Table of Contents

Clear Workspace

```
close all;
clear;
clc;
```

Given Data

```
m = 1637; % kg
g = 9.81; % m/s^2
Iz = 3326; % kg-m^2
l = 2.736; % m
t = 1.7; % m
a = 0.4*l; % 60% front load distribution
b = 0.6*l; % 60% front load distribution
G = 15;
h = 2.4/3.281; % m
```

Maneuver 1

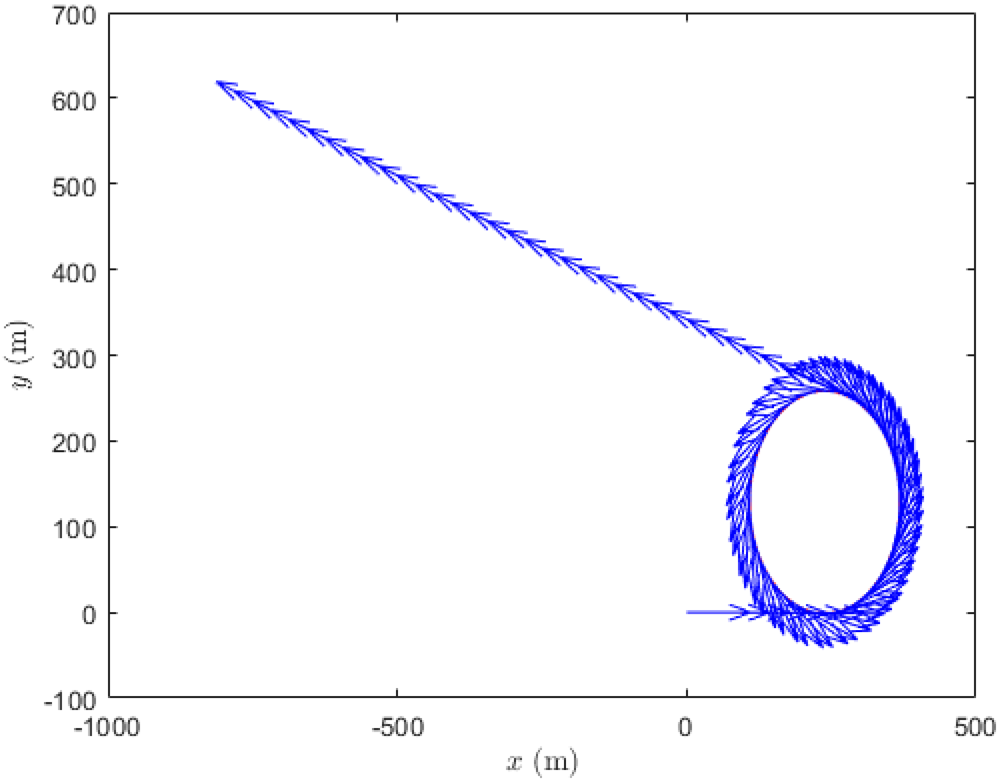
```
% Simulation parameters
v = 74/2.237; % m/s
dt = 0.001; % s
X = [];
X(:,1) = [0;0];
Xdot = [];
Xint(:,1) = [0;0];
Bdot = 0;
V = [];
P = [0;0];
Sf = (m*g*0.6)/2; % 60% front (static) load distribution
Sr = (m*g*0.4)/2; % 60% front (static) load distribution
ay = [];
j = 1;

% Simulate from t=0 to t=7
U = 0; % Control input (@ 0 deg steering wheel angle)
for i = 0+dt:dt:7
    ay(j) = v*(Bdot+X(2,j));
    FZfl = Sf;
    FZfr = Sf;
```

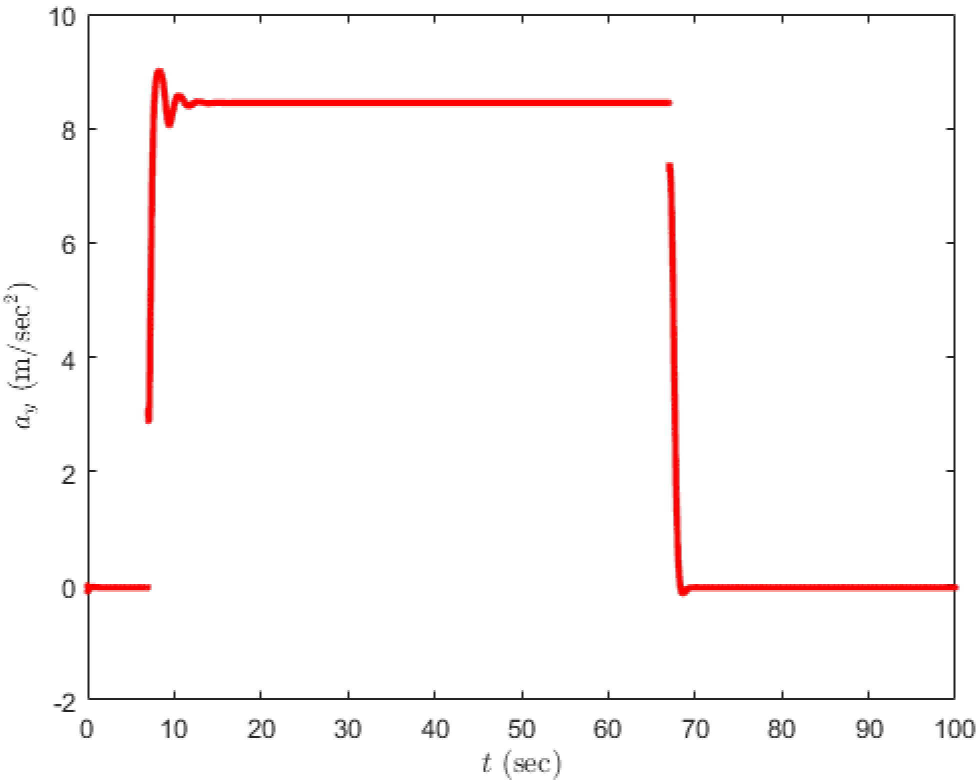
```
    FZrl = Sr;
    FZrr = Sr;
    af(j) = U - (X(2,j)*a)/v - X(1,j);
    ar(j) = (X(2,j)*b)/v - X(1,j);
    FYfl = -nonlintire(af(j),FZfl,v);
    FYfr = -nonlintire(af(j),FZfr,v);
    FYf = FYfl+FYfr;
    FYrl = -nonlintire(ar(j),FZrl,v);
    FYrr = -nonlintire(ar(j),FZrr,v);
    FYr = FYrl+FYrr;
    Xdot(1,j) = (FYf+FYr)/(m*v) - X(2,j);
    Xdot(2,j) = (FYf*a-FYr*b)/(Iz);
    X(:,j+1) = X(:,j) + Xdot(:,j)*dt;
    Xint(:,j+1) = Xint(:,j) + X(:,j)*dt;
    V(:,j) = [v*cos(X(1,j)+Xint(2,j)); v*sin(X(1,j)+Xint(2,j))];
    P(:,j+1) = P(:,j) + V(:,j)*dt;
    Bdot = Xdot(1,j);
    j = j+1;
end

% Simulate from t=7 to t=67
U = (45*(pi/180))/G; % Control input (@ 45 deg steering wheel angle)
for i = 7+dt:dt:67
    ay(j) = v*(Bdot+X(2,j));
    FZfl = Sf;
    FZfr = Sf;
    FZrl = Sr;
    FZrr = Sr;
    af(j) = U - (X(2,j)*a)/v - X(1,j);
    ar(j) = (X(2,j)*b)/v - X(1,j);
    FYfl = -nonlintire(af(j),FZfl,v);
    FYfr = -nonlintire(af(j),FZfr,v);
    FYf = FYfl+FYfr;
    FYrl = -nonlintire(ar(j),FZrl,v);
    FYrr = -nonlintire(ar(j),FZrr,v);
    FYr = FYrl+FYrr;
    Xdot(1,j) = (FYf+FYr)/(m*v) - X(2,j);
    Xdot(2,j) = (FYf*a-FYr*b)/(Iz);
    X(:,j+1) = X(:,j) + Xdot(:,j)*dt;
    Xint(:,j+1) = Xint(:,j) + X(:,j)*dt;
    V(:,j) = [v*cos(X(1,j)+Xint(2,j)); v*sin(X(1,j)+Xint(2,j))];
    P(:,j+1) = P(:,j) + V(:,j)*dt;
    Bdot = Xdot(1,j);
    j = j+1;
end

% Simulate from t=67 to t=100
U = 0; % Control input (@ 0 deg steering wheel angle)
for i = 67+dt:dt:100
    ay(j) = v*(Bdot+X(2,j));
    FZfl = Sf;
    FZfr = Sf;
    FZrl = Sr;
    FZrr = Sr;
```

```
    af(j) = U - (X(2,j)*a)/v - X(1,j);
    ar(j) = (X(2,j)*b)/v - X(1,j);
    FYfl = -nonlintire(af(j),FZfl,v);
    FYfr = -nonlintire(af(j),FZfr,v);
    FYf = FYfl+FYfr;
    FYrl = -nonlintire(ar(j),FZrl,v);
    FYrr = -nonlintire(ar(j),FZrr,v);
    FYr = FYrl+FYrr;
    Xdot(1,j) = (FYf+FYr)/(m*v) - X(2,j);
    Xdot(2,j) = (FYf*a-FYr*b)/(Iz);
    X(:,j+1) = X(:,j) + Xdot(:,j)*dt;
    Xint(:,j+1) = Xint(:,j) + X(:,j)*dt;
    V(:,j) = [v*cos(X(1,j)+Xint(2,j)); v*sin(X(1,j)+Xint(2,j))];
    P(:,j+1) = P(:,j) + V(:,j)*dt;
    Bdot = Xdot(1,j);
    j = j+1;
end

% Concatenate array of steering angle inputs
d = [zeros(size(0:dt:7)) ones(size(7+dt:dt:67))*(45*(pi/180))/G
 zeros(size(67+dt:dt:100))];

% Plot trajectory
PosX = P(1,:);
PosX_sec = PosX(1:1000:end-1000);
PosY = P(2,:);
PosY_sec = PosY(1:1000:end-1000);
VelX = V(1,:);
VelX_sec = VelX(1:1000:end);
VelY = V(2,:);
VelY_sec = VelY(1:1000:end);
figure(1)
plot(PosX,PosY,'color','red')
%comet(PosX,PosY)
hold on
quiver(PosX_sec,PosY_sec,VelX_sec,VelY_sec,'color','blue')
xlabel('${x}$ (m)','interpreter','latex')
ylabel('${y}$ (m)','interpreter','latex')

% Plot ay vs t
figure(2)
plot((0:dt:100),[0 ay],'.','color','red')
xlabel('${t}$ (sec)','interpreter','latex')
ylabel('${a_y}$ (m/sec$^2$)','interpreter','latex')

% Plot d vs ay
figure(3)
plot([0 ay],d,'.','color','red')
xlabel('${a_y}$ (m/sec$^2$)','interpreter','latex')
ylabel('${\delta}$ (rad)','interpreter','latex')

% Calculate UG (for steady state ay, af, ar values)
ay = ay(50000);
af = af(50000);
```

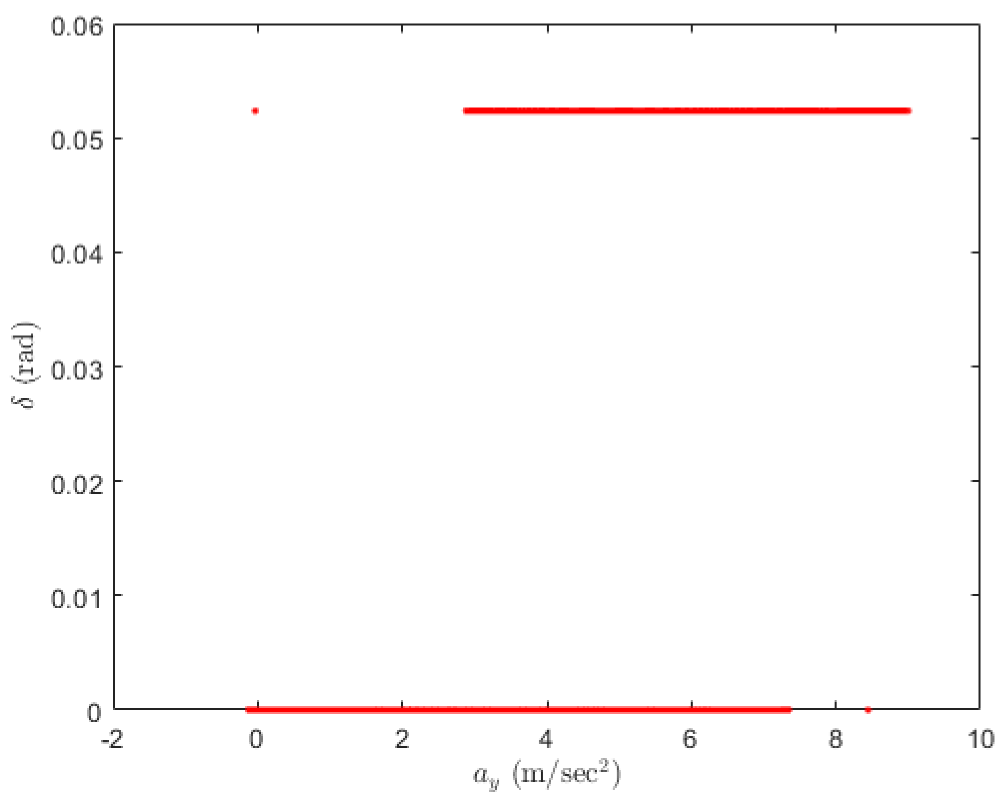
```
ar = ar(50000);
UG = (af-ar)/ay;
fprintf('UG for Maneuver 1 with Non-Linear Tire Model is %f rad sec^2
 m^-1\n',UG)
```

UG for Maneuver 1 with Non-Linear Tire Model is 0.003700 rad sec^2 m^-1





10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90
100
t (sec)
a_y (m/sec^2)



0.06
0.05
0.04
0.03
0.02
0.01
0
-2
0
2
4
6
8
10
a_y (m/sec^2)
δ (rad)

Maneuver 2

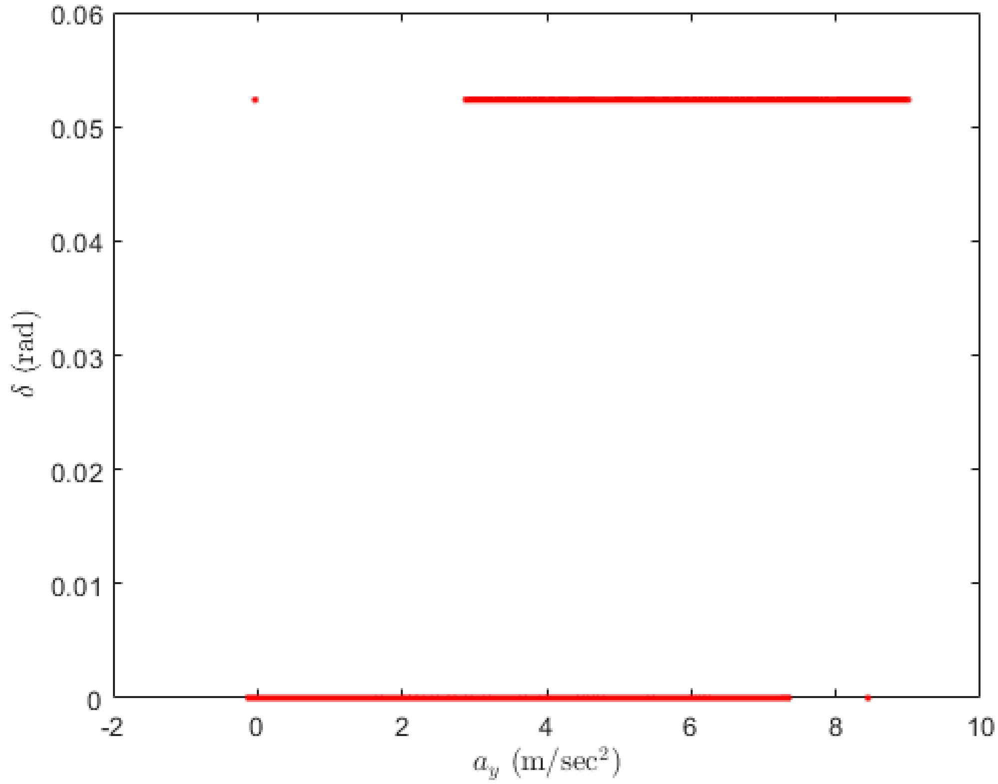
```
% Simulation parameters
v = 50/2.237; % m/s
dt = 0.001; % s
X = [];
X(:,1) = [0;0];
Xdot = [];
Xint(:,1) = [0;0];
Bdot = 0;
V = [];
P = [0;0];
Sf = (m*g*0.6)/2; % 60% front (static) load distribution
Sr = (m*g*0.4)/2; % 60% front (static) load distribution
ay = [];
j = 1;

% Simulate from t=0 to t=5
U = 0; % Control input (@ 0 deg steering wheel angle)
for i = 0+dt:dt:5
    ay(j) = v*(Bdot+X(2,j));
    FZfl = Sf;
    FZfr = Sf;
    FZrl = Sr;
    FZrr = Sr;
    af = U - (X(2,j)*a)/v - X(1,j);
    ar = (X(2,j)*b)/v - X(1,j);
    FYfl = -nonlintire(af,FZfl,v);
    FYfr = -nonlintire(af,FZfr,v);
    FYf = FYfl+FYfr;
    FYrl = -nonlintire(ar,FZrl,v);
    FYrr = -nonlintire(ar,FZrr,v);
    FYr = FYrl+FYrr;
    Xdot(1,j) = (FYf+FYr)/(m*v) - X(2,j);
    Xdot(2,j) = (FYf*a-FYr*b)/(Iz);
    X(:,j+1) = X(:,j) + Xdot(:,j)*dt;
    Xint(:,j+1) = Xint(:,j) + X(:,j)*dt;
    V(:,j) = [v*cos(X(1,j)+Xint(2,j)); v*sin(X(1,j)+Xint(2,j))];
    P(:,j+1) = P(:,j) + V(:,j)*dt;
    Bdot = Xdot(1,j);
    j = j+1;
end

% Simulate from t=5 to t=23.621
U = 0:((14.5*(pi/180))/G)*dt:(270*(pi/180))/G; % Control input (@ 0-270 deg
 steering wheel angle)
for i = 5+dt:dt:23.621
    ay(j) = v*(Bdot+X(2,j));
    FZfl = Sf;
    FZfr = Sf;
    FZrl = Sr;
    FZrr = Sr;
    af = U(j-5000) - (X(2,j)*a)/v - X(1,j);
```

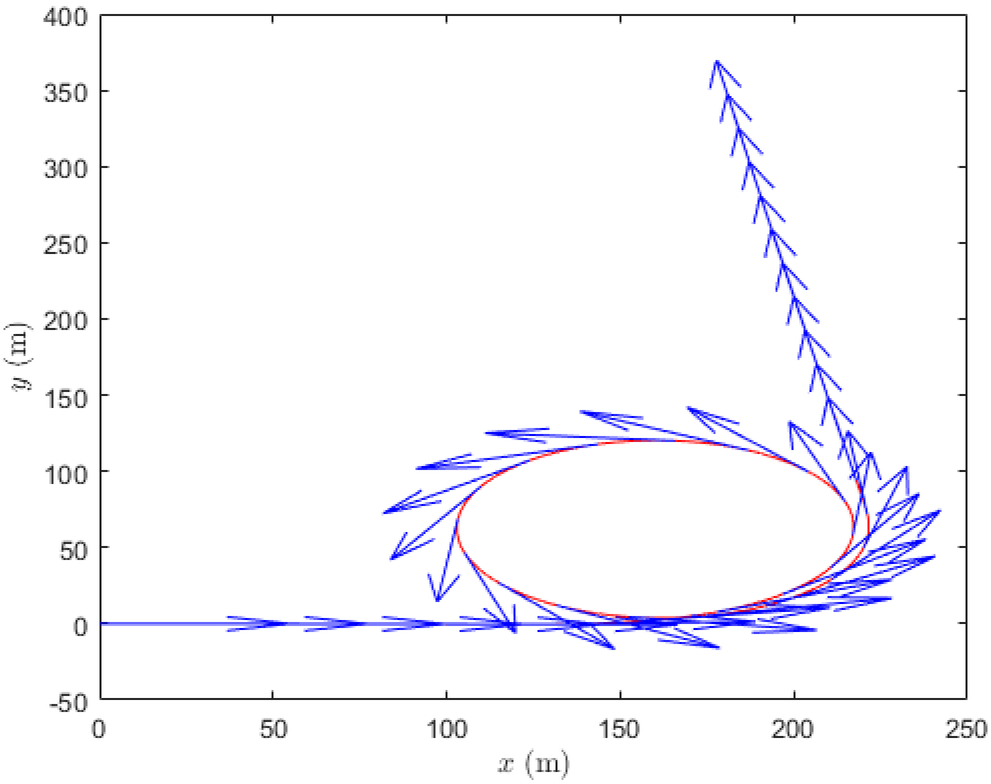
```
    ar = (X(2,j)*b)/v - X(1,j);
    FYfl = -nonlintire(af,FZfl,v);
    FYfr = -nonlintire(af,FZfr,v);
    FYf = FYfl+FYfr;
    FYrl = -nonlintire(ar,FZrl,v);
    FYrr = -nonlintire(ar,FZrr,v);
    FYr = FYrl+FYrr;
    Xdot(1,j) = (FYf+FYr)/(m*v) - X(2,j);
    Xdot(2,j) = (FYf*a-FYr*b)/(Iz);
    X(:,j+1) = X(:,j) + Xdot(:,j)*dt;
    Xint(:,j+1) = Xint(:,j) + X(:,j)*dt;
    V(:,j) = [v*cos(X(1,j)+Xint(2,j)); v*sin(X(1,j)+Xint(2,j))];
    P(:,j+1) = P(:,j) + V(:,j)*dt;
    Bdot = Xdot(1,j);
    j = j+1;
end

% Simulate from t=23.621 to t=27.621
U = (270*(pi/180))/G; % Control input (@ 270 deg steering wheel angle)
for i = 23.621+dt:dt:27.621
    ay(j) = v*(Bdot+X(2,j));
    FZfl = Sf;
    FZfr = Sf;
    FZrl = Sr;
    FZrr = Sr;
    af = U - (X(2,j)*a)/v - X(1,j);
    ar = (X(2,j)*b)/v - X(1,j);
    FYfl = -nonlintire(af,FZfl,v);
    FYfr = -nonlintire(af,FZfr,v);
    FYf = FYfl+FYfr;
    FYrl = -nonlintire(ar,FZrl,v);
    FYrr = -nonlintire(ar,FZrr,v);
    FYr = FYrl+FYrr;
    Xdot(1,j) = (FYf+FYr)/(m*v) - X(2,j);
    Xdot(2,j) = (FYf*a-FYr*b)/(Iz);
    X(:,j+1) = X(:,j) + Xdot(:,j)*dt;
    Xint(:,j+1) = Xint(:,j) + X(:,j)*dt;
    V(:,j) = [v*cos(X(1,j)+Xint(2,j)); v*sin(X(1,j)+Xint(2,j))];
    P(:,j+1) = P(:,j) + V(:,j)*dt;
    Bdot = Xdot(1,j);
    j = j+1;
end

% Simulate from t=27.621 to t=40
U = 0; % Control input (@ 0 deg steering wheel angle)
for i = 27.621+dt:dt:40
    ay(j) = v*(Bdot+X(2,j));
    FZfl = Sf;
    FZfr = Sf;
    FZrl = Sr;
    FZrr = Sr;
    af = U - (X(2,j)*a)/v - X(1,j);
    ar = (X(2,j)*b)/v - X(1,j);
    FYfl = -nonlintire(af,FZfl,v);
```

```
    FYfr = -nonlintire(af,FZfr,v);
    FYf = FYfl+FYfr;
    FYrl = -nonlintire(ar,FZrl,v);
    FYrr = -nonlintire(ar,FZrr,v);
    FYr = FYrl+FYrr;
    Xdot(1,j) = (FYf+FYr)/(m*v) - X(2,j);
    Xdot(2,j) = (FYf*a-FYr*b)/(Iz);
    X(:,j+1) = X(:,j) + Xdot(:,j)*dt;
    Xint(:,j+1) = Xint(:,j) + X(:,j)*dt;
    V(:,j) = [v*cos(X(1,j)+Xint(2,j)); v*sin(X(1,j)+Xint(2,j))];
    P(:,j+1) = P(:,j) + V(:,j)*dt;
    Bdot = Xdot(1,j);
    j = j+1;
end

% Concatenate array of steering angle inputs
d = [zeros(size(0:dt:5)) ones(size(5+dt:dt:23.621))*0:((14.5*(pi/180))/
G)*dt:(270*(pi/180))/G ones(size(23.621+dt:dt:27.621))*(270*(pi/180))/G
 zeros(size(27.621+dt:dt:40))];

% Plot trajectory
PosX = P(1,:);
PosX_sec = PosX(1:1000:end-1000);
PosY = P(2,:);
PosY_sec = PosY(1:1000:end-1000);
VelX = V(1,:);
VelX_sec = VelX(1:1000:end);
VelY = V(2,:);
VelY_sec = VelY(1:1000:end);
figure(4)
plot(PosX,PosY,'color','red')
%comet(PosX,PosY)
hold on
quiver(PosX_sec,PosY_sec,VelX_sec,VelY_sec,'color','blue')
xlabel('${x}$ (m)','interpreter','latex')
ylabel('${y}$ (m)','interpreter','latex')

% Plot ay vs t
figure(5)
plot((0:dt:40),[0 ay],'.','color','red')
xlabel('${t}$ (sec)','interpreter','latex')
ylabel('${a_y}$ (m/sec$^2$)','interpreter','latex')

% Plot d vs ay
figure(6)
plot([0 ay],d,'.','color','red')
xlabel('${a_y}$ (m/sec$^2$)','interpreter','latex')
ylabel('${\delta}$ (rad)','interpreter','latex')

% Calculate UG (from linear region of d vs. ay plot)
d_ay = polyfit(ay(5020:8300),d(5020:8300),1);
figure(7)
plot(ay(5200:8300),d(5200:8300),'.','color','red')
hold on
```

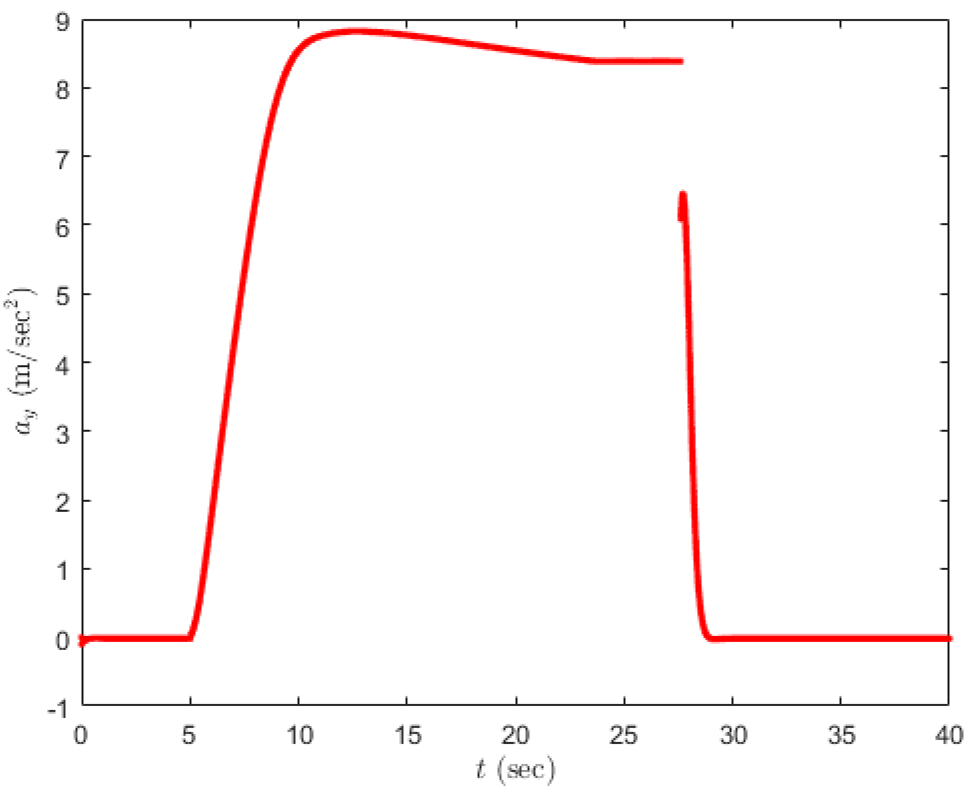
```
plot(ay(5200:8300),polyval(d_ay,ay(5200:8300)),'.','color','blue')
legend('Simulated Data','1st Order Polyfit','Location','NW')
xlabel('${a_y}$ (m/sec$^2$)','interpreter','latex')
ylabel('${\delta}$ (rad)','interpreter','latex')
UG = polyder(d_ay)-(l/v^2);
fprintf('UG for Maneuver 2 with Non-Linear Tire Model is %f rad sec^2
 m^-1\n',UG)
```

UG for Maneuver 2 with Non-Linear Tire Model is 0.002029 rad sec^2 m^-1

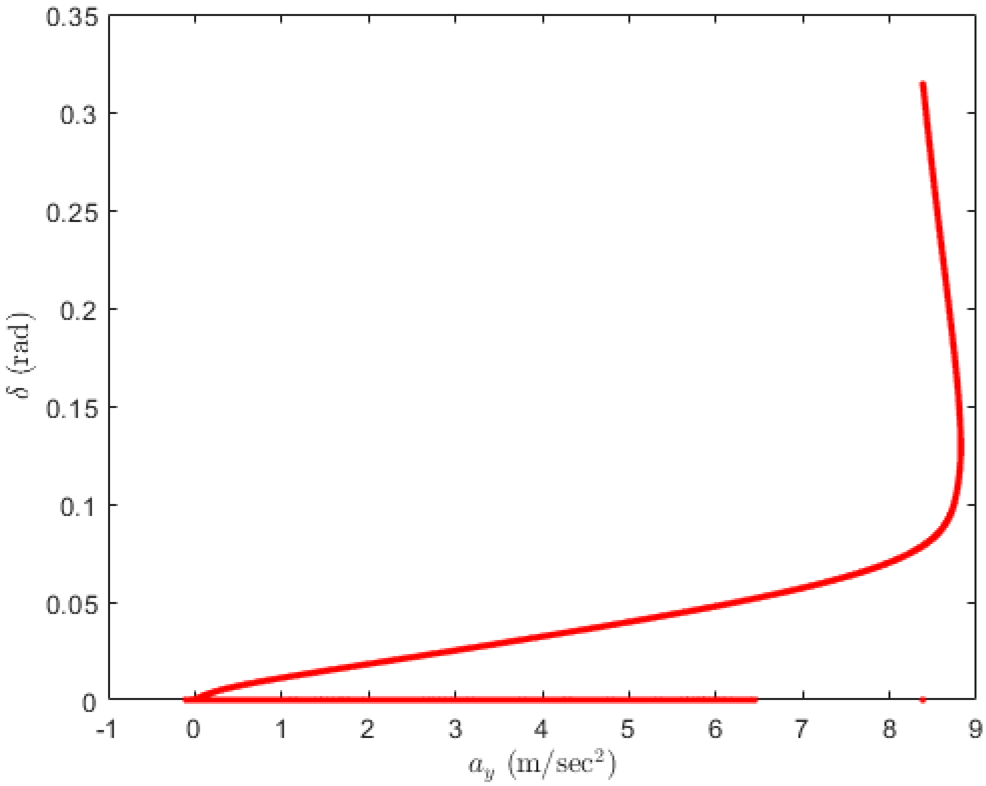




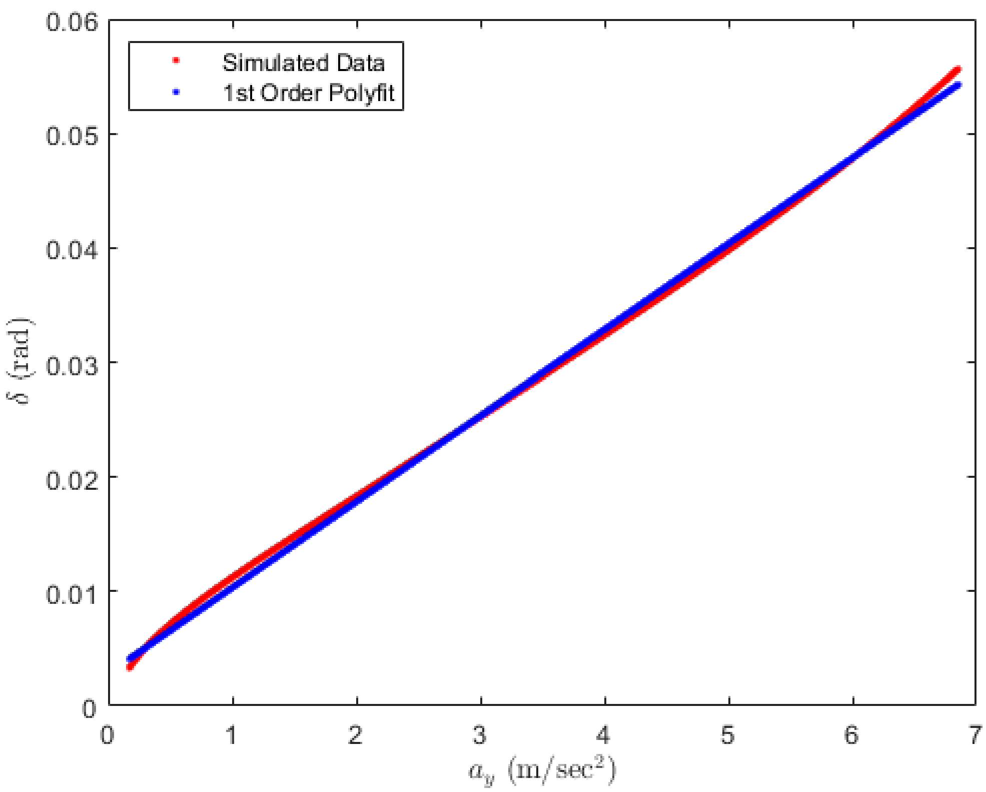
400
350
300
250
200
150
100
50
0
-50
0
50
100
150
200
250
y (m)
x (m)



9
8
7
6
5
4
3
2
1
0
-1
0
5
10
15
20
25
30
35
40
a_y (m/sec^2)
t (sec)



0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-1
0
1
2
3
4
5
6
7
8
9
δ (rad)
a_y (m/sec^2)



Simulated Data
1st Order Polyfit
0.06
0.05
0.04
0.03
0.02
0.01
0
0
1
2
3
4
5
6
7
δ (rad)
a_y (m/sec^2)

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