2+(theta(index)*dt)^2);
    v_matrix=[0 -alpha(index)*dt
beta(index)*dt; alpha(index)*dt 0 -
theta(index)*dt; -beta(index)*dt
theta(index)*dt 0];
    if v_matrix==[0 0 0; 0 0 0; 0 0 0]
        exp_v_at_identity=id;
        R(:,:,index)=R(:,:,index-
1)*exp_v_at_identity;
    else

exp_v_at_identity=id+(sin(v_norm)/v_norm)*v_
matrix+((1-
cos(v_norm))/v_norm^2)*(v_matrix)^2;
        R(:,:,index)=R(:,:,index-
1)*exp_v_at_identity;
    end;

end;


M=1.815; %in kg
g=9.8; %in m/s^2
for index_1=1:m

F_xb(index_1)=k2*dot(R(:,3,index_1),id(:,1))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)));

F_yb(index_1)=k2*dot(R(:,3,index_1),id(:,2))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)));

F_zb(index_1)=k2*dot(R(:,3,index_1),id(:,3))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)))-M*g;

end;


Linear_Velocity(:,:,1)=Linear_Velocity_Initi
al;
x_dot(1)=Linear_Velocity(1,1,1);
y_dot(1)=Linear_Velocity(1,2,1);
z_dot(1)=Linear_Velocity(1,3,1);
for index_2=2:m
    x_dot(index_2)=x_dot(index_2-
1)+(1/M)*(F_xb(index_2-
1)+F_xb(index_2))*dt/2;
    y_dot(index_2)=y_dot(index_2-
1)+(1/M)*(F_yb(index_2-
1)+F_yb(index_2))*dt/2;
    z_dot(index_2)=z_dot(index_2-
1)+(1/M)*(F_zb(index_2-
1)+F_zb(index_2))*dt/2;

Linear_Velocity(:,:,index_2)=[x_dot(index_2)
y_dot(index_2) z_dot(index_2)];
end;



Position(:,:,1)=Position_Initial;
```

```
x(1)=Position(1,1,1);
y(1)=Position(1,2,1);
z(1)=Position(1,3,1);
for index_3=2:m
    x(index_3)=x(index_3-1)+(x_dot(index_3-
1)+x_dot(index_3))*dt/2;
    y(index_3)=y(index_3-1)+(y_dot(index_3-
1)+y_dot(index_3))*dt/2;
    z(index_3)=z(index_3-1)+(z_dot(index_3-
1)+z_dot(index_3))*dt/2;
    Position(:,:,index_3)=[x(index_3)
y(index_3) z(index_3)];

end;
elseif T == 0

[Linear_Velocity]=Linear_Velocity_Initial;
end
```

Orientation_Matrix function

```
function
[R]=Orientation_Matrix(phi1_dot_initial,phi2
_dot_initial,phi3_dot_initial,phi4_dot_initi
al,T,rate1,rate2,rate3,rate4,Orientation_Ini
tial,Position_Initial,Rate_of_Change_R_Initi
al,Linear_Velocity_Initial)

if T>0;
dt=0.0005;
phi1_dot(1)=phi1_dot_initial;
phi2_dot(1)=phi2_dot_initial;
phi3_dot(1)=phi3_dot_initial;
phi4_dot(1)=phi4_dot_initial;
i=2;
for time=dt:dt:T
    phi1_dot(i)=phi1_dot(i-1)+rate1*dt;
    phi2_dot(i)=phi2_dot(i-1)-rate2*dt;
    phi3_dot(i)=phi3_dot(i-1)+rate3*dt;
    phi4_dot(i)=phi4_dot(i-1)-rate4*dt;
    i=i+1;
end;

l=0.315; %in meters
k1=5.86465*10^(-3);
k2=5.86465*10^(-3);
[a m]=size(phi1_dot);
for n=1:m
    F_alpha(n)=-
k1*((abs(phi1_dot(n))*phi1_dot(n))+(abs(phi2
_dot(n))*phi2_dot(n))+(abs(phi3_dot(n))*phi3
_dot(n))+(abs(phi4_dot(n))*phi4_dot(n)));

F_beta(n)=l*k2*((abs(phi3_dot(n))*phi3_dot(n
))-(abs(phi1_dot(n))*phi1_dot(n)));

F_theta(n)=l*k2*((abs(phi4_dot(n))*phi4_dot(
n))-(abs(phi2_dot(n))*phi2_dot(n)));
end


Rate_of_Change_R(:,:,1)=Rate_of_Change_R_Ini
tial;
alpha(1)=Rate_of_Change_R(1,1,1);
%alpha_initial
beta(1)=Rate_of_Change_R(1,2,1);
%beta_initial
theta(1)=Rate_of_Change_R(1,3,1);
%theta_initial
Ixx=0.0887; %in kg*m^2
Iyy=0.0887; %in kg*m^2
Izz=0.6062; %in kg*m^2
for k=2:m
    alpha(k)=alpha(k-1)+((F_alpha(k-
1)+F_alpha(k))/Izz)*dt/2;
    beta(k)=beta(k-1)+((F_beta(k-
1)+F_beta(k))/Iyy)*dt/2;
    theta(k)=theta(k-1)+((F_theta(k-
1)+F_theta(k))/Ixx)*dt/2;
    Rate_of_Change_R(:,:,k)=[alpha(k)
beta(k) theta(k)];

end;

R(:,:,1)=Orientation_Initial;
id=[1 0 0; 0 1 0; 0 0 1];
for index=2:m

v_norm=sqrt((alpha(index)*dt)^2+(beta(index)
*dt)^2+(theta(index)*dt)^2);
    v_matrix=[0 -alpha(index)*dt
beta(index)*dt; alpha(index)*dt 0 -
theta(index)*dt; -beta(index)*dt
theta(index)*dt 0];
    if v_matrix==[0 0 0; 0 0 0; 0 0 0]
        exp_v_at_identity=id;
        R(:,:,index)=R(:,:,index-
1)*exp_v_at_identity;
    else

exp_v_at_identity=id+(sin(v_norm)/v_norm)*v_
matrix+((1-
cos(v_norm))/v_norm^2)*(v_matrix)^2;
        R(:,:,index)=R(:,:,index-
1)*exp_v_at_identity;
    end;

end;


M=1.815; %in kg
g=9.8; %in m/s^2
for index_1=1:m

F_xb(index_1)=k2*dot(R(:,3,index_1),id(:,1))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)));

F_yb(index_1)=k2*dot(R(:,3,index_1),id(:,2))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)));

F_zb(index_1)=k2*dot(R(:,3,index_1),id(:,3))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)))-M*g;

end;


Linear_Velocity(:,:,1)=Linear_Velocity_Initi
al;
x_dot(1)=Linear_Velocity(1,1,1);
y_dot(1)=Linear_Velocity(1,2,1);
z_dot(1)=Linear_Velocity(1,3,1);
for index_2=2:m
    x_dot(index_2)=x_dot(index_2-
1)+(1/M)*(F_xb(index_2-
1)+F_xb(index_2))*dt/2;
    y_dot(index_2)=y_dot(index_2-
1)+(1/M)*(F_yb(index_2-
1)+F_yb(index_2))*dt/2;
    z_dot(index_2)=z_dot(index_2-
1)+(1/M)*(F_zb(index_2-
1)+F_zb(index_2))*dt/2;

Linear_Velocity(:,:,index_2)=[x_dot(index_2)
y_dot(index_2) z_dot(index_2)];
end;



Position(:,:,1)=Position_Initial;
x(1)=Position(1,1,1);
y(1)=Position(1,2,1);
z(1)=Position(1,3,1);
```

```
for index_3=2:m
    x(index_3)=x(index_3-1)+(x_dot(index_3-
1)+x_dot(index_3))*dt/2;
    y(index_3)=y(index_3-1)+(y_dot(index_3-
1)+y_dot(index_3))*dt/2;
    z(index_3)=z(index_3-1)+(z_dot(index_3-
1)+z_dot(index_3))*dt/2;
    Position(:,:,index_3)=[x(index_3)
y(index_3) z(index_3)];

end;
elseif T == 0;
    [R]=Orientation_Initial;
end
```

Rate_of_Change_R_Matrix function

```
function
[Rate_of_Change_R]=Rate_of_Change_R_Matrix(p
hi1_dot_initial,phi2_dot_initial,phi3_dot_in
itial,phi4_dot_initial,T,rate1,rate2,rate3,r
ate4,Orientation_Initial,Position_Initial,Ra
te_of_Change_R_Initial,Linear_Velocity_Initi
al)
if T>0;
dt=0.0005;
phi1_dot(1)=phi1_dot_initial;
phi2_dot(1)=phi2_dot_initial;
phi3_dot(1)=phi3_dot_initial;
phi4_dot(1)=phi4_dot_initial;
i=2;
for time=dt:dt:T
    phi1_dot(i)=phi1_dot(i-1)+rate1*dt;
    phi2_dot(i)=phi2_dot(i-1)-rate2*dt;
    phi3_dot(i)=phi3_dot(i-1)+rate3*dt;
    phi4_dot(i)=phi4_dot(i-1)-rate4*dt;
    i=i+1;
end;

l=0.315; %in meters
k1=5.86465*10^(-3);
k2=5.86465*10^(-3);
[a m]=size(phi1_dot);
for n=1:m
    F_alpha(n)=-
k1*((abs(phi1_dot(n))*phi1_dot(n))+(abs(phi2
_dot(n))*phi2_dot(n))+(abs(phi3_dot(n))*phi3
_dot(n))+(abs(phi4_dot(n))*phi4_dot(n)));

F_beta(n)=l*k2*((abs(phi3_dot(n))*phi3_dot(n
))-(abs(phi1_dot(n))*phi1_dot(n)));

F_theta(n)=l*k2*((abs(phi4_dot(n))*phi4_dot(
n))-(abs(phi2_dot(n))*phi2_dot(n)));
end


Rate_of_Change_R(:,:,1)=Rate_of_Change_R_Ini
tial;
alpha(1)=Rate_of_Change_R(1,1,1);
%alpha_initial
beta(1)=Rate_of_Change_R(1,2,1);
%beta_initial
theta(1)=Rate_of_Change_R(1,3,1);
%theta_initial
Ixx=0.0887; %in kg*m^2
Iyy=0.0887; %in kg*m^2
Izz=0.6062; %in kg*m^2
for k=2:m
    alpha(k)=alpha(k-1)+((F_alpha(k-
1)+F_alpha(k))/Izz)*dt/2;
    beta(k)=beta(k-1)+((F_beta(k-
1)+F_beta(k))/Iyy)*dt/2;
    theta(k)=theta(k-1)+((F_theta(k-
1)+F_theta(k))/Ixx)*dt/2;
    Rate_of_Change_R(:,:,k)=[alpha(k)
beta(k) theta(k)];

end;

R(:,:,1)=Orientation_Initial;
id=[1 0 0; 0 1 0; 0 0 1];
for index=2:m

v_norm=sqrt((alpha(index)*dt)^2+(beta(index)
*dt)^2+(theta(index)*dt)^2);
    v_matrix=[0 -alpha(index)*dt
beta(index)*dt; alpha(index)*dt 0 -
theta(index)*dt; -beta(index)*dt
theta(index)*dt 0];
    if v_matrix==[0 0 0; 0 0 0; 0 0 0]
        exp_v_at_identity=id;
        R(:,:,index)=R(:,:,index-
1)*exp_v_at_identity;
    else

exp_v_at_identity=id+(sin(v_norm)/v_norm)*v_
matrix+((1-
cos(v_norm))/v_norm^2)*(v_matrix)^2;
        R(:,:,index)=R(:,:,index-
1)*exp_v_at_identity;
    end;

end;


M=1.815; %in kg
g=9.8; %in m/s^2
for index_1=1:m

F_xb(index_1)=k2*dot(R(:,3,index_1),id(:,1))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)));

F_yb(index_1)=k2*dot(R(:,3,index_1),id(:,2))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)));

F_zb(index_1)=k2*dot(R(:,3,index_1),id(:,3))
*((abs(phi1_dot(n))*phi1_dot(n))-
(abs(phi2_dot(n))*phi2_dot(n))+(abs(phi3_dot
(n))*phi3_dot(n))-
(abs(phi4_dot(n))*phi4_dot(n)))-M*g;

end;


Linear_Velocity(:,:,1)=Linear_Velocity_Initi
al;
x_dot(1)=Linear_Velocity(1,1,1);
y_dot(1)=Linear_Velocity(1,2,1);
z_dot(1)=Linear_Velocity(1,3,1);
for index_2=2:m
    x_dot(index_2)=x_dot(index_2-
1)+(1/M)*(F_xb(index_2-
1)+F_xb(index_2))*dt/2;
    y_dot(index_2)=y_dot(index_2-
1)+(1/M)*(F_yb(index_2-
1)+F_yb(index_2))*dt/2;
    z_dot(index_2)=z_dot(index_2-
1)+(1/M)*(F_zb(index_2-
1)+F_zb(index_2))*dt/2;

Linear_Velocity(:,:,index_2)=[x_dot(index_2)
y_dot(index_2) z_dot(index_2)];
end;



Position(:,:,1)=Position_Initial;
x(1)=Position(1,1,1);
y(1)=Position(1,2,1);
z(1)=Position(1,3,1);
```

```
for index_3=2:m
    x(index_3)=x(index_3-1)+(x_dot(index_3-
1)+x_dot(index_3))*dt/2;
    y(index_3)=y(index_3-1)+(y_dot(index_3-
1)+y_dot(index_3))*dt/2;
    z(index_3)=z(index_3-1)+(z_dot(index_3-
1)+z_dot(index_3))*dt/2;
    Position(:,:,index_3)=[x(index_3)
y(index_3) z(index_3)];

end;
elseif T == 0

[Rate_of_Change_R]=Rate_of_Change_R_Initial;
end
```

Last_Element_Function

```
function
[End_Element]=Last_Element_Function(three_di
m_array)
[a b c]=size(three_dim_array);
End_Element=three_dim_array(:,:,c);
```

Sanity_Check function

```
function [Matrix] = Sanity_Check (Matrix)

[a b] = size(Matrix);
for row = 1:a
    for col = 1:b
        if abs(Matrix(row,col)) < 8*10^(-4)
            Matrix(row,col) = 0;
        end

        if Matrix(row,col) > 0
            if abs(Matrix(row,col)-1) <
8*10^(-4)
                Matrix(row,col) = 1;
            end
        end

        if Matrix(row,col) < 0
            if abs(Matrix(row,col)-(-1)) <
8*10^(-4)
                Matrix(row,col) = -1;
            end
        end
    end
end
```

stop_function

```
function
[b_1,b_2,b_3,position_vector,Linear_Velocity
_vector,Rate_of_Change_R_vector,R_end_tilt_7
,position_end_tilt_7,Rate_of_Change_R_end_ti
lt_7,Linear_Velocity_end_tilt_7]=stop_functi
on(Orientation_Initial,Position_Initial,Rate
_of_change_Orientation_Initial,Linear_veloci
ty_Initial,T_1,T_2,T_4,T_6,rate)



T_3=2*T_1;
T_5=T_3;
T_7=T_1;


if T_2 ~= 0

%for this maneuver, motor 1 and 2 will
always maintain their hovering speed at
27.53596541rad/s.
%Phase 1:
%motor 3 and motor 4
%accelerating at a constant rate of 3
rad/s/s for 0.1s.
phi1_dot=27.53596541;
phi2_dot=-27.53596541;
phi3_dot=27.53596541;
phi4_dot=-27.53596541;
rate_1=rate;
rate_2=rate;
rate_3=0;
rate_4=0;



R_tilt_1=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3
,rate_4,Orientation_Initial,Position_Initial
,Rate_of_change_Orientation_Initial,Linear_v
elocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_1=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,ra
te_3,rate_4,Orientation_Initial,Position_Ini
tial,Rate_of_change_Orientation_Initial,Line
ar_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_1=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,ra
te_1,rate_2,rate_3,rate_4,Orientation_Initia
l,Position_Initial,Rate_of_change_Orientatio
n_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_1=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,
rate_1,rate_2,rate_3,rate_4,Orientation_Init
ial,Position_Initial,Rate_of_change_Orientat
ion_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

[size_1]=size(R_tilt_1);
for index_1=1:size_1(1,3)

b_1_tilt_1(index_1,:)=R_tilt_1(:,1,index_1).
';

b_2_tilt_1(index_1,:)=R_tilt_1(:,2,index_1).
';

b_3_tilt_1(index_1,:)=R_tilt_1(:,3,index_1).
';

position_vector_1(index_1,:)=position_tilt_1
(1,:,index_1);

Linear_Velocity_vector_1(index_1,:)=Linear_V
elocity_tilt_1(1,:,index_1);

Rate_of_Change_R_vector_1(index_1,:)=Rate_of
_Change_R_tilt_1(1,:,index_1);
end


R_end_tilt_1=Last_Element_Function(R_tilt_1)
;
position_end_tilt_1=Last_Element_Function(po
sition_tilt_1);
Linear_Velocity_end_tilt_1=Last_Element_Func
tion(Linear_Velocity_tilt_1);
Rate_of_Change_R_end_tilt_1=Last_Element_Fun
ction(Rate_of_Change_R_tilt_1);


%Phase 2:
%motor 3 and 4 maintain speed at the end of
phase 1 for 0.3052915087s
%phase 2 runs for 0.3052915087s.

phi1_dot=phi1_dot+rate_1*T_1;
phi2_dot=phi2_dot-rate_2*T_1;
phi3_dot=phi3_dot+rate_3*T_1;
phi4_dot=phi4_dot-rate_4*T_1;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;


R_tilt_2=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_2,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_1,position_end_tilt_1,Rat
e_of_Change_R_end_tilt_1,Linear_Velocity_end
_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_2=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_2,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_1,position_end_tilt_1
,Rate_of_Change_R_end_tilt_1,Linear_Velocity
_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
```

```
Linear_Velocity_tilt_2=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_1,posit
ion_end_tilt_1,Rate_of_Change_R_end_tilt_1,L
inear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_2=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_1,pos
ition_end_tilt_1,Rate_of_Change_R_end_tilt_1
,Linear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_2]=size(R_tilt_2);
for index_2=1:size_2(1,3)

b_1_tilt_2(index_2,:)=R_tilt_2(:,1,index_2).
';

b_2_tilt_2(index_2,:)=R_tilt_2(:,2,index_2).
';

b_3_tilt_2(index_2,:)=R_tilt_2(:,3,index_2).
';

position_vector_2(index_2,:)=position_tilt_2
(1,:,index_2);

Linear_Velocity_vector_2(index_2,:)=Linear_V
elocity_tilt_2(1,:,index_2);

Rate_of_Change_R_vector_2(index_2,:)=Rate_of
_Change_R_tilt_2(1,:,index_2);
end


R_end_tilt_2=Last_Element_Function(R_tilt_2)
;
position_end_tilt_2=Last_Element_Function(po
sition_tilt_2);
Linear_Velocity_end_tilt_2=Last_Element_Func
tion(Linear_Velocity_tilt_2);
Rate_of_Change_R_end_tilt_2=Last_Element_Fun
ction(Rate_of_Change_R_tilt_2);


%phase 3:
%motor 3 and 4 decelerate at a rate of 3
rad/s/s.
%phase 3 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_2;
phi2_dot=phi2_dot-rate_2*T_2;
phi3_dot=phi3_dot+rate_3*T_2;
phi4_dot=phi4_dot-rate_4*T_2;
rate_1=-rate;
rate_2=-rate;
rate_3=0;
rate_4=0;


R_tilt_3=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_3,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_2,position_end_tilt_2,Rat
e_of_Change_R_end_tilt_2,Linear_Velocity_end
_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_3=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_2,position_end_tilt_2
,Rate_of_Change_R_end_tilt_2,Linear_Velocity
_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_3=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_2,posit
ion_end_tilt_2,Rate_of_Change_R_end_tilt_2,L
inear_Velocity_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_3=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_2,pos
ition_end_tilt_2,Rate_of_Change_R_end_tilt_2
,Linear_Velocity_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_3]=size(R_tilt_3);
for index_3=1:size_3(1,3)

b_1_tilt_3(index_3,:)=R_tilt_3(:,1,index_3).
';

b_2_tilt_3(index_3,:)=R_tilt_3(:,2,index_3).
';

b_3_tilt_3(index_3,:)=R_tilt_3(:,3,index_3).
';

position_vector_3(index_3,:)=position_tilt_3
(1,:,index_3);

Linear_Velocity_vector_3(index_3,:)=Linear_V
elocity_tilt_3(1,:,index_3);

Rate_of_Change_R_vector_3(index_3,:)=Rate_of
_Change_R_tilt_3(1,:,index_3);
end


R_end_tilt_3=Last_Element_Function(R_tilt_3)
;
position_end_tilt_3=Last_Element_Function(po
sition_tilt_3);
Linear_Velocity_end_tilt_3=Last_Element_Func
tion(Linear_Velocity_tilt_3);
Rate_of_Change_R_end_tilt_3=Last_Element_Fun
ction(Rate_of_Change_R_tilt_3);


%Phase 4:
```

```
%motor 3 and 4 maintain speed at the end of
phase 3 for 0.7189148253s
%phase 4 runs for 0.7189148253s.

phi1_dot=phi1_dot+rate_1*T_3;
phi2_dot=phi2_dot-rate_2*T_3;
phi3_dot=phi3_dot+rate_3*T_3;
phi4_dot=phi4_dot-rate_4*T_3;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;



R_tilt_4=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_4,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_3,position_end_tilt_3,Rat
e_of_Change_R_end_tilt_3,Linear_Velocity_end
_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_4=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_3,position_end_tilt_3
,Rate_of_Change_R_end_tilt_3,Linear_Velocity
_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_4=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_3,posit
ion_end_tilt_3,Rate_of_Change_R_end_tilt_3,L
inear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_4=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_3,pos
ition_end_tilt_3,Rate_of_Change_R_end_tilt_3
,Linear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_4]=size(R_tilt_4);
for index_4=1:size_4(1,3)

b_1_tilt_4(index_4,:)=R_tilt_4(:,1,index_4).
';

b_2_tilt_4(index_4,:)=R_tilt_4(:,2,index_4).
';

b_3_tilt_4(index_4,:)=R_tilt_4(:,3,index_4).
';

position_vector_4(index_4,:)=position_tilt_4
(1,:,index_4);

Linear_Velocity_vector_4(index_4,:)=Linear_V
elocity_tilt_4(1,:,index_4);

Rate_of_Change_R_vector_4(index_4,:)=Rate_of
_Change_R_tilt_4(1,:,index_4);
end


R_end_tilt_4=Last_Element_Function(R_tilt_4)
;
position_end_tilt_4=Last_Element_Function(po
sition_tilt_4);
Linear_Velocity_end_tilt_4=Last_Element_Funct
ion(Linear_Velocity_tilt_4);
Rate_of_Change_R_end_tilt_4=Last_Element_Fun
ction(Rate_of_Change_R_tilt_4);


%phase 5:
%motor 3 and 4 accelerate at a rate of 3
rad/s/s.
%phase 5 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_4;
phi2_dot=phi2_dot-rate_2*T_4;
phi3_dot=phi3_dot+rate_3*T_4;
phi4_dot=phi4_dot-rate_4*T_4;
rate_1=rate;
rate_2=rate;
rate_3=0;
rate_4=0;



R_tilt_5=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_5,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_4,position_end_tilt_4,Rat
e_of_Change_R_end_tilt_4,Linear_Velocity_end
_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_5=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_4,position_end_tilt_4
,Rate_of_Change_R_end_tilt_4,Linear_Velocity
_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_5=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_4,posit
ion_end_tilt_4,Rate_of_Change_R_end_tilt_4,L
inear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_5=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_4,pos
ition_end_tilt_4,Rate_of_Change_R_end_tilt_4
,Linear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_5]=size(R_tilt_5);
```

```
for index_5=1:size_5(1,3)

b_1_tilt_5(index_5,:)=R_tilt_5(:,1,index_5).
';

b_2_tilt_5(index_5,:)=R_tilt_5(:,2,index_5).
';

b_3_tilt_5(index_5,:)=R_tilt_5(:,3,index_5).
';

position_vector_5(index_5,:)=position_tilt_5
(1,:,index_5);

Linear_Velocity_vector_5(index_5,:)=Linear_V
elocity_tilt_5(1,:,index_5);

Rate_of_Change_R_vector_5(index_5,:)=Rate_of
_Change_R_tilt_5(1,:,index_5);
end


R_end_tilt_5=Last_Element_Function(R_tilt_5)
;
position_end_tilt_5=Last_Element_Function(po
sition_tilt_5);
Linear_Velocity_end_tilt_5=Last_Element_Func
tion(Linear_Velocity_tilt_5);
Rate_of_Change_R_end_tilt_5=Last_Element_Fun
ction(Rate_of_Change_R_tilt_5);


%phase 6:
%motor 3 and 4 maintain speed at the end of
phase 5 for 0.3052915087s.
%phase 6 runs for 0.3052915087s.

phi1_dot=phi1_dot+rate_1*T_5;
phi2_dot=phi2_dot-rate_2*T_5;
phi3_dot=phi3_dot+rate_3*T_5;
phi4_dot=phi4_dot-rate_4*T_5;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;


R_tilt_6=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_6,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_5,position_end_tilt_5,Rat
e_of_Change_R_end_tilt_5,Linear_Velocity_end
_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_6=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_6,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_5,position_end_tilt_5
,Rate_of_Change_R_end_tilt_5,Linear_Velocity
_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_6=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_6,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_5,posit
ion_end_tilt_5,Rate_of_Change_R_end_tilt_5,L
inear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_6=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_6,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_5,pos
ition_end_tilt_5,Rate_of_Change_R_end_tilt_5
,Linear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_6]=size(R_tilt_6);
for index_6=1:size_6(1,3)

b_1_tilt_6(index_6,:)=R_tilt_6(:,1,index_6).
';

b_2_tilt_6(index_6,:)=R_tilt_6(:,2,index_6).
';

b_3_tilt_6(index_6,:)=R_tilt_6(:,3,index_6).
';

position_vector_6(index_6,:)=position_tilt_6
(1,:,index_6);

Linear_Velocity_vector_6(index_6,:)=Linear_V
elocity_tilt_6(1,:,index_6);

Rate_of_Change_R_vector_6(index_6,:)=Rate_of
_Change_R_tilt_6(1,:,index_6);
end


R_end_tilt_6=Last_Element_Function(R_tilt_6)
;
position_end_tilt_6=Last_Element_Function(po
sition_tilt_6);
Linear_Velocity_end_tilt_6=Last_Element_Func
tion(Linear_Velocity_tilt_6);
Rate_of_Change_R_end_tilt_6=Last_Element_Fun
ction(Rate_of_Change_R_tilt_6);


%phase 7:
%motor 3 and 4decelerate at a rate of 3
rad/s/s.
%phase 7 runs for 0.1s.

phi1_dot=phi1_dot+rate_1*T_6;
phi2_dot=phi2_dot-rate_2*T_6;
phi3_dot=phi3_dot+rate_3*T_6;
phi4_dot=phi4_dot-rate_4*T_6;
rate_1=-rate;
rate_2=-rate;
rate_3=0;
rate_4=0;


R_tilt_7=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_7,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_6,position_end_tilt_6,Rat
e_of_Change_R_end_tilt_6,Linear_Velocity_end
_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
```

```
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_7=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_6,position_end_tilt_6
,Rate_of_Change_R_end_tilt_6,Linear_Velocity
_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_7=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_6,posit
ion_end_tilt_6,Rate_of_Change_R_end_tilt_6,L
inear_Velocity_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_7=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_6,pos
ition_end_tilt_6,Rate_of_Change_R_end_tilt_6
,Linear_Velocity_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_7]=size(R_tilt_7);
for index_7=1:size_7(1,3)

b_1_tilt_7(index_7,:)=R_tilt_7(:,1,index_7).
';

b_2_tilt_7(index_7,:)=R_tilt_7(:,2,index_7).
';

b_3_tilt_7(index_7,:)=R_tilt_7(:,3,index_7).
';

position_vector_7(index_7,:)=position_tilt_7
(1,:,index_7);

Linear_Velocity_vector_7(index_7,:)=Linear_V
elocity_tilt_7(1,:,index_7);

Rate_of_Change_R_vector_7(index_7,:)=Rate_of
_Change_R_tilt_7(1,:,index_7);
end


R_end_tilt_7=Last_Element_Function(R_tilt_7)
;
position_end_tilt_7=Last_Element_Function(po
sition_tilt_7);
Linear_Velocity_end_tilt_7=Last_Element_Func
tion(Linear_Velocity_tilt_7);
Rate_of_Change_R_end_tilt_7=Last_Element_Fun
ction(Rate_of_Change_R_tilt_7);



%% Animation.
b_1=cat(1,b_1_tilt_1,b_1_tilt_2,b_1_tilt_3,b
_1_tilt_4,b_1_tilt_5,b_1_tilt_6,b_1_tilt_7);
b_2=cat(1,b_2_tilt_1,b_2_tilt_2,b_2_tilt_3,b
_2_tilt_4,b_2_tilt_5,b_2_tilt_6,b_2_tilt_7);
b_3=cat(1,b_3_tilt_1,b_3_tilt_2,b_3_tilt_3,b
_3_tilt_4,b_3_tilt_5,b_3_tilt_6,b_3_tilt_7);
position_vector=cat(1,position_vector_1,posi
tion_vector_2,position_vector_3,position_vec
tor_4,position_vector_5,position_vector_6,po
sition_vector_7);
Linear_Velocity_vector=cat(1,Linear_Velocity
_vector_1,Linear_Velocity_vector_2,Linear_Ve
locity_vector_3,Linear_Velocity_vector_4,Lin
ear_Velocity_vector_5,Linear_Velocity_vector
_6,Linear_Velocity_vector_7);
Rate_of_Change_R_vector=cat(1,Rate_of_Change
_R_vector_1,Rate_of_Change_R_vector_2,Rate_o
f_Change_R_vector_3,Rate_of_Change_R_vector_
4,Rate_of_Change_R_vector_5,Rate_of_Change_R
_vector_6,Rate_of_Change_R_vector_7);


else

%for this manuver, motor 1 and 2 will always
maintain their hovering speed at
27.53596541rad/s.
%Phase 1:
%motor 3 and motor 4
%accelerating at a constant rate of 3
rad/s/s for 0.1s.
phi1_dot=27.53596541;
phi2_dot=-27.53596541;
phi3_dot=27.53596541;
phi4_dot=-27.53596541;
rate_1=rate;
rate_2=rate;
rate_3=0;
rate_4=0;



R_tilt_1=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3
,rate_4,Orientation_Initial,Position_Initial
,Rate_of_change_Orientation_Initial,Linear_v
elocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_1=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,ra
te_3,rate_4,Orientation_Initial,Position_Ini
tial,Rate_of_change_Orientation_Initial,Line
ar_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_1=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,ra
te_1,rate_2,rate_3,rate_4,Orientation_Initia
l,Position_Initial,Rate_of_change_Orientatio
n_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_1=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,
rate_1,rate_2,rate_3,rate_4,Orientation_Init
ial,Position_Initial,Rate_of_change_Orientat
ion_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
```

```
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

[size_1]=size(R_tilt_1);
for index_1=1:size_1(1,3)

b_1_tilt_1(index_1,:)=R_tilt_1(:,1,index_1).
';

b_2_tilt_1(index_1,:)=R_tilt_1(:,2,index_1).
';

b_3_tilt_1(index_1,:)=R_tilt_1(:,3,index_1).
';

position_vector_1(index_1,:)=position_tilt_1
(1,:,index_1);

Linear_Velocity_vector_1(index_1,:)=Linear_V
elocity_tilt_1(1,:,index_1);

Rate_of_Change_R_vector_1(index_1,:)=Rate_of
_Change_R_tilt_1(1,:,index_1);
end


R_end_tilt_1=Last_Element_Function(R_tilt_1)
;
position_end_tilt_1=Last_Element_Function(po
sition_tilt_1);
Linear_Velocity_end_tilt_1=Last_Element_Func
tion(Linear_Velocity_tilt_1);
Rate_of_Change_R_end_tilt_1=Last_Element_Fun
ction(Rate_of_Change_R_tilt_1);



%phase 3:
%motor 3 and 4 decelerate at a rate of 3
rad/s/s.
%phase 3 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_1;
phi2_dot=phi2_dot-rate_2*T_1;
phi3_dot=phi3_dot+rate_3*T_1;
phi4_dot=phi4_dot-rate_4*T_1;
rate_1=-rate;
rate_2=-rate;
rate_3=0;
rate_4=0;



R_tilt_3=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_3,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_1,position_end_tilt_1,Rat
e_of_Change_R_end_tilt_1,Linear_Velocity_end
_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_3=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_1,position_end_tilt_1
,Rate_of_Change_R_end_tilt_1,Linear_Velocity
_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_3=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_1,posit
ion_end_tilt_1,Rate_of_Change_R_end_tilt_1,L
inear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_3=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_1,pos
ition_end_tilt_1,Rate_of_Change_R_end_tilt_1
,Linear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_3]=size(R_tilt_3);
for index_3=1:size_3(1,3)

b_1_tilt_3(index_3,:)=R_tilt_3(:,1,index_3).
';

b_2_tilt_3(index_3,:)=R_tilt_3(:,2,index_3).
';

b_3_tilt_3(index_3,:)=R_tilt_3(:,3,index_3).
';

position_vector_3(index_3,:)=position_tilt_3
(1,:,index_3);

Linear_Velocity_vector_3(index_3,:)=Linear_V
elocity_tilt_3(1,:,index_3);

Rate_of_Change_R_vector_3(index_3,:)=Rate_of
_Change_R_tilt_3(1,:,index_3);
end


R_end_tilt_3=Last_Element_Function(R_tilt_3)
;
position_end_tilt_3=Last_Element_Function(po
sition_tilt_3);
Linear_Velocity_end_tilt_3=Last_Element_Func
tion(Linear_Velocity_tilt_3);
Rate_of_Change_R_end_tilt_3=Last_Element_Fun
ction(Rate_of_Change_R_tilt_3);


%Phase 4:
%motor 3 and 4 maintain speed at the end of
phase 3 for 0.7189148253s
%phase 4 runs for T_4s.

phi1_dot=phi1_dot+rate_1*T_3;
phi2_dot=phi2_dot-rate_2*T_3;
phi3_dot=phi3_dot+rate_3*T_3;
phi4_dot=phi4_dot-rate_4*T_3;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;
```

```
R_tilt_4=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_4,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_3,position_end_tilt_3,Rat
e_of_Change_R_end_tilt_3,Linear_Velocity_end
_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_4=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_3,position_end_tilt_3
,Rate_of_Change_R_end_tilt_3,Linear_Velocity
_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_4=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_3,posit
ion_end_tilt_3,Rate_of_Change_R_end_tilt_3,L
inear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_4=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_3,pos
ition_end_tilt_3,Rate_of_Change_R_end_tilt_3
,Linear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_4]=size(R_tilt_4);
for index_4=1:size_4(1,3)

b_1_tilt_4(index_4,:)=R_tilt_4(:,1,index_4).
';

b_2_tilt_4(index_4,:)=R_tilt_4(:,2,index_4).
';

b_3_tilt_4(index_4,:)=R_tilt_4(:,3,index_4).
';

position_vector_4(index_4,:)=position_tilt_4
(1,:,index_4);

Linear_Velocity_vector_4(index_4,:)=Linear_V
elocity_tilt_4(1,:,index_4);

Rate_of_Change_R_vector_4(index_4,:)=Rate_of
_Change_R_tilt_4(1,:,index_4);
end


R_end_tilt_4=Last_Element_Function(R_tilt_4)
;
position_end_tilt_4=Last_Element_Function(po
sition_tilt_4);
Linear_Velocity_end_tilt_4=Last_Element_Func
tion(Linear_Velocity_tilt_4);
Rate_of_Change_R_end_tilt_4=Last_Element_Fun
ction(Rate_of_Change_R_tilt_4);
```

```
%phase 5:
%motor 3 and 4 accelerate at a rate of 3
rad/s/s.
%phase 5 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_4;
phi2_dot=phi2_dot-rate_2*T_4;
phi3_dot=phi3_dot+rate_3*T_4;
phi4_dot=phi4_dot-rate_4*T_4;
rate_1=rate;
rate_2=rate;
rate_3=0;
rate_4=0;



R_tilt_5=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_5,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_4,position_end_tilt_4,Rat
e_of_Change_R_end_tilt_4,Linear_Velocity_end
_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_5=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_4,position_end_tilt_4
,Rate_of_Change_R_end_tilt_4,Linear_Velocity
_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_5=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_4,posit
ion_end_tilt_4,Rate_of_Change_R_end_tilt_4,L
inear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_5=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_4,pos
ition_end_tilt_4,Rate_of_Change_R_end_tilt_4
,Linear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_5]=size(R_tilt_5);
for index_5=1:size_5(1,3)

b_1_tilt_5(index_5,:)=R_tilt_5(:,1,index_5).
';

b_2_tilt_5(index_5,:)=R_tilt_5(:,2,index_5).
';

b_3_tilt_5(index_5,:)=R_tilt_5(:,3,index_5).
';

position_vector_5(index_5,:)=position_tilt_5
(1,:,index_5);

Linear_Velocity_vector_5(index_5,:)=Linear_V
elocity_tilt_5(1,:,index_5);
```

```
Rate_of_Change_R_vector_5(index_5,:)=Rate_of
_Change_R_tilt_5(1,:,index_5);
end


R_end_tilt_5=Last_Element_Function(R_tilt_5)
;
position_end_tilt_5=Last_Element_Function(po
sition_tilt_5);
Linear_Velocity_end_tilt_5=Last_Element_Func
tion(Linear_Velocity_tilt_5);
Rate_of_Change_R_end_tilt_5=Last_Element_Fun
ction(Rate_of_Change_R_tilt_5);



%phase 7:
%motor 3 and 4decelerate at a rate of 3
rad/s/s.
%phase 7 runs for 0.1s.

phi1_dot=phi1_dot+rate_1*T_5;
phi2_dot=phi2_dot-rate_2*T_5;
phi3_dot=phi3_dot+rate_3*T_5;
phi4_dot=phi4_dot-rate_4*T_5;
rate_1=-rate;
rate_2=-rate;
rate_3=0;
rate_4=0;



R_tilt_7=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_7,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_5,position_end_tilt_5,Rat
e_of_Change_R_end_tilt_5,Linear_Velocity_end
_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_7=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_5,position_end_tilt_5
,Rate_of_Change_R_end_tilt_5,Linear_Velocity
_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_7=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_5,posit
ion_end_tilt_5,Rate_of_Change_R_end_tilt_5,L
inear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_7=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_5,pos
ition_end_tilt_5,Rate_of_Change_R_end_tilt_5
,Linear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
[size_7]=size(R_tilt_7);
for index_7=1:size_7(1,3)

b_1_tilt_7(index_7,:)=R_tilt_7(:,1,index_7).
';

b_2_tilt_7(index_7,:)=R_tilt_7(:,2,index_7).
';

b_3_tilt_7(index_7,:)=R_tilt_7(:,3,index_7).
';

position_vector_7(index_7,:)=position_tilt_7
(1,:,index_7);

Linear_Velocity_vector_7(index_7,:)=Linear_V
elocity_tilt_7(1,:,index_7);

Rate_of_Change_R_vector_7(index_7,:)=Rate_of
_Change_R_tilt_7(1,:,index_7);
end


R_end_tilt_7=Last_Element_Function(R_tilt_7)
;
position_end_tilt_7=Last_Element_Function(po
sition_tilt_7);
Linear_Velocity_end_tilt_7=Last_Element_Func
tion(Linear_Velocity_tilt_7);
Rate_of_Change_R_end_tilt_7=Last_Element_Fun
ction(Rate_of_Change_R_tilt_7);



%% Animation outputs.
b_1=cat(1,b_1_tilt_1,b_1_tilt_3,b_1_tilt_4,b
_1_tilt_5,b_1_tilt_7);
b_2=cat(1,b_2_tilt_1,b_2_tilt_3,b_2_tilt_4,b
_2_tilt_5,b_2_tilt_7);
b_3=cat(1,b_3_tilt_1,b_3_tilt_3,b_3_tilt_4,b
_3_tilt_5,b_3_tilt_7);
position_vector=cat(1,position_vector_1,posi
tion_vector_3,position_vector_4,position_vec
tor_5,position_vector_7);
Linear_Velocity_vector=cat(1,Linear_Velocity
_vector_1,Linear_Velocity_vector_3,Linear_Ve
locity_vector_4,Linear_Velocity_vector_5,Lin
ear_Velocity_vector_7);
Rate_of_Change_R_vector=cat(1,Rate_of_Change
_R_vector_1,Rate_of_Change_R_vector_3,Rate_o
f_Change_R_vector_4,Rate_of_Change_R_vector_
5,Rate_of_Change_R_vector_7);


end
```

stop_function_forward function

```
function
[b_1,b_2,b_3,position_vector,Linear_Velocity
_vector,Rate_of_Change_R_vector,R_end_tilt_7
,position_end_tilt_7,Rate_of_Change_R_end_ti
lt_7,Linear_Velocity_end_tilt_7]=stop_functi
on_forward(Orientation_Initial,Position_Init
ial,Rate_of_change_Orientation_Initial,Linea
r_velocity_Initial,T_1,T_2,T_4,T_6,rate)



T_3=2*T_1;
T_5=T_3;
T_7=T_1;



if T_2 ~= 0

%for this manuver, motor 1 and 2 will always
maintain their hovering speed at
27.53596541rad/s.
%Phase 1:
%motor 3 and motor 4
%accelerating at a constant rate of 3
rad/s/s for 0.1s.
phi1_dot=27.53596541;
phi2_dot=-27.53596541;
phi3_dot=27.53596541;
phi4_dot=-27.53596541;
rate_1=0;
rate_2=0;
rate_3=rate;
rate_4=rate;



R_tilt_1=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3
,rate_4,Orientation_Initial,Position_Initial
,Rate_of_change_Orientation_Initial,Linear_v
elocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_1=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,ra
te_3,rate_4,Orientation_Initial,Position_Ini
tial,Rate_of_change_Orientation_Initial,Line
ar_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_1=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,ra
te_1,rate_2,rate_3,rate_4,Orientation_Initia
l,Position_Initial,Rate_of_change_Orientatio
n_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_1=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,
rate_1,rate_2,rate_3,rate_4,Orientation_Init
ial,Position_Initial,Rate_of_change_Orientat
ion_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

[size_1]=size(R_tilt_1);
for index_1=1:size_1(1,3)

b_1_tilt_1(index_1,:)=R_tilt_1(:,1,index_1).
';

b_2_tilt_1(index_1,:)=R_tilt_1(:,2,index_1).
';

b_3_tilt_1(index_1,:)=R_tilt_1(:,3,index_1).
';

position_vector_1(index_1,:)=position_tilt_1
(1,:,index_1);

Linear_Velocity_vector_1(index_1,:)=Linear_V
elocity_tilt_1(1,:,index_1);

Rate_of_Change_R_vector_1(index_1,:)=Rate_of
_Change_R_tilt_1(1,:,index_1);
end



R_end_tilt_1=Last_Element_Function(R_tilt_1)
;
position_end_tilt_1=Last_Element_Function(po
sition_tilt_1);
Linear_Velocity_end_tilt_1=Last_Element_Funct
tion(Linear_Velocity_tilt_1);
Rate_of_Change_R_end_tilt_1=Last_Element_Fun
ction(Rate_of_Change_R_tilt_1);



%Phase 2:
%motor 3 and 4 maintain speed at the end of
phase 1 for 0.3052915087s
%phase 2 runs for 0.3052915087s.

phi1_dot=phi1_dot+rate_1*T_1;
phi2_dot=phi2_dot-rate_2*T_1;
phi3_dot=phi3_dot+rate_3*T_1;
phi4_dot=phi4_dot-rate_4*T_1;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;



R_tilt_2=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_2,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_1,position_end_tilt_1,Rat
e_of_Change_R_end_tilt_1,Linear_Velocity_end
_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_2=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_2,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_1,position_end_tilt_1
,Rate_of_Change_R_end_tilt_1,Linear_Velocity
_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
```

```
Linear_Velocity_tilt_2=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_1,posit
ion_end_tilt_1,Rate_of_Change_R_end_tilt_1,L
inear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_2=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_1,pos
ition_end_tilt_1,Rate_of_Change_R_end_tilt_1
,Linear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_2]=size(R_tilt_2);
for index_2=1:size_2(1,3)

b_1_tilt_2(index_2,:)=R_tilt_2(:,1,index_2).
';

b_2_tilt_2(index_2,:)=R_tilt_2(:,2,index_2).
';

b_3_tilt_2(index_2,:)=R_tilt_2(:,3,index_2).
';

position_vector_2(index_2,:)=position_tilt_2
(1,:,index_2);

Linear_Velocity_vector_2(index_2,:)=Linear_V
elocity_tilt_2(1,:,index_2);

Rate_of_Change_R_vector_2(index_2,:)=Rate_of
_Change_R_tilt_2(1,:,index_2);
end


R_end_tilt_2=Last_Element_Function(R_tilt_2)
;
position_end_tilt_2=Last_Element_Function(po
sition_tilt_2);
Linear_Velocity_end_tilt_2=Last_Element_Func
tion(Linear_Velocity_tilt_2);
Rate_of_Change_R_end_tilt_2=Last_Element_Fun
ction(Rate_of_Change_R_tilt_2);


%phase 3:
%motor 3 and 4 decelerate at a rate of 3
rad/s/s.
%phase 3 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_2;
phi2_dot=phi2_dot-rate_2*T_2;
phi3_dot=phi3_dot+rate_3*T_2;
phi4_dot=phi4_dot-rate_4*T_2;
rate_1=0;
rate_2=0;
rate_3=-rate;
rate_4=-rate;



R_tilt_3=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_3,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_2,position_end_tilt_2,Rat
e_of_Change_R_end_tilt_2,Linear_Velocity_end
_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_3=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_2,position_end_tilt_2
,Rate_of_Change_R_end_tilt_2,Linear_Velocity
_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_3=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_2,posit
ion_end_tilt_2,Rate_of_Change_R_end_tilt_2,L
inear_Velocity_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_3=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_2,pos
ition_end_tilt_2,Rate_of_Change_R_end_tilt_2
,Linear_Velocity_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_3]=size(R_tilt_3);
for index_3=1:size_3(1,3)

b_1_tilt_3(index_3,:)=R_tilt_3(:,1,index_3).
';

b_2_tilt_3(index_3,:)=R_tilt_3(:,2,index_3).
';

b_3_tilt_3(index_3,:)=R_tilt_3(:,3,index_3).
';

position_vector_3(index_3,:)=position_tilt_3
(1,:,index_3);

Linear_Velocity_vector_3(index_3,:)=Linear_V
elocity_tilt_3(1,:,index_3);

Rate_of_Change_R_vector_3(index_3,:)=Rate_of
_Change_R_tilt_3(1,:,index_3);
end


R_end_tilt_3=Last_Element_Function(R_tilt_3)
;
position_end_tilt_3=Last_Element_Function(po
sition_tilt_3);
Linear_Velocity_end_tilt_3=Last_Element_Func
tion(Linear_Velocity_tilt_3);
Rate_of_Change_R_end_tilt_3=Last_Element_Fun
ction(Rate_of_Change_R_tilt_3);


%Phase 4:
```

```
%motor 3 and 4 maintain speed at the end of
phase 3 for 0.7189148253s
%phase 4 runs for 0.7189148253s.

phi1_dot=phi1_dot+rate_1*T_3;
phi2_dot=phi2_dot-rate_2*T_3;
phi3_dot=phi3_dot+rate_3*T_3;
phi4_dot=phi4_dot-rate_4*T_3;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;



R_tilt_4=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_4,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_3,position_end_tilt_3,Rat
e_of_Change_R_end_tilt_3,Linear_Velocity_end
_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_4=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_3,position_end_tilt_3
,Rate_of_Change_R_end_tilt_3,Linear_Velocity
_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_4=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_3,posit
ion_end_tilt_3,Rate_of_Change_R_end_tilt_3,L
inear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_4=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_3,pos
ition_end_tilt_3,Rate_of_Change_R_end_tilt_3
,Linear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_4]=size(R_tilt_4);
for index_4=1:size_4(1,3)

b_1_tilt_4(index_4,:)=R_tilt_4(:,1,index_4).
';

b_2_tilt_4(index_4,:)=R_tilt_4(:,2,index_4).
';

b_3_tilt_4(index_4,:)=R_tilt_4(:,3,index_4).
';

position_vector_4(index_4,:)=position_tilt_4
(1,:,index_4);

Linear_Velocity_vector_4(index_4,:)=Linear_V
elocity_tilt_4(1,:,index_4);

Rate_of_Change_R_vector_4(index_4,:)=Rate_of
_Change_R_tilt_4(1,:,index_4);
end


R_end_tilt_4=Last_Element_Function(R_tilt_4)
;
position_end_tilt_4=Last_Element_Function(po
sition_tilt_4);
Linear_Velocity_end_tilt_4=Last_Element_Funct
tion(Linear_Velocity_tilt_4);
Rate_of_Change_R_end_tilt_4=Last_Element_Fun
ction(Rate_of_Change_R_tilt_4);


%phase 5:
%motor 3 and 4 accelerate at a rate of 3
rad/s/s.
%phase 5 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_4;
phi2_dot=phi2_dot-rate_2*T_4;
phi3_dot=phi3_dot+rate_3*T_4;
phi4_dot=phi4_dot-rate_4*T_4;
rate_1=0;
rate_2=0;
rate_3=rate;
rate_4=rate;



R_tilt_5=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_5,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_4,position_end_tilt_4,Rat
e_of_Change_R_end_tilt_4,Linear_Velocity_end
_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_5=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_4,position_end_tilt_4
,Rate_of_Change_R_end_tilt_4,Linear_Velocity
_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_5=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_4,posit
ion_end_tilt_4,Rate_of_Change_R_end_tilt_4,L
inear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_5=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_4,pos
ition_end_tilt_4,Rate_of_Change_R_end_tilt_4
,Linear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_5]=size(R_tilt_5);
```

```
for index_5=1:size_5(1,3)

b_1_tilt_5(index_5,:)=R_tilt_5(:,1,index_5).
';

b_2_tilt_5(index_5,:)=R_tilt_5(:,2,index_5).
';

b_3_tilt_5(index_5,:)=R_tilt_5(:,3,index_5).
';

position_vector_5(index_5,:)=position_tilt_5
(1,:,index_5);

Linear_Velocity_vector_5(index_5,:)=Linear_V
elocity_tilt_5(1,:,index_5);

Rate_of_Change_R_vector_5(index_5,:)=Rate_of
_Change_R_tilt_5(1,:,index_5);
end


R_end_tilt_5=Last_Element_Function(R_tilt_5)
;
position_end_tilt_5=Last_Element_Function(po
sition_tilt_5);
Linear_Velocity_end_tilt_5=Last_Element_Func
tion(Linear_Velocity_tilt_5);
Rate_of_Change_R_end_tilt_5=Last_Element_Fun
ction(Rate_of_Change_R_tilt_5);


%phase 6:
%motor 3 and 4 maintain speed at the end of
phase 5 for 0.3052915087s.
%phase 6 runs for 0.3052915087s.

phi1_dot=phi1_dot+rate_1*T_5;
phi2_dot=phi2_dot-rate_2*T_5;
phi3_dot=phi3_dot+rate_3*T_5;
phi4_dot=phi4_dot-rate_4*T_5;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;


R_tilt_6=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_6,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_5,position_end_tilt_5,Rat
e_of_Change_R_end_tilt_5,Linear_Velocity_end
_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_6=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_6,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_5,position_end_tilt_5
,Rate_of_Change_R_end_tilt_5,Linear_Velocity
_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_6=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_6,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_5,posit
ion_end_tilt_5,Rate_of_Change_R_end_tilt_5,L
inear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_6=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_6,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_5,pos
ition_end_tilt_5,Rate_of_Change_R_end_tilt_5
,Linear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_6]=size(R_tilt_6);
for index_6=1:size_6(1,3)

b_1_tilt_6(index_6,:)=R_tilt_6(:,1,index_6).
';

b_2_tilt_6(index_6,:)=R_tilt_6(:,2,index_6).
';

b_3_tilt_6(index_6,:)=R_tilt_6(:,3,index_6).
';

position_vector_6(index_6,:)=position_tilt_6
(1,:,index_6);

Linear_Velocity_vector_6(index_6,:)=Linear_V
elocity_tilt_6(1,:,index_6);

Rate_of_Change_R_vector_6(index_6,:)=Rate_of
_Change_R_tilt_6(1,:,index_6);
end


R_end_tilt_6=Last_Element_Function(R_tilt_6)
;
position_end_tilt_6=Last_Element_Function(po
sition_tilt_6);
Linear_Velocity_end_tilt_6=Last_Element_Func
tion(Linear_Velocity_tilt_6);
Rate_of_Change_R_end_tilt_6=Last_Element_Fun
ction(Rate_of_Change_R_tilt_6);


%phase 7:
%motor 3 and 4decelerate at a rate of 3
rad/s/s.
%phase 7 runs for 0.1s.

phi1_dot=phi1_dot+rate_1*T_6;
phi2_dot=phi2_dot-rate_2*T_6;
phi3_dot=phi3_dot+rate_3*T_6;
phi4_dot=phi4_dot-rate_4*T_6;
rate_1=0;
rate_2=0;
rate_3=-rate;
rate_4=-rate;


R_tilt_7=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_7,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_6,position_end_tilt_6,Rat
e_of_Change_R_end_tilt_6,Linear_Velocity_end
_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
```

```
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_7=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_6,position_end_tilt_6
,Rate_of_Change_R_end_tilt_6,Linear_Velocity
_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_7=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_6,posit
ion_end_tilt_6,Rate_of_Change_R_end_tilt_6,L
inear_Velocity_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_7=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_6,pos
ition_end_tilt_6,Rate_of_Change_R_end_tilt_6
,Linear_Velocity_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_7]=size(R_tilt_7);
for index_7=1:size_7(1,3)

b_1_tilt_7(index_7,:)=R_tilt_7(:,1,index_7).
';

b_2_tilt_7(index_7,:)=R_tilt_7(:,2,index_7).
';

b_3_tilt_7(index_7,:)=R_tilt_7(:,3,index_7).
';

position_vector_7(index_7,:)=position_tilt_7
(1,:,index_7);

Linear_Velocity_vector_7(index_7,:)=Linear_V
elocity_tilt_7(1,:,index_7);

Rate_of_Change_R_vector_7(index_7,:)=Rate_of
_Change_R_tilt_7(1,:,index_7);
end


R_end_tilt_7=Last_Element_Function(R_tilt_7)
;
position_end_tilt_7=Last_Element_Function(po
sition_tilt_7);
Linear_Velocity_end_tilt_7=Last_Element_Func
tion(Linear_Velocity_tilt_7);
Rate_of_Change_R_end_tilt_7=Last_Element_Fun
ction(Rate_of_Change_R_tilt_7);



%% Animation.
b_1=cat(1,b_1_tilt_1,b_1_tilt_2,b_1_tilt_3,b
_1_tilt_4,b_1_tilt_5,b_1_tilt_6,b_1_tilt_7);
b_2=cat(1,b_2_tilt_1,b_2_tilt_2,b_2_tilt_3,b
_2_tilt_4,b_2_tilt_5,b_2_tilt_6,b_2_tilt_7);
b_3=cat(1,b_3_tilt_1,b_3_tilt_2,b_3_tilt_3,b
_3_tilt_4,b_3_tilt_5,b_3_tilt_6,b_3_tilt_7);
position_vector=cat(1,position_vector_1,posi
tion_vector_2,position_vector_3,position_vec
tor_4,position_vector_5,position_vector_6,po
sition_vector_7);
Linear_Velocity_vector=cat(1,Linear_Velocity
_vector_1,Linear_Velocity_vector_2,Linear_Ve
locity_vector_3,Linear_Velocity_vector_4,Lin
ear_Velocity_vector_5,Linear_Velocity_vector
_6,Linear_Velocity_vector_7);
Rate_of_Change_R_vector=cat(1,Rate_of_Change
_R_vector_1,Rate_of_Change_R_vector_2,Rate_o
f_Change_R_vector_3,Rate_of_Change_R_vector_
4,Rate_of_Change_R_vector_5,Rate_of_Change_R
_vector_6,Rate_of_Change_R_vector_7);


else

%for this manuver, motor 1 and 2 will always
maintain their hovering speed at
27.53596541rad/s.
%Phase 1:
%motor 3 and motor 4
%accelerating at a constant rate of 3
rad/s/s for 0.1s.
phi1_dot=27.53596541;
phi2_dot=-27.53596541;
phi3_dot=27.53596541;
phi4_dot=-27.53596541;
rate_1=0;
rate_2=0;
rate_3=rate;
rate_4=rate;



R_tilt_1=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3
,rate_4,Orientation_Initial,Position_Initial
,Rate_of_change_Orientation_Initial,Linear_v
elocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_1=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,ra
te_3,rate_4,Orientation_Initial,Position_Ini
tial,Rate_of_change_Orientation_Initial,Line
ar_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_1=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,ra
te_1,rate_2,rate_3,rate_4,Orientation_Initia
l,Position_Initial,Rate_of_change_Orientatio
n_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_1=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,
rate_1,rate_2,rate_3,rate_4,Orientation_Init
ial,Position_Initial,Rate_of_change_Orientat
ion_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
```

```
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

[size_1]=size(R_tilt_1);
for index_1=1:size_1(1,3)

b_1_tilt_1(index_1,:)=R_tilt_1(:,1,index_1).
';

b_2_tilt_1(index_1,:)=R_tilt_1(:,2,index_1).
';

b_3_tilt_1(index_1,:)=R_tilt_1(:,3,index_1).
';

position_vector_1(index_1,:)=position_tilt_1
(1,:,index_1);

Linear_Velocity_vector_1(index_1,:)=Linear_V
elocity_tilt_1(1,:,index_1);

Rate_of_Change_R_vector_1(index_1,:)=Rate_of
_Change_R_tilt_1(1,:,index_1);
end


R_end_tilt_1=Last_Element_Function(R_tilt_1)
;
position_end_tilt_1=Last_Element_Function(po
sition_tilt_1);
Linear_Velocity_end_tilt_1=Last_Element_Func
tion(Linear_Velocity_tilt_1);
Rate_of_Change_R_end_tilt_1=Last_Element_Fun
ction(Rate_of_Change_R_tilt_1);



%phase 3:
%motor 3 and 4 decelerate at a rate of 3
rad/s/s.
%phase 3 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_1;
phi2_dot=phi2_dot-rate_2*T_1;
phi3_dot=phi3_dot+rate_3*T_1;
phi4_dot=phi4_dot-rate_4*T_1;
rate_1=0;
rate_2=0;
rate_3=-rate;
rate_4=-rate;



R_tilt_3=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_3,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_1,position_end_tilt_1,Rat
e_of_Change_R_end_tilt_1,Linear_Velocity_end
_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_3=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_1,position_end_tilt_1
,Rate_of_Change_R_end_tilt_1,Linear_Velocity
_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_3=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_1,posit
ion_end_tilt_1,Rate_of_Change_R_end_tilt_1,L
inear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_3=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_1,pos
ition_end_tilt_1,Rate_of_Change_R_end_tilt_1
,Linear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_3]=size(R_tilt_3);
for index_3=1:size_3(1,3)

b_1_tilt_3(index_3,:)=R_tilt_3(:,1,index_3).
';

b_2_tilt_3(index_3,:)=R_tilt_3(:,2,index_3).
';

b_3_tilt_3(index_3,:)=R_tilt_3(:,3,index_3).
';

position_vector_3(index_3,:)=position_tilt_3
(1,:,index_3);

Linear_Velocity_vector_3(index_3,:)=Linear_V
elocity_tilt_3(1,:,index_3);

Rate_of_Change_R_vector_3(index_3,:)=Rate_of
_Change_R_tilt_3(1,:,index_3);
end


R_end_tilt_3=Last_Element_Function(R_tilt_3)
;
position_end_tilt_3=Last_Element_Function(po
sition_tilt_3);
Linear_Velocity_end_tilt_3=Last_Element_Func
tion(Linear_Velocity_tilt_3);
Rate_of_Change_R_end_tilt_3=Last_Element_Fun
ction(Rate_of_Change_R_tilt_3);


%Phase 4:
%motor 3 and 4 maintain speed at the end of
phase 3 for 0.7189148253s
%phase 4 runs for T_4s.

phi1_dot=phi1_dot+rate_1*T_3;
phi2_dot=phi2_dot-rate_2*T_3;
phi3_dot=phi3_dot+rate_3*T_3;
phi4_dot=phi4_dot-rate_4*T_3;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;
```

```
R_tilt_4=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_4,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_3,position_end_tilt_3,Rat
e_of_Change_R_end_tilt_3,Linear_Velocity_end
_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_4=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_3,position_end_tilt_3
,Rate_of_Change_R_end_tilt_3,Linear_Velocity
_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_4=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_3,posit
ion_end_tilt_3,Rate_of_Change_R_end_tilt_3,L
inear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_4=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_3,pos
ition_end_tilt_3,Rate_of_Change_R_end_tilt_3
,Linear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_4]=size(R_tilt_4);
for index_4=1:size_4(1,3)

b_1_tilt_4(index_4,:)=R_tilt_4(:,1,index_4).
';

b_2_tilt_4(index_4,:)=R_tilt_4(:,2,index_4).
';

b_3_tilt_4(index_4,:)=R_tilt_4(:,3,index_4).
';

position_vector_4(index_4,:)=position_tilt_4
(1,:,index_4);

Linear_Velocity_vector_4(index_4,:)=Linear_V
elocity_tilt_4(1,:,index_4);

Rate_of_Change_R_vector_4(index_4,:)=Rate_of
_Change_R_tilt_4(1,:,index_4);
end


R_end_tilt_4=Last_Element_Function(R_tilt_4)
;
position_end_tilt_4=Last_Element_Function(po
sition_tilt_4);
Linear_Velocity_end_tilt_4=Last_Element_Func
tion(Linear_Velocity_tilt_4);
Rate_of_Change_R_end_tilt_4=Last_Element_Fun
ction(Rate_of_Change_R_tilt_4);
```

```
%phase 5:
%motor 3 and 4 accelerate at a rate of 3
rad/s/s.
%phase 5 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_4;
phi2_dot=phi2_dot-rate_2*T_4;
phi3_dot=phi3_dot+rate_3*T_4;
phi4_dot=phi4_dot-rate_4*T_4;
rate_1=0;
rate_2=0;
rate_3=rate;
rate_4=rate;



R_tilt_5=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_5,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_4,position_end_tilt_4,Rat
e_of_Change_R_end_tilt_4,Linear_Velocity_end
_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_5=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_4,position_end_tilt_4
,Rate_of_Change_R_end_tilt_4,Linear_Velocity
_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_5=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_4,posit
ion_end_tilt_4,Rate_of_Change_R_end_tilt_4,L
inear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_5=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_4,pos
ition_end_tilt_4,Rate_of_Change_R_end_tilt_4
,Linear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_5]=size(R_tilt_5);
for index_5=1:size_5(1,3)

b_1_tilt_5(index_5,:)=R_tilt_5(:,1,index_5).
';

b_2_tilt_5(index_5,:)=R_tilt_5(:,2,index_5).
';

b_3_tilt_5(index_5,:)=R_tilt_5(:,3,index_5).
';

position_vector_5(index_5,:)=position_tilt_5
(1,:,index_5);

Linear_Velocity_vector_5(index_5,:)=Linear_V
elocity_tilt_5(1,:,index_5);
```

```
Rate_of_Change_R_vector_5(index_5,:)=Rate_of
_Change_R_tilt_5(1,:,index_5);
end


R_end_tilt_5=Last_Element_Function(R_tilt_5)
;
position_end_tilt_5=Last_Element_Function(po
sition_tilt_5);
Linear_Velocity_end_tilt_5=Last_Element_Func
tion(Linear_Velocity_tilt_5);
Rate_of_Change_R_end_tilt_5=Last_Element_Fun
ction(Rate_of_Change_R_tilt_5);



%phase 7:
%motor 3 and 4decelerate at a rate of 3
rad/s/s.
%phase 7 runs for 0.1s.

phi1_dot=phi1_dot+rate_1*T_5;
phi2_dot=phi2_dot-rate_2*T_5;
phi3_dot=phi3_dot+rate_3*T_5;
phi4_dot=phi4_dot-rate_4*T_5;
rate_1=0;
rate_2=0;
rate_3=-rate;
rate_4=-rate;



R_tilt_7=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_7,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_5,position_end_tilt_5,Rat
e_of_Change_R_end_tilt_5,Linear_Velocity_end
_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_7=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_5,position_end_tilt_5
,Rate_of_Change_R_end_tilt_5,Linear_Velocity
_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_7=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_5,posit
ion_end_tilt_5,Rate_of_Change_R_end_tilt_5,L
inear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_7=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_5,pos
ition_end_tilt_5,Rate_of_Change_R_end_tilt_5
,Linear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
[size_7]=size(R_tilt_7);
for index_7=1:size_7(1,3)

b_1_tilt_7(index_7,:)=R_tilt_7(:,1,index_7).
';

b_2_tilt_7(index_7,:)=R_tilt_7(:,2,index_7).
';

b_3_tilt_7(index_7,:)=R_tilt_7(:,3,index_7).
';

position_vector_7(index_7,:)=position_tilt_7
(1,:,index_7);

Linear_Velocity_vector_7(index_7,:)=Linear_V
elocity_tilt_7(1,:,index_7);

Rate_of_Change_R_vector_7(index_7,:)=Rate_of
_Change_R_tilt_7(1,:,index_7);
end


R_end_tilt_7=Last_Element_Function(R_tilt_7)
;
position_end_tilt_7=Last_Element_Function(po
sition_tilt_7);
Linear_Velocity_end_tilt_7=Last_Element_Func
tion(Linear_Velocity_tilt_7);
Rate_of_Change_R_end_tilt_7=Last_Element_Fun
ction(Rate_of_Change_R_tilt_7);



%% Animation.
b_1=cat(1,b_1_tilt_1,b_1_tilt_3,b_1_tilt_4,b
_1_tilt_5,b_1_tilt_7);
b_2=cat(1,b_2_tilt_1,b_2_tilt_3,b_2_tilt_4,b
_2_tilt_5,b_2_tilt_7);
b_3=cat(1,b_3_tilt_1,b_3_tilt_3,b_3_tilt_4,b
_3_tilt_5,b_3_tilt_7);
position_vector=cat(1,position_vector_1,posi
tion_vector_3,position_vector_4,position_vec
tor_5,position_vector_7);
Linear_Velocity_vector=cat(1,Linear_Velocity
_vector_1,Linear_Velocity_vector_3,Linear_Ve
locity_vector_4,Linear_Velocity_vector_5,Lin
ear_Velocity_vector_7);
Rate_of_Change_R_vector=cat(1,Rate_of_Change
_R_vector_1,Rate_of_Change_R_vector_3,Rate_o
f_Change_R_vector_4,Rate_of_Change_R_vector_
5,Rate_of_Change_R_vector_7);


end
```

take_off_function

```
function
[b_1,b_2,b_3,position_vector,R_end_hover_acc
_2,position_end_hover_acc_2]=take_off_functi
on(Orientation_Initial,Position_Initial,hove
r_height);

%% Overview of this function:
%%this function can be called when the
copter is initially at rest with no
%%linear velocity nor rate of change of
orientation.
%%inputs of the function: hovering height
after the function is executed,
%%initial orientation and position of the
copter frame.
%%outputs of this function: b_1,b_2,b_3, and
position_vector record the
%%position and orientation of the copter
throughout this maneuver.
%%R_end_hover_acc_2, and position_end_hover-
acc_2 are the final orientation
%%and position of the copter frame.
%%output assumptions: it is assumed that
there is no linear velocity
%%nor rate of change of the orientation to
the copter after this function
%%is executed.




%input conditions:
Rate_of_change_Orientation_Initial=[0 0 0];
Linear_velocity_Initial=[0 0 0];

%% hover command
%all four motors speeds up at a rate of
13.81783116rad/s/s. for 0.1s.
phi1_dot=27.53596541;
phi2_dot=-27.53596541;
phi3_dot=27.53596541;
phi4_dot=-27.53596541;
rate_1=13.81783116;
rate_2=13.81783116;
rate_3=13.81783116;
rate_4=13.81783116;
T_1=0.1;


R_hover_acc=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rat
e_3,rate_4,Orientation_Initial,Position_Init
ial,Rate_of_change_Orientation_Initial,Linea
r_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_hover_acc=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2
,rate_3,rate_4,Orientation_Initial,Position_
Initial,Rate_of_change_Orientation_Initial,L
inear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_hover_acc=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1
,rate_1,rate_2,rate_3,rate_4,Orientation_Ini
tial,Position_Initial,Rate_of_change_Orienta
tion_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_hover_acc=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_1,rate_1,rate_2,rate_3,rate_4,Orientation_I
nitial,Position_Initial,Rate_of_change_Orien
tation_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_acc]=size(R_hover_acc);
for index_acc=1:size_acc(1,3)

b_1_hover_acc(index_acc,:)=R_hover_acc(:,1,i
ndex_acc).';

b_2_hover_acc(index_acc,:)=R_hover_acc(:,2,i
ndex_acc).';

b_3_hover_acc(index_acc,:)=R_hover_acc(:,3,i
ndex_acc).';

position_vector_acc(index_acc,:)=position_ho
ver_acc(1,:,index_acc);

Linear_Velocity_vector_acc(index_acc,:)=Line
ar_Velocity_hover_acc(1,:,index_acc);

Rate_of_Change_R_vector_acc(index_acc,:)=Rat
e_of_Change_R_hover_acc(1,:,index_acc);
end


R_end_hover_acc=Last_Element_Function(R_hove
r_acc);
position_end_hover_acc=Last_Element_Function
(position_hover_acc);
Linear_Velocity_end_hover_acc=Last_Element_F
unction(Linear_Velocity_hover_acc);
Rate_of_Change_R_end_hover_acc=Last_Element_
Function(Rate_of_Change_R_hover_acc);


%all four motors slows down at a rate of
13.81783116rad/s/s. for 0.1s.
phi1_dot=phi1_dot+rate_1*T_1;
phi2_dot=phi2_dot-rate_2*T_1;
phi3_dot=phi3_dot+rate_3*T_1;
phi4_dot=phi4_dot-rate_4*T_1;
rate_1=-13.81783116;
rate_2=-13.81783116;
rate_3=-13.81783116;
rate_4=-13.81783116;
T_2=0.1;


R_hover_dcc=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_2,rate_1,rate_2,rat
e_3,rate_4,R_end_hover_acc,position_end_hove
```

```
r_acc,Rate_of_Change_R_end_hover_acc,Linear_
Velocity_end_hover_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_hover_dcc=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_2,rate_1,rate_2
,rate_3,rate_4,R_end_hover_acc,position_end_
hover_acc,Rate_of_Change_R_end_hover_acc,Lin
ear_Velocity_end_hover_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_hover_dcc=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2
,rate_1,rate_2,rate_3,rate_4,R_end_hover_acc
,position_end_hover_acc,Rate_of_Change_R_end
_hover_acc,Linear_Velocity_end_hover_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_hover_dcc=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_2,rate_1,rate_2,rate_3,rate_4,R_end_hover_a
cc,position_end_hover_acc,Rate_of_Change_R_e
nd_hover_acc,Linear_Velocity_end_hover_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_dcc]=size(R_hover_dcc);
for index_dcc=1:size_dcc(1,3)

b_1_hover_dcc(index_dcc,:)=R_hover_dcc(:,1,i
ndex_dcc).';

b_2_hover_dcc(index_dcc,:)=R_hover_dcc(:,2,i
ndex_dcc).';

b_3_hover_dcc(index_dcc,:)=R_hover_dcc(:,3,i
ndex_dcc).';

position_vector_dcc(index_dcc,:)=position_ho
ver_dcc(1,:,index_dcc);

Linear_Velocity_vector_dcc(index_dcc,:)=Line
ar_Velocity_hover_dcc(1,:,index_dcc);

Rate_of_Change_R_vector_dcc(index_dcc,:)=Rat
e_of_Change_R_hover_dcc(1,:,index_dcc);
end



R_end_hover_dcc=Last_Element_Function(R_hove
r_dcc);
position_end_hover_dcc=Last_Element_Function
(position_hover_dcc);
Linear_Velocity_end_hover_dcc=Last_Element_F
unction(Linear_Velocity_hover_dcc);
Rate_of_Change_R_end_hover_dcc=Last_Element_
Function(Rate_of_Change_R_hover_dcc);


%quadcopter moving with a uniform speed of
0.1(m/s), for Ts.

hover_height;
v_hover_uniform=Linear_Velocity_end_hover_dc
c(1,3);
T=(hover_height-0.2)/v_hover_uniform;


phi1_dot=phi1_dot+rate_1*T_2;
phi2_dot=phi2_dot-rate_2*T_2;
phi3_dot=phi3_dot+rate_3*T_2;
phi4_dot=phi4_dot-rate_4*T_2;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;
T_3=T;


R_hover_uniform=Orientation_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate_2
,rate_3,rate_4,R_end_hover_dcc,position_end_
hover_dcc,Rate_of_Change_R_end_hover_dcc,Lin
ear_Velocity_end_hover_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_hover_uniform=Position_Matrix(phi1_
dot,phi2_dot,phi3_dot,phi4_dot,T_3,rate_1,ra
te_2,rate_3,rate_4,R_end_hover_dcc,position_
end_hover_dcc,Rate_of_Change_R_end_hover_dcc
,Linear_Velocity_end_hover_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_hover_uniform=Linear_Velocit
y_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot
,T_3,rate_1,rate_2,rate_3,rate_4,R_end_hover
_dcc,position_end_hover_dcc,Rate_of_Change_R
_end_hover_dcc,Linear_Velocity_end_hover_dcc
);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_hover_uniform=Rate_of_Chang
e_R_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_d
ot,T_3,rate_1,rate_2,rate_3,rate_4,R_end_hov
er_dcc,position_end_hover_dcc,Rate_of_Change
_R_end_hover_dcc,Linear_Velocity_end_hover_d
cc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_uniform]=size(R_hover_uniform);
for index_uniform=1:size_uniform(1,3)

b_1_hover_uniform(index_uniform,:)=R_hover_u
niform(:,1,index_uniform).';

b_2_hover_uniform(index_uniform,:)=R_hover_u
niform(:,2,index_uniform).';

b_3_hover_uniform(index_uniform,:)=R_hover_u
niform(:,3,index_uniform).';

position_vector_uniform(index_uniform,:)=pos
ition_hover_uniform(1,:,index_uniform);
```

```
Linear_Velocity_vector_uniform(index_uniform
,:)=Linear_Velocity_hover_uniform(1,:,index_
uniform);

Rate_of_Change_R_vector_uniform(index_unifor
m,:)=Rate_of_Change_R_hover_uniform(1,:,inde
x_uniform);
end



R_end_hover_uniform=Last_Element_Function(R_
hover_uniform);
position_end_hover_uniform=Last_Element_Func
tion(position_hover_uniform);
Linear_Velocity_end_hover_uniform=Last_Eleme
nt_Function(Linear_Velocity_hover_uniform);
Rate_of_Change_R_end_hover_uniform=Last_Elem
ent_Function(Rate_of_Change_R_hover_uniform)
;


%all four motors slows down at a rate of
14.29637932rad/s/s. for 0.1s.


phi1_dot=phi1_dot+rate_1*T_3;
phi2_dot=phi2_dot-rate_2*T_3;
phi3_dot=phi3_dot+rate_3*T_3;
phi4_dot=phi4_dot-rate_4*T_3;
rate_1=-14.29637932;
rate_2=-14.29637932;
rate_3=-14.29637932;
rate_4=-14.29637932;
T_4=0.1;


R_hover_dcc_2=Orientation_Matrix(phi1_dot,ph
i2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2,r
ate_3,rate_4,R_end_hover_uniform,position_en
d_hover_uniform,Rate_of_Change_R_end_hover_u
niform,Linear_Velocity_end_hover_uniform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_hover_dcc_2=Position_Matrix(phi1_do
t,phi2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate
_2,rate_3,rate_4,R_end_hover_uniform,positio
n_end_hover_uniform,Rate_of_Change_R_end_hov
er_uniform,Linear_Velocity_end_hover_uniform
);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_hover_dcc_2=Linear_Velocity_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_4,rate_1,rate_2,rate_3,rate_4,R_end_hover_u
niform,position_end_hover_uniform,Rate_of_Ch
ange_R_end_hover_uniform,Linear_Velocity_end
_hover_uniform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_hover_dcc_2=Rate_of_Change_
R_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot
,T_4,rate_1,rate_2,rate_3,rate_4,R_end_hover
_uniform,position_end_hover_uniform,Rate_of_
Change_R_end_hover_uniform,Linear_Velocity_e
nd_hover_uniform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_dcc_2]=size(R_hover_dcc_2);
for index_dcc_2=1:size_dcc_2(1,3)

b_1_hover_dcc_2(index_dcc_2,:)=R_hover_dcc_2
(:,1,index_dcc_2).';

b_2_hover_dcc_2(index_dcc_2,:)=R_hover_dcc_2
(:,2,index_dcc_2).';

b_3_hover_dcc_2(index_dcc_2,:)=R_hover_dcc_2
(:,3,index_dcc_2).';

position_vector_dcc_2(index_dcc_2,:)=positio
n_hover_dcc_2(1,:,index_dcc_2);

Linear_Velocity_vector_dcc_2(index_dcc_2,:)=
Linear_Velocity_hover_dcc_2(1,:,index_dcc_2)
;

Rate_of_Change_R_vector_dcc_2(index_dcc_2,:)
=Rate_of_Change_R_hover_dcc_2(1,:,index_dcc_
2);
end


R_end_hover_dcc_2=Last_Element_Function(R_ho
ver_dcc_2);
position_end_hover_dcc_2=Last_Element_Functi
on(position_hover_dcc_2);
Linear_Velocity_end_hover_dcc_2=Last_Element
_Function(Linear_Velocity_hover_dcc_2);
Rate_of_Change_R_end_hover_dcc_2=Last_Elemen
t_Function(Rate_of_Change_R_hover_dcc_2);


%all four motors spped up at a rate of
14.29637932rad/s/s. for 0.1s.


phi1_dot=phi1_dot+rate_1*T_4;
phi2_dot=phi2_dot-rate_2*T_4;
phi3_dot=phi3_dot+rate_3*T_4;
phi4_dot=phi4_dot-rate_4*T_4;
rate_1=14.29637932;
rate_2=14.29637932;
rate_3=14.29637932;
rate_4=14.29637932;
T_5=0.1;


R_hover_acc_2=Orientation_Matrix(phi1_dot,ph
i2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2,r
ate_3,rate_4,R_end_hover_dcc_2,position_end_
hover_dcc_2,Rate_of_Change_R_end_hover_dcc_2
,Linear_Velocity_end_hover_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_hover_acc_2=Position_Matrix(phi1_do
t,phi2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate
_2,rate_3,rate_4,R_end_hover_dcc_2,position_
end_hover_dcc_2,Rate_of_Change_R_end_hover_d
```

```
cc_2,Linear_Velocity_end_hover_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_hover_acc_2=Linear_Velocity_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_5,rate_1,rate_2,rate_3,rate_4,R_end_hover_d
cc_2,position_end_hover_dcc_2,Rate_of_Change
_R_end_hover_dcc_2,Linear_Velocity_end_hover
_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_hover_acc_2=Rate_of_Change_
R_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot
,T_5,rate_1,rate_2,rate_3,rate_4,R_end_hover
_dcc_2,position_end_hover_dcc_2,Rate_of_Chan
ge_R_end_hover_dcc_2,Linear_Velocity_end_hov
er_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_acc_2]=size(R_hover_acc_2);
for index_acc_2=1:size_acc_2(1,3)

b_1_hover_acc_2(index_acc_2,:)=R_hover_acc_2
(:,1,index_acc_2).';

b_2_hover_acc_2(index_acc_2,:)=R_hover_acc_2
(:,2,index_acc_2).';

b_3_hover_acc_2(index_acc_2,:)=R_hover_acc_2
(:,3,index_acc_2).';

position_vector_acc_2(index_acc_2,:)=positio
n_hover_acc_2(1,:,index_acc_2);

Linear_Velocity_vector_acc_2(index_acc_2,:)=
Linear_Velocity_hover_acc_2(1,:,index_acc_2)
;

Rate_of_Change_R_vector_acc_2(index_acc_2,:)
=Rate_of_Change_R_hover_acc_2(1,:,index_acc_
2);
end



R_end_hover_acc_2=Last_Element_Function(R_ho
ver_acc_2);
position_end_hover_acc_2=Last_Element_Functi
on(position_hover_acc_2);
Linear_Velocity_end_hover_acc_2=Last_Element
_Function(Linear_Velocity_hover_acc_2);
Rate_of_Change_R_end_hover_acc_2=Last_Elemen
t_Function(Rate_of_Change_R_hover_acc_2);



phi1_dot=phi1_dot+rate_1*T_5;
phi2_dot=phi2_dot-rate_2*T_5;
phi3_dot=phi3_dot+rate_3*T_5;
phi4_dot=phi4_dot-rate_4*T_5;
```

```
%% Animation.
b_1=cat(1,b_1_hover_acc,b_1_hover_dcc,b_1_ho
ver_uniform,b_1_hover_dcc_2,b_1_hover_acc_2)
;
b_2=cat(1,b_2_hover_acc,b_2_hover_dcc,b_2_ho
ver_uniform,b_2_hover_dcc_2,b_2_hover_acc_2)
;
b_3=cat(1,b_3_hover_acc,b_3_hover_dcc,b_3_ho
ver_uniform,b_3_hover_dcc_2,b_3_hover_acc_2)
;
position_vector=cat(1,position_vector_acc,po
sition_vector_dcc,position_vector_uniform,po
sition_vector_dcc_2,position_vector_acc_2);
Linear_Velocity_vector=cat(1,Linear_Velocity
_vector_acc,Linear_Velocity_vector_dcc,Linea
r_Velocity_vector_uniform,Linear_Velocity_ve
ctor_dcc_2,Linear_Velocity_vector_acc_2);
Rate_of_Change_R_vector=cat(1,Rate_of_Change
_R_vector_acc,Rate_of_Change_R_vector_dcc,Ra
te_of_Change_R_vector_uniform,Rate_of_Change
_R_vector_dcc_2,Rate_of_Change_R_vector_acc_
2);
```

tilt_moving_forward function

```
function [b_1,b_2,b_3,position_vector,position_coast_end,R_coast_end,Linear_Velocity_coast_end] = tilt_moving_forward(position_initial,orientation_initial,T_coast)

%%OverView of this function:
%%This function gives the quadcopter a hicc up so it will till and return to upright orientation,
%%thus generate a forward linear velocity,
%%and the quadcopter will coast forward for a given period of time (T_coast).
%%The function has input the initial position (position_initial), initial orientation (orientation_initial), given the assumption
%%that the quadcopter has no linear velocity, no rate of change of
%%orientation.
%%the output of this
%%function is the linear velocity at the end of the coasting, used as an input for next manuver air_brake function.
%%output R_coast_end and position_coast_end specifies the position
%%and orientation of the quadcopter after this function is executed.
%%output b_1, b_2, b_3 and postion_vector records the orientaion and
%%position of the copter while the function is excuted and they will be
%%used for animation plot.
%%it is assumed that after this function is excecuted, the orientation of
%%the copter will not chage from the initial orientation, and the there
%%will be no rate of change of orientation, also no linear velocity in
%%vertical direction. these output assumptions, which are verified by the
%%simulation results within very small error (on the order of e^-5~e^-9),
%%so it's safe to make these assumptions as long as the input conditions
%%are satisfied. these output assumptions will become the input conditions
%%for the next stage manuver: air_brake_after_coasting.


%%Implementation of this function:




%for this manuver, motor 1 and 2 will always maintain their hovering speed at 27.53596541rad/s.
%Phase 1:
%motor 3 and motor 4
%accelerating at a constant rate of 3 rad/s/s for 0.1s.

orientation_initial=Sanity_Check(orientation_initial);
phi1_dot=27.53596541;
phi2_dot=-27.53596541;
phi3_dot=27.53596541;
phi4_dot=-27.53596541;
rate_1=0;
rate_2=0;
rate_3=3;
rate_4=3;
T_1=0.1;


R_tilt_1=Orientation_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3,rate_4,orientation_initial,position_initial,[0 0 0],[0 0 0]);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)
position_tilt_1=Position_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3,rate_4,orientation_initial,position_initial,[0 0 0],[0 0 0]);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)
Linear_Velocity_tilt_1=Linear_Velocity_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3,rate_4,orientation_initial,position_initial,[0 0 0],[0 0 0]);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)
Rate_of_Change_R_tilt_1=Rate_of_Change_R_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3,rate_4,orientation_initial,position_initial,[0 0 0],[0 0 0]);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)

[size_1]=size(R_tilt_1);
for index_1=1:size_1(1,3)

b_1_tilt_1(index_1,:)=R_tilt_1(:,1,index_1).';

b_2_tilt_1(index_1,:)=R_tilt_1(:,2,index_1).';

b_3_tilt_1(index_1,:)=R_tilt_1(:,3,index_1).';

position_vector_1(index_1,:)=position_tilt_1(1,:,index_1);

Linear_Velocity_vector_1(index_1,:)=Linear_Velocity_tilt_1(1,:,index_1);

Rate_of_Change_R_vector_1(index_1,:)=Rate_of_Change_R_tilt_1(1,:,index_1);
end
```

```
R_end_tilt_1=Last_Element_Function(R_tilt_1)
;
position_end_tilt_1=Last_Element_Function(po
sition_tilt_1);
Linear_Velocity_end_tilt_1=Last_Element_Func
tion(Linear_Velocity_tilt_1);
Rate_of_Change_R_end_tilt_1=Last_Element_Fun
ction(Rate_of_Change_R_tilt_1);


%Phase 2:
%motor 3 and 4 maintain speed at the end of
phase 1 for 0.3052915087s
%phase 2 runs for 0.3052915087s.

phi1_dot=phi1_dot+rate_1*T_1;
phi2_dot=phi2_dot-rate_2*T_1;
phi3_dot=phi3_dot+rate_3*T_1;
phi4_dot=phi4_dot-rate_4*T_1;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;
T_2=0.3052915087;

R_tilt_2=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_2,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_1,position_end_tilt_1,Rat
e_of_Change_R_end_tilt_1,Linear_Velocity_end
_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_2=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_2,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_1,position_end_tilt_1
,Rate_of_Change_R_end_tilt_1,Linear_Velocity
_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_2=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_1,posit
ion_end_tilt_1,Rate_of_Change_R_end_tilt_1,L
inear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_2=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_1,pos
ition_end_tilt_1,Rate_of_Change_R_end_tilt_1
,Linear_Velocity_end_tilt_1);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_2]=size(R_tilt_2);
for index_2=1:size_2(1,3)

b_1_tilt_2(index_2,:)=R_tilt_2(:,1,index_2).
';

b_2_tilt_2(index_2,:)=R_tilt_2(:,2,index_2).
';

b_3_tilt_2(index_2,:)=R_tilt_2(:,3,index_2).
';

position_vector_2(index_2,:)=position_tilt_2
(1,:,index_2);

Linear_Velocity_vector_2(index_2,:)=Linear_V
elocity_tilt_2(1,:,index_2);

Rate_of_Change_R_vector_2(index_2,:)=Rate_of
_Change_R_tilt_2(1,:,index_2);
end


R_end_tilt_2=Last_Element_Function(R_tilt_2)
;
position_end_tilt_2=Last_Element_Function(po
sition_tilt_2);
Linear_Velocity_end_tilt_2=Last_Element_Func
tion(Linear_Velocity_tilt_2);
Rate_of_Change_R_end_tilt_2=Last_Element_Fun
ction(Rate_of_Change_R_tilt_2);


%phase 3:
%motor 3 and 4 decelerate at a rate of 3
rad/s/s.
%phase 3 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_2;
phi2_dot=phi2_dot-rate_2*T_2;
phi3_dot=phi3_dot+rate_3*T_2;
phi4_dot=phi4_dot-rate_4*T_2;
rate_1=0;
rate_2=0;
rate_3=-3;
rate_4=-3;
T_3=0.2;


R_tilt_3=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_3,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_2,position_end_tilt_2,Rat
e_of_Change_R_end_tilt_2,Linear_Velocity_end
_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_3=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_2,position_end_tilt_2
,Rate_of_Change_R_end_tilt_2,Linear_Velocity
_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_3=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_2,posit
ion_end_tilt_2,Rate_of_Change_R_end_tilt_2,L
inear_Velocity_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_3=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_3,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_2,pos
```

```
ition_end_tilt_2,Rate_of_Change_R_end_tilt_2
,Linear_Velocity_end_tilt_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_3]=size(R_tilt_3);
for index_3=1:size_3(1,3)

b_1_tilt_3(index_3,:)=R_tilt_3(:,1,index_3).
';

b_2_tilt_3(index_3,:)=R_tilt_3(:,2,index_3).
';

b_3_tilt_3(index_3,:)=R_tilt_3(:,3,index_3).
';

position_vector_3(index_3,:)=position_tilt_3
(1,:,index_3);

Linear_Velocity_vector_3(index_3,:)=Linear_V
elocity_tilt_3(1,:,index_3);

Rate_of_Change_R_vector_3(index_3,:)=Rate_of
_Change_R_tilt_3(1,:,index_3);
end


R_end_tilt_3=Last_Element_Function(R_tilt_3)
;
position_end_tilt_3=Last_Element_Function(po
sition_tilt_3);
Linear_Velocity_end_tilt_3=Last_Element_Func
tion(Linear_Velocity_tilt_3);
Rate_of_Change_R_end_tilt_3=Last_Element_Fun
ction(Rate_of_Change_R_tilt_3);


%Phase 4:
%motor 3 and 4 maintain speed at the end of
phase 3 for 0.7189148253s
%phase 4 runs for 0.7189148253s.

phi1_dot=phi1_dot+rate_1*T_3;
phi2_dot=phi2_dot-rate_2*T_3;
phi3_dot=phi3_dot+rate_3*T_3;
phi4_dot=phi4_dot-rate_4*T_3;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;
T_4=0.7189148253;


R_tilt_4=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_4,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_3,position_end_tilt_3,Rat
e_of_Change_R_end_tilt_3,Linear_Velocity_end
_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_4=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_3,position_end_tilt_3
,Rate_of_Change_R_end_tilt_3,Linear_Velocity
_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_4=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_3,posit
ion_end_tilt_3,Rate_of_Change_R_end_tilt_3,L
inear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_4=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_3,pos
ition_end_tilt_3,Rate_of_Change_R_end_tilt_3
,Linear_Velocity_end_tilt_3);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_4]=size(R_tilt_4);
for index_4=1:size_4(1,3)

b_1_tilt_4(index_4,:)=R_tilt_4(:,1,index_4).
';

b_2_tilt_4(index_4,:)=R_tilt_4(:,2,index_4).
';

b_3_tilt_4(index_4,:)=R_tilt_4(:,3,index_4).
';

position_vector_4(index_4,:)=position_tilt_4
(1,:,index_4);

Linear_Velocity_vector_4(index_4,:)=Linear_V
elocity_tilt_4(1,:,index_4);

Rate_of_Change_R_vector_4(index_4,:)=Rate_of
_Change_R_tilt_4(1,:,index_4);
end


R_end_tilt_4=Last_Element_Function(R_tilt_4)
;
position_end_tilt_4=Last_Element_Function(po
sition_tilt_4);
Linear_Velocity_end_tilt_4=Last_Element_Func
tion(Linear_Velocity_tilt_4);
Rate_of_Change_R_end_tilt_4=Last_Element_Fun
ction(Rate_of_Change_R_tilt_4);


%phase 5:
%motor 3 and 4 accelerate at a rate of 3
rad/s/s.
%phase 5 runs for 0.2s.

phi1_dot=phi1_dot+rate_1*T_4;
phi2_dot=phi2_dot-rate_2*T_4;
phi3_dot=phi3_dot+rate_3*T_4;
phi4_dot=phi4_dot-rate_4*T_4;
rate_1=0;
rate_2=0;
rate_3=3;
rate_4=3;
T_5=0.2;
```

```
R_tilt_5=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_5,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_4,position_end_tilt_4,Rat
e_of_Change_R_end_tilt_4,Linear_Velocity_end
_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_5=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_4,position_end_tilt_4
,Rate_of_Change_R_end_tilt_4,Linear_Velocity
_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_5=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_4,posit
ion_end_tilt_4,Rate_of_Change_R_end_tilt_4,L
inear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_5=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_4,pos
ition_end_tilt_4,Rate_of_Change_R_end_tilt_4
,Linear_Velocity_end_tilt_4);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_5]=size(R_tilt_5);
for index_5=1:size_5(1,3)

b_1_tilt_5(index_5,:)=R_tilt_5(:,1,index_5).
';

b_2_tilt_5(index_5,:)=R_tilt_5(:,2,index_5).
';

b_3_tilt_5(index_5,:)=R_tilt_5(:,3,index_5).
';

position_vector_5(index_5,:)=position_tilt_5
(1,:,index_5);

Linear_Velocity_vector_5(index_5,:)=Linear_V
elocity_tilt_5(1,:,index_5);

Rate_of_Change_R_vector_5(index_5,:)=Rate_of
_Change_R_tilt_5(1,:,index_5);
end


R_end_tilt_5=Last_Element_Function(R_tilt_5)
;
position_end_tilt_5=Last_Element_Function(po
sition_tilt_5);
Linear_Velocity_end_tilt_5=Last_Element_Func
tion(Linear_Velocity_tilt_5);
Rate_of_Change_R_end_tilt_5=Last_Element_Fun
ction(Rate_of_Change_R_tilt_5);

%phase 6:
%motor 3 and 4 maintain speed at the end of
phase 5 for 0.3052915087s.
%phase 6 runs for 0.3052915087s.

phi1_dot=phi1_dot+rate_1*T_5;
phi2_dot=phi2_dot-rate_2*T_5;
phi3_dot=phi3_dot+rate_3*T_5;
phi4_dot=phi4_dot-rate_4*T_5;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;
T_6=0.3052915087;


R_tilt_6=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_6,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_5,position_end_tilt_5,Rat
e_of_Change_R_end_tilt_5,Linear_Velocity_end
_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_6=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_6,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_5,position_end_tilt_5
,Rate_of_Change_R_end_tilt_5,Linear_Velocity
_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_6=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_6,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_5,posit
ion_end_tilt_5,Rate_of_Change_R_end_tilt_5,L
inear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_6=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_6,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_5,pos
ition_end_tilt_5,Rate_of_Change_R_end_tilt_5
,Linear_Velocity_end_tilt_5);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_6]=size(R_tilt_6);
for index_6=1:size_6(1,3)

b_1_tilt_6(index_6,:)=R_tilt_6(:,1,index_6).
';

b_2_tilt_6(index_6,:)=R_tilt_6(:,2,index_6).
';

b_3_tilt_6(index_6,:)=R_tilt_6(:,3,index_6).
';

position_vector_6(index_6,:)=position_tilt_6
(1,:,index_6);
```

```
Linear_Velocity_vector_6(index_6,:)=Linear_V
elocity_tilt_6(1,:,index_6);

Rate_of_Change_R_vector_6(index_6,:)=Rate_of
_Change_R_tilt_6(1,:,index_6);
end


R_end_tilt_6=Last_Element_Function(R_tilt_6)
;
position_end_tilt_6=Last_Element_Function(po
sition_tilt_6);
Linear_Velocity_end_tilt_6=Last_Element_Func
tion(Linear_Velocity_tilt_6);
Rate_of_Change_R_end_tilt_6=Last_Element_Fun
ction(Rate_of_Change_R_tilt_6);


%phase 7:
%motor 3 and 4decelerate at a rate of 3
rad/s/s.
%phase 7 runs for 0.1s.

phi1_dot=phi1_dot+rate_1*T_6;
phi2_dot=phi2_dot-rate_2*T_6;
phi3_dot=phi3_dot+rate_3*T_6;
phi4_dot=phi4_dot-rate_4*T_6;
rate_1=0;
rate_2=0;
rate_3=-3;
rate_4=-3;
T_7=0.1;


R_tilt_7=Orientation_Matrix(phi1_dot,phi2_do
t,phi3_dot,phi4_dot,T_7,rate_1,rate_2,rate_3
,rate_4,R_end_tilt_6,position_end_tilt_6,Rat
e_of_Change_R_end_tilt_6,Linear_Velocity_end
_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_tilt_7=Position_Matrix(phi1_dot,phi
2_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2,ra
te_3,rate_4,R_end_tilt_6,position_end_tilt_6
,Rate_of_Change_R_end_tilt_6,Linear_Velocity
_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_tilt_7=Linear_Velocity_Matri
x(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,ra
te_1,rate_2,rate_3,rate_4,R_end_tilt_6,posit
ion_end_tilt_6,Rate_of_Change_R_end_tilt_6,L
inear_Velocity_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_tilt_7=Rate_of_Change_R_Mat
rix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,
rate_1,rate_2,rate_3,rate_4,R_end_tilt_6,pos
ition_end_tilt_6,Rate_of_Change_R_end_tilt_6
,Linear_Velocity_end_tilt_6);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

[size_7]=size(R_tilt_7);
for index_7=1:size_7(1,3)

b_1_tilt_7(index_7,:)=R_tilt_7(:,1,index_7).
';

b_2_tilt_7(index_7,:)=R_tilt_7(:,2,index_7).
';

b_3_tilt_7(index_7,:)=R_tilt_7(:,3,index_7).
';

position_vector_7(index_7,:)=position_tilt_7
(1,:,index_7);

Linear_Velocity_vector_7(index_7,:)=Linear_V
elocity_tilt_7(1,:,index_7);

Rate_of_Change_R_vector_7(index_7,:)=Rate_of
_Change_R_tilt_7(1,:,index_7);
end


R_end_tilt_7=Last_Element_Function(R_tilt_7)
;
position_end_tilt_7=Last_Element_Function(po
sition_tilt_7);
Linear_Velocity_end_tilt_7=Last_Element_Func
tion(Linear_Velocity_tilt_7);
Rate_of_Change_R_end_tilt_7=Last_Element_Fun
ction(Rate_of_Change_R_tilt_7);


%% eliminate vertical movement at the end of
tilting.

% all four motors accelerate at a rate of
4.789487632rad/s/s for 0.1s
phi1_dot=phi1_dot+rate_1*T_7;
phi2_dot=phi2_dot-rate_2*T_7;
phi3_dot=phi3_dot+rate_3*T_7;
phi4_dot=phi4_dot-rate_4*T_7;
rate_1=4.789487632;
rate_2=4.789487632;
rate_3=4.789487632;
rate_4=4.789487632;
T_level_acc=0.1;


R_level_acc=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_level_acc,rate_1,ra
te_2,rate_3,rate_4,R_end_tilt_7,position_end
_tilt_7,Rate_of_Change_R_end_tilt_7,Linear_V
elocity_end_tilt_7);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_level_acc=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_level_acc,rate_
1,rate_2,rate_3,rate_4,R_end_tilt_7,position
_end_tilt_7,Rate_of_Change_R_end_tilt_7,Line
ar_Velocity_end_tilt_7);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_level_acc=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_l
```

```
evel_acc,rate_1,rate_2,rate_3,rate_4,R_end_t
ilt_7,position_end_tilt_7,Rate_of_Change_R_e
nd_tilt_7,Linear_Velocity_end_tilt_7);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_level_acc=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_level_acc,rate_1,rate_2,rate_3,rate_4,R_end
_tilt_7,position_end_tilt_7,Rate_of_Change_R
_end_tilt_7,Linear_Velocity_end_tilt_7);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_level_acc]=size(R_level_acc);
for index_level_acc=1:size_level_acc(1,3)

b_1_level_acc(index_level_acc,:)=R_level_acc
(:,1,index_level_acc).';

b_2_level_acc(index_level_acc,:)=R_level_acc
(:,2,index_level_acc).';

b_3_level_acc(index_level_acc,:)=R_level_acc
(:,3,index_level_acc).';

position_vector_level_acc(index_level_acc,:)
=position_level_acc(1,:,index_level_acc);

Linear_Velocity_vector_level_acc(index_level
_acc,:)=Linear_Velocity_level_acc(1,:,index_
level_acc);

Rate_of_Change_R_vector_level_acc(index_leve
l_acc,:)=Rate_of_Change_R_level_acc(1,:,inde
x_level_acc);
end


R_end_level_acc=Last_Element_Function(R_leve
l_acc);
position_end_level_acc=Last_Element_Function
(position_level_acc);
Linear_Velocity_end_level_acc=Last_Element_F
unction(Linear_Velocity_level_acc);
Rate_of_Change_R_end_level_acc=Last_Element_
Function(Rate_of_Change_R_level_acc);


% all four motors decelerate at a rate of
4.789487632rad/s/s for 0.1s
phi1_dot=phi1_dot+rate_1*T_level_acc;
phi2_dot=phi2_dot-rate_2*T_level_acc;
phi3_dot=phi3_dot+rate_3*T_level_acc;
phi4_dot=phi4_dot-rate_4*T_level_acc;
rate_1=-4.789487632;
rate_2=-4.789487632;
rate_3=-4.789487632;
rate_4=-4.789487632;
T_level_dcc=0.1;


R_level_dcc=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_level_dcc,rate_1,ra
te_2,rate_3,rate_4,R_end_level_acc,position_
end_level_acc,Rate_of_Change_R_end_level_acc
,Linear_Velocity_end_level_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_level_dcc=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_level_dcc,rate_
1,rate_2,rate_3,rate_4,R_end_level_acc,posit
ion_end_level_acc,Rate_of_Change_R_end_level
_acc,Linear_Velocity_end_level_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_level_dcc=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_l
evel_dcc,rate_1,rate_2,rate_3,rate_4,R_end_l
evel_acc,position_end_level_acc,Rate_of_Chan
ge_R_end_level_acc,Linear_Velocity_end_level
_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_level_dcc=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_level_dcc,rate_1,rate_2,rate_3,rate_4,R_end
_level_acc,position_end_level_acc,Rate_of_Ch
ange_R_end_level_acc,Linear_Velocity_end_lev
el_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_level_dcc]=size(R_level_dcc);
for index_level_dcc=1:size_level_dcc(1,3)

b_1_level_dcc(index_level_dcc,:)=R_level_dcc
(:,1,index_level_dcc).';

b_2_level_dcc(index_level_dcc,:)=R_level_dcc
(:,2,index_level_dcc).';

b_3_level_dcc(index_level_dcc,:)=R_level_dcc
(:,3,index_level_dcc).';

position_vector_level_dcc(index_level_dcc,:)
=position_level_dcc(1,:,index_level_dcc);

Linear_Velocity_vector_level_dcc(index_level
_dcc,:)=Linear_Velocity_level_dcc(1,:,index_
level_dcc);

Rate_of_Change_R_vector_level_dcc(index_leve
l_dcc,:)=Rate_of_Change_R_level_dcc(1,:,inde
x_level_dcc);
end



R_end_level_dcc=Last_Element_Function(R_leve
l_dcc);
position_end_level_dcc=Last_Element_Function
(position_level_dcc);
Linear_Velocity_end_level_dcc=Last_Element_F
unction(Linear_Velocity_level_dcc);
Rate_of_Change_R_end_level_dcc=Last_Element_
Function(Rate_of_Change_R_level_dcc);
```

```
%%Moving forward. (based on the simulation
results: R_end_level_dcc is sufficiently
%%close (on the order of e-5) to identy
matrix: Rate_of_Change_R_end_level_dcc is
sufficiently
%%close (on the order of e-5) to [0 0 0]:
vertical linear velocity is
%%sufficiently close to 0 (on the order of
e-5).

phi1_dot=phi1_dot+rate_1*T_level_acc;
phi2_dot=phi2_dot-rate_2*T_level_acc;
phi3_dot=phi3_dot+rate_3*T_level_acc;
phi4_dot=phi4_dot-rate_4*T_level_acc;
rate_1=0;
rate_2=0;
rate_3=0;
rate_4=0;



R_coast_start = orientation_initial;
Rate_of_Change_R_coast_start = [0,0,0];
position_coast_start =
position_end_level_dcc;
Linear_Velocity_coast_start =
[Linear_Velocity_end_level_dcc(1,1)
Linear_Velocity_end_level_dcc(1,2) 0];



R_coast=Orientation_Matrix(phi1_dot,phi2_dot
,phi3_dot,phi4_dot,T_coast,rate_1,rate_2,rat
e_3,rate_4,R_coast_start,position_coast_star
t,Rate_of_Change_R_coast_start,Linear_Veloci
ty_coast_start);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
position_coast=Position_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_coast,rate_1,rate_2
,rate_3,rate_4,R_coast_start,position_coast_
start,Rate_of_Change_R_coast_start,Linear_Ve
locity_coast_start);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Linear_Velocity_coast=Linear_Velocity_Matrix
(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_coast
,rate_1,rate_2,rate_3,rate_4,R_coast_start,p
osition_coast_start,Rate_of_Change_R_coast_s
tart,Linear_Velocity_coast_start);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
Rate_of_Change_R_coast=Rate_of_Change_R_Matr
ix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_coa
st,rate_1,rate_2,rate_3,rate_4,R_coast_start
,position_coast_start,Rate_of_Change_R_coast
_start,Linear_Velocity_coast_start);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


[size_coast]=size(R_coast);
for index_coast=1:size_coast(1,3)

b_1_coast(index_coast,:)=R_coast(:,1,index_c
oast).';

b_2_coast(index_coast,:)=R_coast(:,2,index_c
oast).';

b_3_coast(index_coast,:)=R_coast(:,3,index_c
oast).';

position_vector_coast(index_coast,:)=positio
n_coast(1,:,index_coast);

Linear_Velocity_vector_coast(index_coast,:)=
Linear_Velocity_coast(1,:,index_coast);

Rate_of_Change_R_vector_coast(index_coast,:)
=Rate_of_Change_R_coast(1,:,index_coast);
end



R_coast_end=Last_Element_Function(R_coast);
R_coast_end=Sanity_Check(R_coast_end);
position_coast_end=Last_Element_Function(pos
ition_coast);
Linear_Velocity_coast_end=Last_Element_Funct
ion(Linear_Velocity_coast);
Rate_of_Change_R_coast_end=Last_Element_Func
tion(Rate_of_Change_R_coast);



%%For Animation.
b_1=cat(1,b_1_tilt_1,b_1_tilt_2,b_1_tilt_3,b
_1_tilt_4,b_1_tilt_5,b_1_tilt_6,b_1_tilt_7,b
_1_level_acc,b_1_level_dcc,b_1_coast);
b_2=cat(1,b_2_tilt_1,b_2_tilt_2,b_2_tilt_3,b
_2_tilt_4,b_2_tilt_5,b_2_tilt_6,b_2_tilt_7,b
_2_level_acc,b_2_level_dcc,b_2_coast);
b_3=cat(1,b_3_tilt_1,b_3_tilt_2,b_3_tilt_3,b
_3_tilt_4,b_3_tilt_5,b_3_tilt_6,b_3_tilt_7,b
_3_level_acc,b_3_level_dcc,b_3_coast);
position_vector=cat(1,position_vector_1,posi
tion_vector_2,position_vector_3,position_vec
tor_4,position_vector_5,position_vector_6,po
sition_vector_7,position_vector_level_acc,po
sition_vector_level_dcc,position_vector_coas
t);
Linear_Velocity_vector=cat(1,Linear_Velocity
_vector_1,Linear_Velocity_vector_2,Linear_Ve
locity_vector_3,Linear_Velocity_vector_4,Lin
ear_Velocity_vector_5,Linear_Velocity_vector
_6,Linear_Velocity_vector_7,Linear_Velocity_
vector_level_acc,Linear_Velocity_vector_leve
l_dcc,Linear_Velocity_vector_coast);
Rate_of_Change_R_vector=cat(1,Rate_of_Change
_R_vector_1,Rate_of_Change_R_vector_2,Rate_o
```

```
f_Change_R_vector_3,Rate_of_Change_R_vector_
4,Rate_of_Change_R_vector_5,Rate_of_Change_R
_vector_6,Rate_of_Change_R_vector_7,Rate_of_
Change_R_vector_level_acc,Rate_of_Change_R_v
ector_level_dcc,Rate_of_Change_R_vector_coas
t);
```

air_brake_after_coasting function

```
function
[b_1,b_2,b_3,position_vector,position_end,or
ientation_end,Linear_Velocity_output] =
air_brake_after_coasting(Orientation_Initial
,Position_Initial,Linear_Velocity)

%% **NOTE: this function only works
(eliminates the horizontal linear velocity)
%%when input linear velocity and input
orientation satisfies
%%dot(Linear_Velocity,b_1) =
dot(Linear_Velocity, b_2)
%%i.e. the direction which the copter is
headed in is 45 degrees from both
%%b_1 and b_2 body axis.
%%ex, input orientation identity matrix and
input linear velocity [positive positive
...]
%%will work correctly, but identity matrix
and [positive negative ...] will
%%not work.

%% Overview of this function:
%%this function stops the copter after given
an initial horizontal
%%velocity, but no initial vertical
velocity.
%%assumption of the input conditions: the
initial orientation will be upright
%%(i.e. b3 is always <0,0,1>) and
%%is the last orientation output of
tilt_moving_forward function; Initial
%%position will be the last position output
of tilt_moving_forward function;
%%And linear velocity is inherited from the
linear velocity output of
%%tilt_moving_forward function.
%%the outputs of the function:
%%position_end and orientation_end these two
specify the position and
%%orientation of the copter after this
maneuver is executed, and they will
%%become the inputs of the next stage
maneuver yaw_function.
%%outputs b_1,b_2,b_3 and position_vector
store the orientation
%%(b_1,b_2,b_3) and position
(position_vector) information of the
%%quadcopter throughout this function call,
and they will be used for
%%animation plot.
%%output assumptions of the function:
%%1.the orientation of copter should be
upright, and by executing this
%%function for various input linear
velocities (range from 0.1 to 1 m/s)
%%the output orientations are sufficiently
close to be the identity within
%%in very small error (on the order of e^-6
to e^-9), so it is safe to
%%assume this output condition for most of
the input velocities we'll be
%%working with.
%%2.the rate of change of orientation after
this function is executed is
%%a zero vector [0 0 0].
%%3.the horizontal linear velocities (i.e.
linear velocities along b1 and b2 body axis)
are sufficiently
%%close to zero, that is guaranteed by while
loop
%%such that the horizontal linear velocity
will be reduced to less than
%%5*e^-4, which is sufficiently close to
zero by our standards.


%% Implementation of the function:



Orientation_Initial=Sanity_Check(Orientation
_Initial);
t_3_acc=0.1;
t_3_c=0.25;
t_3_c_2=2.021909032*(t_3_c)+0.1016431777;
%equation relating t_3_c and t_3_c_2 only
depends on the t_3_acc and rate
rate=3;

Rate_of_Change_R=[0 0 0];


[b_1_stop_1,b_2_stop_1,b_3_stop_1,position_v
ector_stop_1,Linear_Velocity_vector_stop_1,R
ate_of_Change_R_vector_stop_1,R_end_stop_1,P
osition_end_stop_1,Rate_of_Change_R_end_stop
_1,Linear_Velocity_end_stop_1]=stop_function
(Orientation_Initial,Position_Initial,Rate_o
f_Change_R,Linear_Velocity,t_3_acc,t_3_c,t_3
_c_2,t_3_c,rate);



t_3_c=0.3;
t_3_c_2=2.010924598*t_3_c+0.05040967256;
t_3_acc=0.05;
rate=3;
[b_1_stop_2,b_2_stop_2,b_3_stop_2,position_v
ector_stop_2,Linear_Velocity_vector_stop_2,R
ate_of_Change_R_vector_stop_2,R_end_stop_2,P
osition_end_stop_2,Rate_of_Change_R_end_stop
_2,Linear_Velocity_end_stop_2]=stop_function
(R_end_stop_1,Position_end_stop_1,Rate_of_Ch
ange_R_end_stop_1,Linear_Velocity_end_stop_1
,t_3_acc,t_3_c,t_3_c_2,t_3_c,rate);


t_3_c=0.15;
t_3_c_2=2.005454850*t_3_c+0.05020455692;
t_3_acc=0.05;
rate=1.5;
[b_1_stop_3,b_2_stop_3,b_3_stop_3,position_v
ector_stop_3,Linear_Velocity_vector_stop_3,R
ate_of_Change_R_vector_stop_3,R_end_stop_3,P
osition_end_stop_3,Rate_of_Change_R_end_stop
_3,Linear_Velocity_end_stop_3]=stop_function
(R_end_stop_2,Position_end_stop_2,Rate_of_Ch
ange_R_end_stop_2,Linear_Velocity_end_stop_2
,t_3_acc,t_3_c,t_3_c_2,t_3_c,rate);


R_end_stop_3=Sanity_Check(R_end_stop_3);
R_end_stop(:,:,1)=R_end_stop_3;
Position_end_stop(:,:,1)=Position_end_stop_3
;
Rate_of_Change_R_end_stop(:,:,1)=Rate_of_Cha
nge_R_end_stop_3;
```

```
Linear_Velocity_end_stop(:,:,1)=Linear_Veloc
ity_end_stop_3;
Linear_Velocity_end=Linear_Velocity_end_stop
_3(1,1);


b_1 =
cat(1,b_1_stop_1,b_1_stop_2,b_1_stop_3);
b_2 =
cat(1,b_2_stop_1,b_2_stop_2,b_2_stop_3);
b_3 =
cat(1,b_3_stop_1,b_3_stop_2,b_3_stop_3);
position_vector =
cat(1,position_vector_stop_1,position_vector
_stop_2,position_vector_stop_3);




index=1;



while abs(Linear_Velocity_end) > 5*10^(-4)
    if
dot(Linear_Velocity_end_stop(:,:,index),(R_e
nd_stop(:,1,index).')) > 0
        t_3_c=0.005;

t_3_c_2=2.005454850*t_3_c+0.05020455692;
        t_3_acc=0.05;
        rate=1.5;



[b_1_stop,b_2_stop,b_3_stop,position_vector_
stop,Linear_Velocity_vector_stop,Rate_of_Cha
nge_R_vector_stop,R_end_stop(:,:,index+1),Po
sition_end_stop(:,:,index+1),Rate_of_Change_
R_end_stop(:,:,index+1),Linear_Velocity_end_
stop(:,:,index+1)]=stop_function([R_end_stop
(1,1,index) R_end_stop(1,2,index) 0;
R_end_stop(2,1,index) R_end_stop(2,2,index)
0; R_end_stop(3,1,index)
R_end_stop(3,2,index)
1],Position_end_stop(:,:,index),[0 0
0],Linear_Velocity_end_stop(:,:,index),t_3_a
cc,t_3_c,t_3_c_2,t_3_c,rate);


Linear_Velocity_end=Linear_Velocity_end_stop
(1,1,index+1);

        b_1 = cat(1,b_1,b_1_stop);
        b_2 = cat(1,b_2,b_2_stop);
        b_3 = cat(1,b_3,b_3_stop);
        position_vector =
cat(1,position_vector,position_vector_stop);

        index=index+1;
    elseif
dot(Linear_Velocity_end_stop(:,:,index),(R_e
nd_stop(:,1,index).')) < 0
        t_3_c=0.005;

t_3_c_2=2.005454850*t_3_c+0.05020455692;
        t_3_acc=0.05;
        rate=1.5;


[b_1_stop,b_2_stop,b_3_stop,position_vector_
stop,Linear_Velocity_vector_stop,Rate_of_Cha
nge_R_vector_stop,R_end_stop(:,:,index+1),Po
sition_end_stop(:,:,index+1),Rate_of_Change_
R_end_stop(:,:,index+1),Linear_Velocity_end_
stop(:,:,index+1)]=stop_function_forward([R_
end_stop(1,1,index) R_end_stop(1,2,index) 0;
R_end_stop(2,1,index) R_end_stop(2,2,index)
0; R_end_stop(3,1,index)
R_end_stop(3,2,index)
1],Position_end_stop(:,:,index),[0 0
0],Linear_Velocity_end_stop(:,:,index),t_3_a
cc,t_3_c,t_3_c_2,t_3_c,rate);

Linear_Velocity_end=Linear_Velocity_end_stop
(1,1,index+1);


        b_1 = cat(1,b_1,b_1_stop);
        b_2 = cat(1,b_2,b_2_stop);
        b_3 = cat(1,b_3,b_3_stop);
        position_vector =
cat(1,position_vector,position_vector_stop);


        index=index+1;
    end


end

position_end =
Last_Element_Function(Position_end_stop);
orientation_end =
Last_Element_Function(R_end_stop);
orientation_end =
Sanity_Check(orientation_end);
Linear_Velocity_output =
Last_Element_Function(Linear_Velocity_end_st
op);




%%Note: there will still be a vertical
linear velocity to be eliminated,
%%but is sufficiently small enough to
ignore.
```

yaw_function

```
function
[b_1,b_2,b_3,position_vector,position_end_level_acc,R_end_level_acc]=yaw_function(Orientation_Initial,Position_Initial,yaw_command,angle_of_rotation)

%%Overview of this function:
%%For yaw command, 01 means rotate clockwise and 10 means rotate
%%counter clockwise, and angle_of_rotation is the desired angle of rotation in units of degrees.
%%this function assumes that the quadcopter is initially in hovering state
%%i.e. all rotors are rotating at 27.53596541(rad/s), no rate of change of orientation,
%%Rate_of_change_Orientation = [0 0 0];
%%Linear_Velocity is zero in all components, Linear_velocity_Initial = [0 0 0]
%%the initial orientation of the copter is the last orientation output of
%%the previous function call (air_break_after_coasting function).
%%the output of this function is b_1, b_2, b_3 record the orientation of the body
%%frame in spatial frame during the maneuver.
%%output position_vector records the position of the center of mass of the
%%frame throughout this maneuver.
%%output position_end_level_acc is the position of C.M. at the
%%end of this maneuver.
%%It is assumed that, the orientation at the end of maneuver is sufficiently
%%close to be upright (b3 = <0,0,1>) and in reality, it is. linear velocity of the
%%center of mass will be [0 0 0], rate of change of orientation of frame
%%will also be [0 0 0].

%%Implementation of this function:


%% Assumptions:

Orientation_Initial=Sanity_Check(Orientation_Initial);
Rate_of_change_Orientation_Initial=[0 0 0];
Linear_velocity_Initial=[0 0 0];




%% yaw control. freedom of movement ]0,90(degree)[.
%copter starts out hovering,

if yaw_command == 01 %(CW)

    phi1_dot=27.53596541;
    phi2_dot=-27.53596541;
    phi3_dot=27.53596541;
    phi4_dot=-27.53596541;
    rate_1=14.64035000;
    rate_2=0;
    rate_3=14.64035000;
    rate_4=0;
    T_1=0.1;



R_yaw_acc=Orientation_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3,rate_4,Orientation_Initial,Position_Initial,Rate_of_change_Orientation_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)

position_yaw_acc=Position_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3,rate_4,Orientation_Initial,Position_Initial,Rate_of_change_Orientation_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)

Linear_Velocity_yaw_acc=Linear_Velocity_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3,rate_4,Orientation_Initial,Position_Initial,Rate_of_change_Orientation_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)

Rate_of_Change_R_yaw_acc=Rate_of_Change_R_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_3,rate_4,Orientation_Initial,Position_Initial,Rate_of_change_Orientation_Initial,Linear_velocity_Initial);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)


    [size_acc]=size(R_yaw_acc);
    for index_acc=1:size_acc(1,3)

b_1_yaw_acc(index_acc,:)=R_yaw_acc(:,1,index_acc).';

b_2_yaw_acc(index_acc,:)=R_yaw_acc(:,2,index_acc).';

b_3_yaw_acc(index_acc,:)=R_yaw_acc(:,3,index_acc).';

position_vector_acc(index_acc,:)=position_yaw_acc(1,:,index_acc);

Linear_Velocity_vector_acc(index_acc,:)=Linear_Velocity_yaw_acc(1,:,index_acc);

Rate_of_Change_R_vector_acc(index_acc,:)=Rate_of_Change_R_yaw_acc(1,:,index_acc);
    end
```

```
R_end_yaw_acc=Last_Element_Function(R_yaw_ac
c);

position_end_yaw_acc=Last_Element_Function(p
osition_yaw_acc);

Linear_Velocity_end_yaw_acc=Last_Element_Fun
ction(Linear_Velocity_yaw_acc);

Rate_of_Change_R_end_yaw_acc=Last_Element_Fu
nction(Rate_of_Change_R_yaw_acc);


    %phase 2 motor 1 and 3 slow down a rate
of 14.64035000rad/s/s in 0.1s
    %and return to hovering speed.

    phi1_dot=phi1_dot+rate_1*T_1;
    phi2_dot=phi2_dot-rate_2*T_1;
    phi3_dot=phi3_dot+rate_3*T_1;
    phi4_dot=phi4_dot-rate_4*T_1;
    rate_1=-14.640350000;
    rate_2=0;
    rate_3=-14.64035000;
    rate_4=0;
    T_2=0.1;


R_yaw_dcc=Orientation_Matrix(phi1_dot,phi2_d
ot,phi3_dot,phi4_dot,T_2,rate_1,rate_2,rate_
3,rate_4,R_end_yaw_acc,position_end_yaw_acc,
Rate_of_Change_R_end_yaw_acc,Linear_Velocity
_end_yaw_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_yaw_dcc=Position_Matrix(phi1_dot,ph
i2_dot,phi3_dot,phi4_dot,T_2,rate_1,rate_2,r
ate_3,rate_4,R_end_yaw_acc,position_end_yaw_
acc,Rate_of_Change_R_end_yaw_acc,Linear_Velo
city_end_yaw_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_dcc=Linear_Velocity_Matr
ix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2,r
ate_1,rate_2,rate_3,rate_4,R_end_yaw_acc,pos
ition_end_yaw_acc,Rate_of_Change_R_end_yaw_a
cc,Linear_Velocity_end_yaw_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_dcc=Rate_of_Change_R_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2
,rate_1,rate_2,rate_3,rate_4,R_end_yaw_acc,p
osition_end_yaw_acc,Rate_of_Change_R_end_yaw
_acc,Linear_Velocity_end_yaw_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_dcc]=size(R_yaw_dcc);
    for index_dcc=1:size_dcc(1,3)

b_1_yaw_dcc(index_dcc,:)=R_yaw_dcc(:,1,index
_dcc).';

b_2_yaw_dcc(index_dcc,:)=R_yaw_dcc(:,2,index
_dcc).';

b_3_yaw_dcc(index_dcc,:)=R_yaw_dcc(:,3,index
_dcc).';

position_vector_dcc(index_dcc,:)=position_ya
w_dcc(1,:,index_dcc);

Linear_Velocity_vector_dcc(index_dcc,:)=Line
ar_Velocity_yaw_dcc(1,:,index_dcc);

Rate_of_Change_R_vector_dcc(index_dcc,:)=Rat
e_of_Change_R_yaw_dcc(1,:,index_dcc);
    end



R_end_yaw_dcc=Last_Element_Function(R_yaw_dc
c);

position_end_yaw_dcc=Last_Element_Function(p
osition_yaw_dcc);

Linear_Velocity_end_yaw_dcc=Last_Element_Fun
ction(Linear_Velocity_yaw_dcc);

Rate_of_Change_R_end_yaw_dcc=Last_Element_Fu
nction(Rate_of_Change_R_yaw_dcc);


    %phase 3. all four motors maintain
hovering speed and phase 3 runs for
    %T s.
    %at the end of phase 2 quadcopter has
rotated through 0.9096828578
    %degree around b3. (v_beta_end_dcc =
9.096828572 degrees/s).


v_beta_end_dcc=abs(Rate_of_Change_R_end_yaw_
dcc(1,1));
    T=(((angle_of_rotation-
2*0.9096828578)/180)*pi)/v_beta_end_dcc;


    phi1_dot=phi1_dot+rate_1*T_2;
    phi2_dot=phi2_dot-rate_2*T_2;
    phi3_dot=phi3_dot+rate_3*T_2;
    phi4_dot=phi4_dot-rate_4*T_2;
    rate_1=0;
    rate_2=0;
    rate_3=0;
    rate_4=0;
    T_3=T;


R_yaw_uniform=Orientation_Matrix(phi1_dot,ph
i2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate_2,r
ate_3,rate_4,R_end_yaw_dcc,position_end_yaw_
dcc,Rate_of_Change_R_end_yaw_dcc,Linear_Velo
city_end_yaw_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)
```

```
position_yaw_uniform=Position_Matrix(phi1_do
t,phi2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate
_2,rate_3,rate_4,R_end_yaw_dcc,position_end_
yaw_dcc,Rate_of_Change_R_end_yaw_dcc,Linear_
Velocity_end_yaw_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_uniform=Linear_Velocity_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_3,rate_1,rate_2,rate_3,rate_4,R_end_yaw_dcc
,position_end_yaw_dcc,Rate_of_Change_R_end_y
aw_dcc,Linear_Velocity_end_yaw_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_uniform=Rate_of_Change_
R_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot
,T_3,rate_1,rate_2,rate_3,rate_4,R_end_yaw_d
cc,position_end_yaw_dcc,Rate_of_Change_R_end
_yaw_dcc,Linear_Velocity_end_yaw_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_uniform]=size(R_yaw_uniform);
    for index_uniform=1:size_uniform(1,3)

b_1_yaw_uniform(index_uniform,:)=R_yaw_unifo
rm(:,1,index_uniform).';

b_2_yaw_uniform(index_uniform,:)=R_yaw_unifo
rm(:,2,index_uniform).';

b_3_yaw_uniform(index_uniform,:)=R_yaw_unifo
rm(:,3,index_uniform).';

position_vector_uniform(index_uniform,:)=pos
ition_yaw_uniform(1,:,index_uniform);

Linear_Velocity_vector_uniform(index_uniform
,:)=Linear_Velocity_yaw_uniform(1,:,index_un
iform);

Rate_of_Change_R_vector_uniform(index_unifor
m,:)=Rate_of_Change_R_yaw_uniform(1,:,index_
uniform);
    end


R_end_yaw_uniform=Last_Element_Function(R_ya
w_uniform);

position_end_yaw_uniform=Last_Element_Functi
on(position_yaw_uniform);

Linear_Velocity_end_yaw_uniform=Last_Element
_Function(Linear_Velocity_yaw_uniform);

Rate_of_Change_R_end_yaw_uniform=Last_Elemen
t_Function(Rate_of_Change_R_yaw_uniform);
```

```
    %phase 4 motor 2 and 4 speed up at a
rate of 14.64035000rad/s/s in 0.1s
    %and reaches speed of 29 rad/s.
    phi1_dot=phi1_dot+rate_1*T_3;
    phi2_dot=phi2_dot-rate_2*T_3;
    phi3_dot=phi3_dot+rate_3*T_3;
    phi4_dot=phi4_dot-rate_4*T_3;
    rate_1=0;
    rate_2=14.64035000;
    rate_3=0;
    rate_4=14.64035000;
    T_4=0.1;


R_yaw_acc_2=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2,rat
e_3,rate_4,R_end_yaw_uniform,position_end_ya
w_uniform,Rate_of_Change_R_end_yaw_uniform,L
inear_Velocity_end_yaw_uniform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_yaw_acc_2=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2
,rate_3,rate_4,R_end_yaw_uniform,position_en
d_yaw_uniform,Rate_of_Change_R_end_yaw_unifo
rm,Linear_Velocity_end_yaw_uniform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_acc_2=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4
,rate_1,rate_2,rate_3,rate_4,R_end_yaw_unifo
rm,position_end_yaw_uniform,Rate_of_Change_R
_end_yaw_uniform,Linear_Velocity_end_yaw_uni
form);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_acc_2=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_4,rate_1,rate_2,rate_3,rate_4,R_end_yaw_uni
form,position_end_yaw_uniform,Rate_of_Change
_R_end_yaw_uniform,Linear_Velocity_end_yaw_u
niform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_acc_2]=size(R_yaw_acc_2);
    for index_acc_2=1:size_acc_2(1,3)

b_1_yaw_acc_2(index_acc_2,:)=R_yaw_acc_2(:,1
,index_acc_2).';

b_2_yaw_acc_2(index_acc_2,:)=R_yaw_acc_2(:,2
,index_acc_2).';

b_3_yaw_acc_2(index_acc_2,:)=R_yaw_acc_2(:,3
,index_acc_2).';
```

```
position_vector_acc_2(index_acc_2,:)=positio
n_yaw_acc_2(1,:,index_acc_2);

Linear_Velocity_vector_acc_2(index_acc_2,:)=
Linear_Velocity_yaw_acc_2(1,:,index_acc_2);

Rate_of_Change_R_vector_acc_2(index_acc_2,:)
=Rate_of_Change_R_yaw_acc_2(1,:,index_acc_2)
;
    end



R_end_yaw_acc_2=Last_Element_Function(R_yaw_
acc_2);

position_end_yaw_acc_2=Last_Element_Function
(position_yaw_acc_2);

Linear_Velocity_end_yaw_acc_2=Last_Element_F
unction(Linear_Velocity_yaw_acc_2);

Rate_of_Change_R_end_yaw_acc_2=Last_Element_
Function(Rate_of_Change_R_yaw_acc_2);


    %phase 5 motor 2 and 4 slow down at a
rate of 14.64035000rad/s/s in 0.1s
    %and return to hovering speed.
    phi1_dot=phi1_dot+rate_1*T_4;
    phi2_dot=phi2_dot-rate_2*T_4;
    phi3_dot=phi3_dot+rate_3*T_4;
    phi4_dot=phi4_dot-rate_4*T_4;
    rate_1=0;
    rate_2=-14.64035000;
    rate_3=0;
    rate_4=-14.64035000;
    T_5=0.1;



R_yaw_dcc_2=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2,rat
e_3,rate_4,R_end_yaw_acc_2,position_end_yaw_
acc_2,Rate_of_Change_R_end_yaw_acc_2,Linear_
Velocity_end_yaw_acc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_yaw_dcc_2=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2
,rate_3,rate_4,R_end_yaw_acc_2,position_end_
yaw_acc_2,Rate_of_Change_R_end_yaw_acc_2,Lin
ear_Velocity_end_yaw_acc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_dcc_2=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5
,rate_1,rate_2,rate_3,rate_4,R_end_yaw_acc_2
,position_end_yaw_acc_2,Rate_of_Change_R_end
_yaw_acc_2,Linear_Velocity_end_yaw_acc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_dcc_2=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_5,rate_1,rate_2,rate_3,rate_4,R_end_yaw_acc
_2,position_end_yaw_acc_2,Rate_of_Change_R_e
nd_yaw_acc_2,Linear_Velocity_end_yaw_acc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_dcc_2]=size(R_yaw_dcc_2);
    for index_dcc_2=1:size_dcc_2(1,3)

b_1_yaw_dcc_2(index_dcc_2,:)=R_yaw_dcc_2(:,1
,index_dcc_2).';

b_2_yaw_dcc_2(index_dcc_2,:)=R_yaw_dcc_2(:,2
,index_dcc_2).';

b_3_yaw_dcc_2(index_dcc_2,:)=R_yaw_dcc_2(:,3
,index_dcc_2).';

position_vector_dcc_2(index_dcc_2,:)=positio
n_yaw_dcc_2(1,:,index_dcc_2);

Linear_Velocity_vector_dcc_2(index_dcc_2,:)=
Linear_Velocity_yaw_dcc_2(1,:,index_dcc_2);

Rate_of_Change_R_vector_dcc_2(index_dcc_2,:)
=Rate_of_Change_R_yaw_dcc_2(1,:,index_dcc_2)
;
    end



R_end_yaw_dcc_2=Last_Element_Function(R_yaw_
dcc_2);

position_end_yaw_dcc_2=Last_Element_Function
(position_yaw_dcc_2);

Linear_Velocity_end_yaw_dcc_2=Last_Element_F
unction(Linear_Velocity_yaw_dcc_2);

Rate_of_Change_R_end_yaw_dcc_2=Last_Element_
Function(Rate_of_Change_R_yaw_dcc_2);



    %%eliminating vertical velocity of the
frame caused by this yaw
    %%process.


    %phase 6 all four motors slow down at a
rate of 15.17870675rad/s/s for 0.1s.

    phi1_dot=phi1_dot+rate_1*T_5;
    phi2_dot=phi2_dot-rate_2*T_5;
    phi3_dot=phi3_dot+rate_3*T_5;
    phi4_dot=phi4_dot-rate_4*T_5;
    rate_1=-15.17870675;
    rate_2=-15.17870675;
    rate_3=-15.17870675;
    rate_4=-15.17870675;
    T_6=0.1;
```

```
R_level_dcc=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_6,rate_1,rate_2,rat
e_3,rate_4,R_end_yaw_dcc_2,position_end_yaw_
dcc_2,Rate_of_Change_R_end_yaw_dcc_2,Linear_
Velocity_end_yaw_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_level_dcc=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_6,rate_1,rate_2
,rate_3,rate_4,R_end_yaw_dcc_2,position_end_
yaw_dcc_2,Rate_of_Change_R_end_yaw_dcc_2,Lin
ear_Velocity_end_yaw_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_level_dcc=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_6
,rate_1,rate_2,rate_3,rate_4,R_end_yaw_dcc_2
,position_end_yaw_dcc_2,Rate_of_Change_R_end
_yaw_dcc_2,Linear_Velocity_end_yaw_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_level_dcc=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_6,rate_1,rate_2,rate_3,rate_4,R_end_yaw_dcc
_2,position_end_yaw_dcc_2,Rate_of_Change_R_e
nd_yaw_dcc_2,Linear_Velocity_end_yaw_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_level_dcc]=size(R_level_dcc);
    for
index_level_dcc=1:size_level_dcc(1,3)

b_1_level_dcc(index_level_dcc,:)=R_level_dcc
(:,1,index_level_dcc).';

b_2_level_dcc(index_level_dcc,:)=R_level_dcc
(:,2,index_level_dcc).';

b_3_level_dcc(index_level_dcc,:)=R_level_dcc
(:,3,index_level_dcc).';

position_vector_level_dcc(index_level_dcc,:)
=position_level_dcc(1,:,index_level_dcc);

Linear_Velocity_vector_level_dcc(index_level
_dcc,:)=Linear_Velocity_level_dcc(1,:,index_
level_dcc);

Rate_of_Change_R_vector_level_dcc(index_leve
l_dcc,:)=Rate_of_Change_R_level_dcc(1,:,inde
x_level_dcc);
    end



R_end_level_dcc=Last_Element_Function(R_leve
l_dcc);

position_end_level_dcc=Last_Element_Function
(position_level_dcc);

Linear_Velocity_end_level_dcc=Last_Element_F
unction(Linear_Velocity_level_dcc);

Rate_of_Change_R_end_level_dcc=Last_Element_
Function(Rate_of_Change_R_level_dcc);


    %phase 7 all four motors speed up at a
rate of 15.17870675rad/s/s for 0.1s.

    phi1_dot=phi1_dot+rate_1*T_6;
    phi2_dot=phi2_dot-rate_2*T_6;
    phi3_dot=phi3_dot+rate_3*T_6;
    phi4_dot=phi4_dot-rate_4*T_6;
    rate_1=15.17870675;
    rate_2=15.17870675;
    rate_3=15.17870675;
    rate_4=15.17870675;
    T_7=0.1;



R_level_acc=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2,rat
e_3,rate_4,R_end_level_dcc,position_end_leve
l_dcc,Rate_of_Change_R_end_level_dcc,Linear_
Velocity_end_level_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_level_acc=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2
,rate_3,rate_4,R_end_level_dcc,position_end_
level_dcc,Rate_of_Change_R_end_level_dcc,Lin
ear_Velocity_end_level_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_level_acc=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7
,rate_1,rate_2,rate_3,rate_4,R_end_level_dcc
,position_end_level_dcc,Rate_of_Change_R_end
_level_dcc,Linear_Velocity_end_level_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_level_acc=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_7,rate_1,rate_2,rate_3,rate_4,R_end_level_d
cc,position_end_level_dcc,Rate_of_Change_R_e
nd_level_dcc,Linear_Velocity_end_level_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_level_acc]=size(R_level_acc);
    for
index_level_acc=1:size_level_acc(1,3)
```

```
b_1_level_acc(index_level_acc,:)=R_level_acc
(:,1,index_level_acc).';

b_2_level_acc(index_level_acc,:)=R_level_acc
(:,2,index_level_acc).';

b_3_level_acc(index_level_acc,:)=R_level_acc
(:,3,index_level_acc).';

position_vector_level_acc(index_level_acc,:)
=position_level_acc(1,:,index_level_acc);

Linear_Velocity_vector_level_acc(index_level
_acc,:)=Linear_Velocity_level_acc(1,:,index_
level_acc);

Rate_of_Change_R_vector_level_acc(index_leve
l_acc,:)=Rate_of_Change_R_level_acc(1,:,inde
x_level_acc);
    end


R_end_level_acc=Last_Element_Function(R_leve
l_acc);

R_end_level_acc=Sanity_Check(R_end_level_acc
);

position_end_level_acc=Last_Element_Function
(position_level_acc);

Linear_Velocity_end_level_acc=Last_Element_F
unction(Linear_Velocity_level_acc);

Rate_of_Change_R_end_level_acc=Last_Element_
Function(Rate_of_Change_R_level_acc);


    %%For Animation.

b_1=cat(1,b_1_yaw_acc,b_1_yaw_dcc,b_1_yaw_un
iform,b_1_yaw_acc_2,b_1_yaw_dcc_2,b_1_level_
dcc,b_1_level_acc);

b_2=cat(1,b_2_yaw_acc,b_2_yaw_dcc,b_2_yaw_un
iform,b_2_yaw_acc_2,b_2_yaw_dcc_2,b_2_level_
dcc,b_2_level_acc);

b_3=cat(1,b_3_yaw_acc,b_3_yaw_dcc,b_3_yaw_un
iform,b_3_yaw_acc_2,b_3_yaw_dcc_2,b_3_level_
dcc,b_3_level_acc);

position_vector=cat(1,position_vector_acc,po
sition_vector_dcc,position_vector_uniform,po
sition_vector_acc_2,position_vector_dcc_2,po
sition_vector_level_dcc,position_vector_leve
l_acc);

Linear_Velocity_vector=cat(1,Linear_Velocity
_vector_acc,Linear_Velocity_vector_dcc,Linea
r_Velocity_vector_uniform,Linear_Velocity_ve
ctor_acc_2,Linear_Velocity_vector_dcc_2,Line
ar_Velocity_vector_level_dcc,Linear_Velocity
_vector_level_acc);

Rate_of_Change_R_vector=cat(1,Rate_of_Change
_R_vector_acc,Rate_of_Change_R_vector_dcc,Ra
te_of_Change_R_vector_uniform,Rate_of_Change
_R_vector_acc_2,Rate_of_Change_R_vector_dcc_
2,Rate_of_Change_R_vector_level_dcc,Rate_of_
Change_R_vector_level_acc);



elseif yaw_command == 10 %(CCW)


    %phase 1 motor 2 and 4 speed up at a
rate of 14.64035000rad/s/s in 0.1s
    %and reaches speed of 29 rad/s.
    phi1_dot=27.53596541;
    phi2_dot=-27.53596541;
    phi3_dot=27.53596541;
    phi4_dot=-27.53596541;
    rate_1=0;
    rate_2=14.64035000;
    rate_3=0;
    rate_4=14.64035000;
    T_1=0.1;


R_yaw_acc=Orientation_Matrix(phi1_dot,phi2_d
ot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,rate_
3,rate_4,[1 0 0; 0 1 0; 0 0 1],[0 0 0],[0 0
0],[0 0 0]);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_yaw_acc=Position_Matrix(phi1_dot,ph
i2_dot,phi3_dot,phi4_dot,T_1,rate_1,rate_2,r
ate_3,rate_4,[1 0 0; 0 1 0; 0 0 1],[0 0
0],[0 0 0],[0 0 0]);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_acc=Linear_Velocity_Matr
ix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1,r
ate_1,rate_2,rate_3,rate_4,[1 0 0; 0 1 0; 0
0 1],[0 0 0],[0 0 0],[0 0 0]);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_acc=Rate_of_Change_R_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_1
,rate_1,rate_2,rate_3,rate_4,[1 0 0; 0 1 0;
0 0 1],[0 0 0],[0 0 0],[0 0 0]);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_acc]=size(R_yaw_acc);
    for index_acc=1:size_acc(1,3)

b_1_yaw_acc(index_acc,:)=R_yaw_acc(:,1,index
_acc).';

b_2_yaw_acc(index_acc,:)=R_yaw_acc(:,2,index
_acc).';
```

```
b_3_yaw_acc(index_acc,:)=R_yaw_acc(:,3,index
_acc).';

position_vector_acc(index_acc,:)=position_ya
w_acc(1,:,index_acc);

Linear_Velocity_vector_acc(index_acc,:)=Line
ar_Velocity_yaw_acc(1,:,index_acc);

Rate_of_Change_R_vector_acc(index_acc,:)=Rat
e_of_Change_R_yaw_acc(1,:,index_acc);
    end



R_end_yaw_acc=Last_Element_Function(R_yaw_ac
c);

position_end_yaw_acc=Last_Element_Function(p
osition_yaw_acc);

Linear_Velocity_end_yaw_acc=Last_Element_Fun
ction(Linear_Velocity_yaw_acc);

Rate_of_Change_R_end_yaw_acc=Last_Element_Fu
nction(Rate_of_Change_R_yaw_acc);


    %phase 2 motor 2 and 4 slow down a rate
of 14.64035000rad/s/s in 0.1s
    %and return to hovering speed.

    phi1_dot=phi1_dot+rate_1*T_1;
    phi2_dot=phi2_dot-rate_2*T_1;
    phi3_dot=phi3_dot+rate_3*T_1;
    phi4_dot=phi4_dot-rate_4*T_1;
    rate_1=0;
    rate_2=-14.64035000;
    rate_3=0;
    rate_4=-14.64035000;
    T_2=0.1;


R_yaw_dcc=Orientation_Matrix(phi1_dot,phi2_d
ot,phi3_dot,phi4_dot,T_2,rate_1,rate_2,rate_
3,rate_4,R_end_yaw_acc,position_end_yaw_acc,
Rate_of_Change_R_end_yaw_acc,Linear_Velocity
_end_yaw_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_yaw_dcc=Position_Matrix(phi1_dot,ph
i2_dot,phi3_dot,phi4_dot,T_2,rate_1,rate_2,r
ate_3,rate_4,R_end_yaw_acc,position_end_yaw_
acc,Rate_of_Change_R_end_yaw_acc,Linear_Velo
city_end_yaw_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_dcc=Linear_Velocity_Matr
ix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2,r
ate_1,rate_2,rate_3,rate_4,R_end_yaw_acc,pos
ition_end_yaw_acc,Rate_of_Change_R_end_yaw_a
cc,Linear_Velocity_end_yaw_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_dcc=Rate_of_Change_R_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_2
,rate_1,rate_2,rate_3,rate_4,R_end_yaw_acc,p
osition_end_yaw_acc,Rate_of_Change_R_end_yaw
_acc,Linear_Velocity_end_yaw_acc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_dcc]=size(R_yaw_dcc);
    for index_dcc=1:size_dcc(1,3)

b_1_yaw_dcc(index_dcc,:)=R_yaw_dcc(:,1,index
_dcc).';

b_2_yaw_dcc(index_dcc,:)=R_yaw_dcc(:,2,index
_dcc).';

b_3_yaw_dcc(index_dcc,:)=R_yaw_dcc(:,3,index
_dcc).';

position_vector_dcc(index_dcc,:)=position_ya
w_dcc(1,:,index_dcc);

Linear_Velocity_vector_dcc(index_dcc,:)=Line
ar_Velocity_yaw_dcc(1,:,index_dcc);

Rate_of_Change_R_vector_dcc(index_dcc,:)=Rat
e_of_Change_R_yaw_dcc(1,:,index_dcc);
    end



R_end_yaw_dcc=Last_Element_Function(R_yaw_dc
c);

position_end_yaw_dcc=Last_Element_Function(p
osition_yaw_dcc);

Linear_Velocity_end_yaw_dcc=Last_Element_Fun
ction(Linear_Velocity_yaw_dcc);

Rate_of_Change_R_end_yaw_dcc=Last_Element_Fu
nction(Rate_of_Change_R_yaw_dcc);


    %phase 3. all four motors maintain
hovering speed and phase 3 runs for
    %T s.
    %at the end of phase 2 quadcopter has
rotated through 0.9096828578
    %degree around b3. (v_beta_end_dcc =
9.096828572 degrees/s).


v_beta_end_dcc=abs(Rate_of_Change_R_end_yaw_
dcc(1,1));
    T=(((angle_of_rotation-
2*0.9096828578)/180)*pi)/v_beta_end_dcc;


    phi1_dot=phi1_dot+rate_1*T_2;
    phi2_dot=phi2_dot-rate_2*T_2;
    phi3_dot=phi3_dot+rate_3*T_2;
    phi4_dot=phi4_dot-rate_4*T_2;
```

```
    rate_1=0;
    rate_2=0;
    rate_3=0;
    rate_4=0;
    T_3=T;


R_yaw_uniform=Orientation_Matrix(phi1_dot,ph
i2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate_2,r
ate_3,rate_4,R_end_yaw_dcc,position_end_yaw_
dcc,Rate_of_Change_R_end_yaw_dcc,Linear_Velo
city_end_yaw_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_yaw_uniform=Position_Matrix(phi1_do
t,phi2_dot,phi3_dot,phi4_dot,T_3,rate_1,rate
_2,rate_3,rate_4,R_end_yaw_dcc,position_end_
yaw_dcc,Rate_of_Change_R_end_yaw_dcc,Linear_
Velocity_end_yaw_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_uniform=Linear_Velocity_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_3,rate_1,rate_2,rate_3,rate_4,R_end_yaw_dcc
,position_end_yaw_dcc,Rate_of_Change_R_end_y
aw_dcc,Linear_Velocity_end_yaw_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_uniform=Rate_of_Change_
R_Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot
,T_3,rate_1,rate_2,rate_3,rate_4,R_end_yaw_d
cc,position_end_yaw_dcc,Rate_of_Change_R_end
_yaw_dcc,Linear_Velocity_end_yaw_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_uniform]=size(R_yaw_uniform);
    for index_uniform=1:size_uniform(1,3)

b_1_yaw_uniform(index_uniform,:)=R_yaw_unifo
rm(:,1,index_uniform).';

b_2_yaw_uniform(index_uniform,:)=R_yaw_unifo
rm(:,2,index_uniform).';

b_3_yaw_uniform(index_uniform,:)=R_yaw_unifo
rm(:,3,index_uniform).';

position_vector_uniform(index_uniform,:)=pos
ition_yaw_uniform(1,:,index_uniform);

Linear_Velocity_vector_uniform(index_uniform
,:)=Linear_Velocity_yaw_uniform(1,:,index_un
iform);

Rate_of_Change_R_vector_uniform(index_unifor
m,:)=Rate_of_Change_R_yaw_uniform(1,:,index_
uniform);
    end

R_end_yaw_uniform=Last_Element_Function(R_ya
w_uniform);

position_end_yaw_uniform=Last_Element_Functi
on(position_yaw_uniform);

Linear_Velocity_end_yaw_uniform=Last_Element
_Function(Linear_Velocity_yaw_uniform);

Rate_of_Change_R_end_yaw_uniform=Last_Elemen
t_Function(Rate_of_Change_R_yaw_uniform);


    %phase 4 motor 1 and 3 speed up at a
rate of 14.64035000rad/s/s in 0.1s
    %and reaches speed of 29 rad/s.
    phi1_dot=phi1_dot+rate_1*T_3;
    phi2_dot=phi2_dot-rate_2*T_3;
    phi3_dot=phi3_dot+rate_3*T_3;
    phi4_dot=phi4_dot-rate_4*T_3;
    rate_1=14.64035000;
    rate_2=0;
    rate_3=14.64035000;
    rate_4=0;
    T_4=0.1;


R_yaw_acc_2=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2,rat
e_3,rate_4,R_end_yaw_uniform,position_end_ya
w_uniform,Rate_of_Change_R_end_yaw_uniform,L
inear_Velocity_end_yaw_uniform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_yaw_acc_2=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_4,rate_1,rate_2
,rate_3,rate_4,R_end_yaw_uniform,position_en
d_yaw_uniform,Rate_of_Change_R_end_yaw_unifo
rm,Linear_Velocity_end_yaw_uniform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_acc_2=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_4
,rate_1,rate_2,rate_3,rate_4,R_end_yaw_unifo
rm,position_end_yaw_uniform,Rate_of_Change_R
_end_yaw_uniform,Linear_Velocity_end_yaw_uni
form);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_acc_2=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_4,rate_1,rate_2,rate_3,rate_4,R_end_yaw_uni
form,position_end_yaw_uniform,Rate_of_Change
_R_end_yaw_uniform,Linear_Velocity_end_yaw_u
niform);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
```

```
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_acc_2]=size(R_yaw_acc_2);
    for index_acc_2=1:size_acc_2(1,3)

b_1_yaw_acc_2(index_acc_2,:)=R_yaw_acc_2(:,1
,index_acc_2).';

b_2_yaw_acc_2(index_acc_2,:)=R_yaw_acc_2(:,2
,index_acc_2).';

b_3_yaw_acc_2(index_acc_2,:)=R_yaw_acc_2(:,3
,index_acc_2).';

position_vector_acc_2(index_acc_2,:)=positio
n_yaw_acc_2(1,:,index_acc_2);

Linear_Velocity_vector_acc_2(index_acc_2,:)=
Linear_Velocity_yaw_acc_2(1,:,index_acc_2);

Rate_of_Change_R_vector_acc_2(index_acc_2,:)
=Rate_of_Change_R_yaw_acc_2(1,:,index_acc_2)
;
    end



R_end_yaw_acc_2=Last_Element_Function(R_yaw_
acc_2);

position_end_yaw_acc_2=Last_Element_Function
(position_yaw_acc_2);

Linear_Velocity_end_yaw_acc_2=Last_Element_F
unction(Linear_Velocity_yaw_acc_2);

Rate_of_Change_R_end_yaw_acc_2=Last_Element_
Function(Rate_of_Change_R_yaw_acc_2);


    %phase 5 motor 1 and 3 slow down at a
rate of 14.64035000rad/s/s in 0.1s
    %and return to hovering speed.
    phi1_dot=phi1_dot+rate_1*T_4;
    phi2_dot=phi2_dot-rate_2*T_4;
    phi3_dot=phi3_dot+rate_3*T_4;
    phi4_dot=phi4_dot-rate_4*T_4;
    rate_1=-14.64035000;
    rate_2=0;
    rate_3=-14.64035000;
    rate_4=0;
    T_5=0.1;



R_yaw_dcc_2=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2,rat
e_3,rate_4,R_end_yaw_acc_2,position_end_yaw_
acc_2,Rate_of_Change_R_end_yaw_acc_2,Linear_
Velocity_end_yaw_acc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_yaw_dcc_2=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_5,rate_1,rate_2
,rate_3,rate_4,R_end_yaw_acc_2,position_end_
yaw_acc_2,Rate_of_Change_R_end_yaw_acc_2,Lin
ear_Velocity_end_yaw_acc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_yaw_dcc_2=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_5
,rate_1,rate_2,rate_3,rate_4,R_end_yaw_acc_2
,position_end_yaw_acc_2,Rate_of_Change_R_end
_yaw_acc_2,Linear_Velocity_end_yaw_acc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_yaw_dcc_2=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_5,rate_1,rate_2,rate_3,rate_4,R_end_yaw_acc
_2,position_end_yaw_acc_2,Rate_of_Change_R_e
nd_yaw_acc_2,Linear_Velocity_end_yaw_acc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_dcc_2]=size(R_yaw_dcc_2);
    for index_dcc_2=1:size_dcc_2(1,3)

b_1_yaw_dcc_2(index_dcc_2,:)=R_yaw_dcc_2(:,1
,index_dcc_2).';

b_2_yaw_dcc_2(index_dcc_2,:)=R_yaw_dcc_2(:,2
,index_dcc_2).';

b_3_yaw_dcc_2(index_dcc_2,:)=R_yaw_dcc_2(:,3
,index_dcc_2).';

position_vector_dcc_2(index_dcc_2,:)=positio
n_yaw_dcc_2(1,:,index_dcc_2);

Linear_Velocity_vector_dcc_2(index_dcc_2,:)=
Linear_Velocity_yaw_dcc_2(1,:,index_dcc_2);

Rate_of_Change_R_vector_dcc_2(index_dcc_2,:)
=Rate_of_Change_R_yaw_dcc_2(1,:,index_dcc_2)
;
    end



R_end_yaw_dcc_2=Last_Element_Function(R_yaw_
dcc_2);

position_end_yaw_dcc_2=Last_Element_Function
(position_yaw_dcc_2);

Linear_Velocity_end_yaw_dcc_2=Last_Element_F
unction(Linear_Velocity_yaw_dcc_2);

Rate_of_Change_R_end_yaw_dcc_2=Last_Element_
Function(Rate_of_Change_R_yaw_dcc_2);



    %%eliminate vertical velocity at the end
of yaw command
```

```
    %phase 6 all four motors slow down at a
rate of 15.17870675rad/s/s for 0.1s.

    phi1_dot=phi1_dot+rate_1*T_5;
    phi2_dot=phi2_dot-rate_2*T_5;
    phi3_dot=phi3_dot+rate_3*T_5;
    phi4_dot=phi4_dot-rate_4*T_5;
    rate_1=-15.17870675;
    rate_2=-15.17870675;
    rate_3=-15.17870675;
    rate_4=-15.17870675;
    T_6=0.1;



R_level_dcc=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_6,rate_1,rate_2,rat
e_3,rate_4,R_end_yaw_dcc_2,position_end_yaw_
dcc_2,Rate_of_Change_R_end_yaw_dcc_2,Linear_
Velocity_end_yaw_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_level_dcc=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_6,rate_1,rate_2
,rate_3,rate_4,R_end_yaw_dcc_2,position_end_
yaw_dcc_2,Rate_of_Change_R_end_yaw_dcc_2,Lin
ear_Velocity_end_yaw_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_level_dcc=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_6
,rate_1,rate_2,rate_3,rate_4,R_end_yaw_dcc_2
,position_end_yaw_dcc_2,Rate_of_Change_R_end
_yaw_dcc_2,Linear_Velocity_end_yaw_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_level_dcc=Rate_of_Change_R_
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T
_6,rate_1,rate_2,rate_3,rate_4,R_end_yaw_dcc
_2,position_end_yaw_dcc_2,Rate_of_Change_R_e
nd_yaw_dcc_2,Linear_Velocity_end_yaw_dcc_2);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)


    [size_level_dcc]=size(R_level_dcc);
    for
index_level_dcc=1:size_level_dcc(1,3)

b_1_level_dcc(index_level_dcc,:)=R_level_dcc
(:,1,index_level_dcc).';

b_2_level_dcc(index_level_dcc,:)=R_level_dcc
(:,2,index_level_dcc).';

b_3_level_dcc(index_level_dcc,:)=R_level_dcc
(:,3,index_level_dcc).';

position_vector_level_dcc(index_level_dcc,:)
=position_level_dcc(1,:,index_level_dcc);

Linear_Velocity_vector_level_dcc(index_level
_dcc,:)=Linear_Velocity_level_dcc(1,:,index_
level_dcc);

Rate_of_Change_R_vector_level_dcc(index_leve
l_dcc,:)=Rate_of_Change_R_level_dcc(1,:,inde
x_level_dcc);
    end



R_end_level_dcc=Last_Element_Function(R_leve
l_dcc);

position_end_level_dcc=Last_Element_Function
(position_level_dcc);

Linear_Velocity_end_level_dcc=Last_Element_F
unction(Linear_Velocity_level_dcc);

Rate_of_Change_R_end_level_dcc=Last_Element_
Function(Rate_of_Change_R_level_dcc);


    %phase 7 all four motors speed up at a
rate of 15.17870675rad/s/s for 0.1s.

    phi1_dot=phi1_dot+rate_1*T_6;
    phi2_dot=phi2_dot-rate_2*T_6;
    phi3_dot=phi3_dot+rate_3*T_6;
    phi4_dot=phi4_dot-rate_4*T_6;
    rate_1=15.17870675;
    rate_2=15.17870675;
    rate_3=15.17870675;
    rate_4=15.17870675;
    T_7=0.1;



R_level_acc=Orientation_Matrix(phi1_dot,phi2
_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2,rat
e_3,rate_4,R_end_level_dcc,position_end_leve
l_dcc,Rate_of_Change_R_end_level_dcc,Linear_
Velocity_end_level_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

position_level_acc=Position_Matrix(phi1_dot,
phi2_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2
,rate_3,rate_4,R_end_level_dcc,position_end_
level_dcc,Rate_of_Change_R_end_level_dcc,Lin
ear_Velocity_end_level_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Linear_Velocity_level_acc=Linear_Velocity_Ma
trix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7
,rate_1,rate_2,rate_3,rate_4,R_end_level_dcc
,position_end_level_dcc,Rate_of_Change_R_end
_level_dcc,Linear_Velocity_end_level_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,run
time,phi_dot_rate_of_change,initial
orientation,initial position,initial rate of
change of R,initial linear velocity)

Rate_of_Change_R_level_acc=Rate_of_Change_R_
```

```
Matrix(phi1_dot,phi2_dot,phi3_dot,phi4_dot,T_7,rate_1,rate_2,rate_3,rate_4,R_end_level_dcc,position_end_level_dcc,Rate_of_Change_R_end_level_dcc,Linear_Velocity_end_level_dcc);
%(phi1_dot,phi2_dot,phi3_dot,phi4_dot,runtime,phi_dot_rate_of_change,initial orientation,initial position,initial rate of change of R,initial linear velocity)


    [size_level_acc]=size(R_level_acc);
    for index_level_acc=1:size_level_acc(1,3)

b_1_level_acc(index_level_acc,:)=R_level_acc(:,1,index_level_acc).';

b_2_level_acc(index_level_acc,:)=R_level_acc(:,2,index_level_acc).';

b_3_level_acc(index_level_acc,:)=R_level_acc(:,3,index_level_acc).';

position_vector_level_acc(index_level_acc,:)=position_level_acc(1,:,index_level_acc);

Linear_Velocity_vector_level_acc(index_level_acc,:)=Linear_Velocity_level_acc(1,:,index_level_acc);

Rate_of_Change_R_vector_level_acc(index_level_acc,:)=Rate_of_Change_R_level_acc(1,:,index_level_acc);
    end



R_end_level_acc=Last_Element_Function(R_level_acc);

R_end_level_acc=Sanity_Check(R_end_level_acc);

position_end_level_acc=Last_Element_Function(position_level_acc);

Linear_Velocity_end_level_acc=Last_Element_Function(Linear_Velocity_level_acc);

Rate_of_Change_R_end_level_acc=Last_Element_Function(Rate_of_Change_R_level_acc);


    %%For Animation.

b_1=cat(1,b_1_yaw_acc,b_1_yaw_dcc,b_1_yaw_uniform,b_1_yaw_acc_2,b_1_yaw_dcc_2,b_1_level_dcc,b_1_level_acc);

b_2=cat(1,b_2_yaw_acc,b_2_yaw_dcc,b_2_yaw_uniform,b_2_yaw_acc_2,b_2_yaw_dcc_2,b_2_level_dcc,b_2_level_acc);

b_3=cat(1,b_3_yaw_acc,b_3_yaw_dcc,b_3_yaw_uniform,b_3_yaw_acc_2,b_3_yaw_dcc_2,b_3_level_dcc,b_3_level_acc);

position_vector=cat(1,position_vector_acc,position_vector_dcc,position_vector_uniform,position_vector_acc_2,position_vector_dcc_2,position_vector_level_dcc,position_vector_level_acc);

Linear_Velocity_vector=cat(1,Linear_Velocity_vector_acc,Linear_Velocity_vector_dcc,Linear_Velocity_vector_uniform,Linear_Velocity_vector_acc_2,Linear_Velocity_vector_dcc_2,Linear_Velocity_vector_level_dcc,Linear_Velocity_vector_level_acc);

Rate_of_Change_R_vector=cat(1,Rate_of_Change_R_vector_acc,Rate_of_Change_R_vector_dcc,Rate_of_Change_R_vector_uniform,Rate_of_Change_R_vector_acc_2,Rate_of_Change_R_vector_dcc_2,Rate_of_Change_R_vector_level_dcc,Rate_of_Change_R_vector_level_acc);


end
```

take_off_moving_forward_flight_pattern

```
%%Take off moving forward flight patern.
clc;
close all;
clear variables;

%%Quadcopter starting out at the origin of
the spatial frame.
%%The copter's initial orientation is
identity
%%initial linear velocity and rate of change
of orientation are both zero
%%vectors.
%%then time duration for moving forward is
chosen
R_Initial = [1 0 0; 0 1 0; 0 0 1];
Position_Initial = [0 0 0];
T_coast = 1;


%% Take off
hover_height=1;
[b_1_take_off,b_2_take_off,b_3_take_off,posi
tion_vector_take_off,R_End_Take_Off,Position
_End_Take_Off]=take_off_function(R_Initial,P
osition_Initial,hover_height);
R_End_Take_Off=Sanity_Check(R_End_Take_Off);


%% Side 1.
%1. tilt_moving_forward function is applied:
[b_1_forward_1,b_2_forward_1,b_3_forward_1,p
osition_vector_forward_1,Position_End_Forwar
d_1,R_End_Forward_1,Linear_Velocity_End_Forw
ard_1] =
tilt_moving_forward(Position_End_Take_Off,R_
End_Take_Off,T_coast);
%2. air_brake_after_coasting function is
applied:
[b_1_stop_1,b_2_stop_1,b_3_stop_1,position_v
ector_stop_1,Position_End_Stop_1,R_End_Stop_
1,Linear_Velocity_End_Stop_1] =
air_brake_after_coasting(R_End_Forward_1,Pos
ition_End_Forward_1,Linear_Velocity_End_Forw
ard_1);



%% Creating arrays for animation:
%%for animation purpose, concatenate all
b_1s, b_2s, b_3s and
%%position_vectors:


b_1=cat(1,b_1_take_off,b_1_forward_1,b_1_sto
p_1);
b_2=cat(1,b_2_take_off,b_2_forward_1,b_2_sto
p_1);
b_3=cat(1,b_3_take_off,b_3_forward_1,b_3_sto
p_1);
position_vector=cat(1,position_vector_take_o
ff,position_vector_forward_1,position_vector
_stop_1);


save b_1_tk_off_forward b_1
save b_2_tk_off_forward b_2
save b_3_tk_off_forward b_3
save position_vector_tk_off_forward
position_vector
```

take_off_moving_forward_flight_pattern animation

```
%% Tk off & forward flight patern animation
clc;
close all;
clear variables;

load b_1_tk_off_forward;
load b_2_tk_off_forward;
load b_3_tk_off_forward;
load position_vector_tk_off_forward;



l=0.315;
[size_plot]=size(position_vector);

for plot_index=1:250:size_plot(1,1)
    x_frame_1=[position_vector(plot_index,1)
position_vector(plot_index,1)+b_1(plot_index
,1)*l];
    y_frame_1=[position_vector(plot_index,2)
position_vector(plot_index,2)+b_1(plot_index
,2)*l];
    z_frame_1=[position_vector(plot_index,3)
position_vector(plot_index,3)+b_1(plot_index
,3)*l];

    x_frame_2=[position_vector(plot_index,1)
position_vector(plot_index,1)+b_2(plot_index
,1)*l];
    y_frame_2=[position_vector(plot_index,2)
position_vector(plot_index,2)+b_2(plot_index
,2)*l];
    z_frame_2=[position_vector(plot_index,3)
position_vector(plot_index,3)+b_2(plot_index
,3)*l];

    x_frame_3=[position_vector(plot_index,1)
position_vector(plot_index,1)-
b_1(plot_index,1)*l];
    y_frame_3=[position_vector(plot_index,2)
position_vector(plot_index,2)-
b_1(plot_index,2)*l];
    z_frame_3=[position_vector(plot_index,3)
position_vector(plot_index,3)-
b_1(plot_index,3)*l];

    x_frame_4=[position_vector(plot_index,1)
position_vector(plot_index,1)-
b_2(plot_index,1)*l];
    y_frame_4=[position_vector(plot_index,2)
position_vector(plot_index,2)-
b_2(plot_index,2)*l];
    z_frame_4=[position_vector(plot_index,3)
position_vector(plot_index,3)-
b_2(plot_index,3)*l];



    figure(1)
    subplot(1,2,1);

plot3(x_frame_1,y_frame_1,z_frame_1,'r');
    hold on;

plot3(position_vector(:,1),position_vector(:
,2),position_vector(:,3),'k');
    hold on
    grid on;
    view([30,40]);

plot3(x_frame_2,y_frame_2,z_frame_2,'b');

plot3(x_frame_3,y_frame_3,z_frame_3,'k');

plot3(x_frame_4,y_frame_4,z_frame_4,'k');
    axis equal;
    grid off;
    axis([-1 3 -1 2 -0.5 4]);
    pause(0.00001);
    hold off




    subplot(1,2,2);

plot3(x_frame_1,y_frame_1,z_frame_1,'r');
    hold on;

plot3(position_vector(:,1),position_vector(:
,2),position_vector(:,3),'k');
    hold on
    grid on;
    view([0,0]);

plot3(x_frame_2,y_frame_2,z_frame_2,'b');

plot3(x_frame_3,y_frame_3,z_frame_3,'k');

plot3(x_frame_4,y_frame_4,z_frame_4,'k');
    axis equal;
    grid off;
    axis([-1 3 -1 3 -0.5 4]);
    pause(0.00001);
    hold off
end
```

square_shape_flight_pattern

```
%%The square patern flight
clc;
close all;
clear variables;

%%Quadcopter starting out at the origin of
the spatial frame.
%%The copter's initial orientation is
identity
%%initial linear velocity and rate of change
of orientation are both zero
%%vectors.
%%then time duration for moving forward is
chosen
R_Initial = [1 0 0; 0 1 0; 0 0 1];
Position_Initial = [0 0 0];
T_coast = 1;


%% Take off
hover_height=1;
[b_1_take_off,b_2_take_off,b_3_take_off,posi
tion_vector_take_off,R_End_Take_Off,Position
_End_Take_Off]=take_off_function(R_Initial,P
osition_Initial,hover_height);
R_End_Take_Off=Sanity_Check(R_End_Take_Off);


%% Side 1.
%1. tilt_moving_forward function is applied:
[b_1_forward_1,b_2_forward_1,b_3_forward_1,p
osition_vector_forward_1,Position_End_Forwar
d_1,R_End_Forward_1,Linear_Velocity_End_Forw
ard_1] =
tilt_moving_forward(Position_End_Take_Off,R_
End_Take_Off,T_coast);
%2. air_brake_after_coasting function is
applied:
[b_1_stop_1,b_2_stop_1,b_3_stop_1,position_v
ector_stop_1,Position_End_Stop_1,R_End_Stop_
1,Linear_Velocity_End_Stop_1] =
air_brake_after_coasting(R_End_Forward_1,Pos
ition_End_Forward_1,Linear_Velocity_End_Forw
ard_1);
%3. yaw_function is applied, rotate copter
clockwise through 90 degrees:
[b_1_yaw_1,b_2_yaw_1,b_3_yaw_1,position_vect
or_yaw_1,Position_End_Yaw_1,R_End_Yaw_1]=yaw
_function(R_End_Stop_1,Position_End_Stop_1,0
1,90);

%these three functions together generate
oneside of the square flight
%patern, repeat above 3 steps 3 more time to
close the square.


%% Side 2.
%1. tilt_moving_forward function is applied:
[b_1_forward_2,b_2_forward_2,b_3_forward_2,p
osition_vector_forward_2,Position_End_Forwar
d_2,R_End_Forward_2,Linear_Velocity_End_Forw
ard_2] =
tilt_moving_forward(Position_End_Yaw_1,R_End
_Yaw_1,T_coast);
%2. air_brake_after_coasting function is
applied:
[b_1_stop_2,b_2_stop_2,b_3_stop_2,position_v
ector_stop_2,Position_End_Stop_2,R_End_Stop_
2,Linear_Velocity_End_Stop_2] =
air_brake_after_coasting(R_End_Forward_2,Pos
ition_End_Forward_2,Linear_Velocity_End_Forw
ard_2);
%3. yaw_function is applied, rotate copter
clockwise through 90 degrees:
[b_1_yaw_2,b_2_yaw_2,b_3_yaw_2,position_vect
or_yaw_2,Position_End_Yaw_2,R_End_Yaw_2]=yaw
_function(R_End_Stop_2,Position_End_Stop_2,0
1,90);


%% Side 3.
%1. tilt_moving_forward function is applied:
[b_1_forward_3,b_2_forward_3,b_3_forward_3,p
osition_vector_forward_3,Position_End_Forwar
d_3,R_End_Forward_3,Linear_Velocity_End_Forw
ard_3] =
tilt_moving_forward(Position_End_Yaw_2,R_End
_Yaw_2,T_coast);
%2. air_brake_after_coasting function is
applied:
[b_1_stop_3,b_2_stop_3,b_3_stop_3,position_v
ector_stop_3,Position_End_Stop_3,R_End_Stop_
3] =
air_brake_after_coasting(R_End_Forward_3,Pos
ition_End_Forward_3,Linear_Velocity_End_Forw
ard_3);
%3. yaw_function is applied, rotate copter
clockwise through 90 degrees:
[b_1_yaw_3,b_2_yaw_3,b_3_yaw_3,position_vect
or_yaw_3,Position_End_Yaw_3,R_End_Yaw_3]=yaw
_function(R_End_Stop_3,Position_End_Stop_3,0
1,90);


%% Side 4.
%1. tilt_moving_forward function is applied:
[b_1_forward_4,b_2_forward_4,b_3_forward_4,p
osition_vector_forward_4,Position_End_Forwar
d_4,R_End_Forward_4,Linear_Velocity_End_Forw
ard_4] =
tilt_moving_forward(Position_End_Yaw_3,R_End
_Yaw_3,T_coast);
%2. air_brake_after_coasting function is
applied:
[b_1_stop_4,b_2_stop_4,b_3_stop_4,position_v
ector_stop_4,Position_End_Stop_4,R_End_Stop_
4] =
air_brake_after_coasting(R_End_Forward_4,Pos
ition_End_Forward_4,Linear_Velocity_End_Forw
ard_4);
%3. yaw_function is applied, rotate copter
clockwise through 90 degrees:
[b_1_yaw_4,b_2_yaw_4,b_3_yaw_4,position_vect
or_yaw_4,Position_End_Yaw_4,R_End_Yaw_4]=yaw
_function(R_End_Stop_4,Position_End_Stop_4,0
1,90);


%% Creating arrays for animation:
%%for animation purpose, concatenate all
b_1s, b_2s, b_3s and
%%position_vectors:


b_1=cat(1,b_1_take_off,b_1_forward_1,b_1_sto
p_1,b_1_yaw_1,b_1_forward_2,b_1_stop_2,b_1_y
aw_2,b_1_forward_3,b_1_stop_3,b_1_yaw_3,b_1_
forward_4,b_1_stop_4,b_1_yaw_4);
```

```
b_2=cat(1,b_2_take_off,b_2_forward_1,b_2_sto
p_1,b_2_yaw_1,b_2_forward_2,b_2_stop_2,b_2_y
aw_2,b_2_forward_3,b_2_stop_3,b_2_yaw_3,b_2_
forward_4,b_2_stop_4,b_2_yaw_4);
b_3=cat(1,b_3_take_off,b_3_forward_1,b_3_sto
p_1,b_3_yaw_1,b_3_forward_2,b_3_stop_2,b_3_y
aw_2,b_3_forward_3,b_3_stop_3,b_3_yaw_3,b_3_
forward_4,b_3_stop_4,b_3_yaw_4);
position_vector=cat(1,position_vector_take_o
ff,position_vector_forward_1,position_vector
_stop_1,position_vector_yaw_1,position_vecto
r_forward_2,position_vector_stop_2,position_
vector_yaw_2,position_vector_forward_3,posit
ion_vector_stop_3,position_vector_yaw_3,posi
tion_vector_forward_4,position_vector_stop_4
,position_vector_yaw_4);


save b_1_square_patern b_1
save b_2_square_patern b_2
save b_3_square_patern b_3
save position_vector_square_patern
position_vector
```

square_pattern_animation

```
%% Square flight patern animation
clc;
close all;
clear variables;

load b_1_square_patern;
load b_2_square_patern;
load b_3_square_patern;
load position_vector_square_patern;



l=0.315;
[size_plot]=size(position_vector);

for plot_index=1:500:size_plot(1,1)
    x_frame_1=[position_vector(plot_index,1)
position_vector(plot_index,1)+b_1(plot_index
,1)*l];
    y_frame_1=[position_vector(plot_index,2)
position_vector(plot_index,2)+b_1(plot_index
,2)*l];
    z_frame_1=[position_vector(plot_index,3)
position_vector(plot_index,3)+b_1(plot_index
,3)*l];

    x_frame_2=[position_vector(plot_index,1)
position_vector(plot_index,1)+b_2(plot_index
,1)*l];
    y_frame_2=[position_vector(plot_index,2)
position_vector(plot_index,2)+b_2(plot_index
,2)*l];
    z_frame_2=[position_vector(plot_index,3)
position_vector(plot_index,3)+b_2(plot_index
,3)*l];

    x_frame_3=[position_vector(plot_index,1)
position_vector(plot_index,1)-
b_1(plot_index,1)*l];
    y_frame_3=[position_vector(plot_index,2)
position_vector(plot_index,2)-
b_1(plot_index,2)*l];
    z_frame_3=[position_vector(plot_index,3)
position_vector(plot_index,3)-
b_1(plot_index,3)*l];

    x_frame_4=[position_vector(plot_index,1)
position_vector(plot_index,1)-
b_2(plot_index,1)*l];
    y_frame_4=[position_vector(plot_index,2)
position_vector(plot_index,2)-
b_2(plot_index,2)*l];
    z_frame_4=[position_vector(plot_index,3)
position_vector(plot_index,3)-
b_2(plot_index,3)*l];



    figure(1)
    subplot(1,2,1);

plot3(x_frame_1,y_frame_1,z_frame_1,'r');
    hold on;

plot3(position_vector(:,1),position_vector(:
,2),position_vector(:,3),'k');
    hold on
    grid on;
    view([30,40]);

plot3(x_frame_2,y_frame_2,z_frame_2,'b');

plot3(x_frame_3,y_frame_3,z_frame_3,'k');

plot3(x_frame_4,y_frame_4,z_frame_4,'k');
    axis equal;
    grid off;
    axis([-2 6 -3 4 -0.5 4]);
    pause(0.00001);
    hold off




    subplot(1,2,2);

plot3(x_frame_1,y_frame_1,z_frame_1,'r');
    hold on;

plot3(position_vector(:,1),position_vector(:
,2),position_vector(:,3),'k');
    hold on
    grid on
    view([0,90]);

plot3(x_frame_2,y_frame_2,z_frame_2,'b');

plot3(x_frame_3,y_frame_3,z_frame_3,'k');

plot3(x_frame_4,y_frame_4,z_frame_4,'k');
    axis equal;
    grid off;
    axis([-2 6 -3 4 -0.5 4]);
    pause(0.00001);
    hold off

end
```