```
function [value, isterminal, direction] = stopCondition(~,y,Thrust_Stop)
   value = y(4) - Thrust_Stop;
   isterminal = 1;
   direction = 0;
end
function [value, isterminal, direction] = stopCondition_1(~,z,massiszero)
   value = z(3) - massiszero;
   isterminal = 1;
   direction = 0;
end
function [value, isterminal, direction] = stopCondition_2(~,f,arrival)
   value = f(1) - arrival;
   isterminal = 1;
   direction = 0;
end
% Constant Definitions
r0 = 10000e3;  % Initial radius (LEO) in meters
m = 1360777.11; % Starship FUEL mass without boosters
R_0_e = 6400e3; % Earth radius [m]
g_0_e = 9.81; % Gravity at Earth's surface [m/s^2]
T = 0.9*6 * 2980e3; % Total thrust of 6 Raptor engines
Isp = 380; % Specific impulse [s]
Thrust_Start = 35786*10^3;
R_0_m = 3400* 10^3;
g_0_m = 3.71;
d = 7.47964*10^10;
V_Leo=(9.81*((6400*10^3)^2)/(r0))^0.5;
arrival = d;
Thrust_Stop = 0.1*m;
massiszero = 0;
G = 6.67430e-11;
M = 5.972e24;
v_theta0 = V_Leo;
v_r0 = 0;
mdot = - T /(Isp*g_0_e);
% initial angular momentum
h = r0 * v_theta0;
% Initial conditions - [r, dr/dt, theta]
y0 = [r0; v_r0; 0;m];
tspan = [0, 15400];
motionODE = @(t, y) [y(2); ...
                     (h^2 / y(1)^3) - (G*M / y(1)^2) +
(t<200)*T/(y(4)+90718.474); ...
                    h / y(1)^2;... %Theta
                     (t<200)*mdot];
options = odeset('RelTol', 1e-16, 'AbsTol', 1e-16,'MaxStep',10);
[t, y] = ode45(motionODE, tspan, y0, options);
r = y(:,1);
theta = y(:,3);
```

```
x = r .* cos(theta);
y_pos = r .* sin(theta);
radius = y(end,1)
figure;
   scatter(x/1e3, y_pos/1e3, 5, t, 'filled');
   hold on;
   plot(10000,0, 'bo', 'MarkerSize', 5, 'MarkerFaceColor', 'k'); % Starship
   plot(0,0, 'bo', 'MarkerSize', 50, 'MarkerFaceColor', 'b'); %Earth
   xlabel('X coordinate [km]');
   ylabel('Y coordinate [km]');
   title('Spacecraft Trajectory Following Tangential Thrust');
   colorbar;
   colormap(jet);
   ylabel(colorbar, 'Time [hours]');
   axis equal;
   grid on;
figure;
   plot(t/3600, y(:,4), 'LineWidth', 2);
   xlabel('Time [Hours]');
   ylabel('Mass [kg]');
   title('Starship Mass Decrease Over Time');
   grid on
figure;
   plot(t/3600, sqrt(y(:,2).^2 + ((9.81*((6400*10^3)^2) ./ y(:,1)).^0.5).^2),
'LineWidth', 2);
   xlabel('Time [Hours]');
   ylabel('Velocity [m/s]');
   title('Starship Velocity Magnitude Over Time');
   grid on
theta_motion = atan((y_pos(end)-y_pos(end-1))/(x(end)-x(end-1)));
%%Now, plotting Earth Mars Trajectory until mass runs out:
transitODE = @(t_1, z) [z(2); ...
   %(T / (z(3) + 90718.474))*abs(((g_0_e * (R_0_e^2 / z(1)^2))/(T / (z(3) +
90718.474))-1)) - g_0_e * (R_0_e^2 / z(1)^2); ...
   (T / (z(3) + 90718.474))*(1-1/(T /(z(3) + 90718.474)/(g_0_e * (R_0_e^2 /
z(1)^2)))); %Computes extra thrust for tangential acceleratation
   mdot]; %Mass to time equation
z0 = [y(end,1); sqrt((9.81*((6400*10^3)^2)/(y(end,1)))); y(end,4)]; % Initial
conditions [radius, sum of TOTAL velocity implying that we launch at fastest
possible spacecraft movement, angle]
tspan_1 = [t(end), 1e12]; % Arbitrary large time span
options_1 = odeset('Events', @(t_1,z) stopCondition_1(t_1,z,massiszero),...
               'RelTol', 1*10^-16, 'AbsTol', 1*10^-16, 'MaxStep', 10);
[t_1, z] = ode45(transitODE, tspan_1, z0,options_1);
x_transit = z(:,1)*cos(theta_motion)-3115.22e3-2884.998e3;
y_transit = z(:,1)*sin(theta_motion)-10078.63e3+2992.34e3;
figure;
plot(t_1/60, z(:,1), 'LineWidth', 2);
xlabel('Time [Minutes]');
```

```
ylabel('Position [m]');
title('Spacecraft Position Over Time For Stage 2');
grid on
figure;
plot(t_1/60, z(:,2), 'LineWidth', 2);
xlabel('Time [Minutes]');
ylabel('Velocity [m/s]');
title('Spacecraft Velocity Over Time For Stage 2');
grid on
figure;
plot(t_1/60, z(:,3), 'LineWidth', 2);
xlabel('Time [Minutes]');
ylabel('Mass [kg]');
title('Spacecraft Mass Decrease Over Time For Stage 2');
grid on
%%Now plotting spacecraft as it moves from Earth to Mars
%Calculating theta from Y(end,1) to mars:
RT_Variation = [10^-4,10^-5,10^-6,10^-7,10^-8,10^-9,10^-10, 10^-11, 10^-12,
10^-13, 10^-14, 10^-15,10^-16];
RT_Exp = [-4,-5,-6,-7,-8,-9,-10, -11, -12, -13, -14, -15,-16];
f2_storage = {};
time_storage = {};
labels = {};
colors = ['r', 'g', 'b', 'm', 'c', 'k'];
index = 1;
for i=1:length(RT_Variation)
transit_1ODE = @(t_2, f) [f(2); - g_0_e * (R_0_e^2 / f(1)^2) + g_0_m * (R_0_m^2
/ ((d - f(1))^2))];
f0 = [z(end,1); z(end,2)]; % Initial conditions [radius, radial velocity,
angle]
tspan_2 = [t_1(end), 1e14]; % Arbitrary large time span
options_2 = odeset('Events', @(t_2,f) stopCondition_2(t_2,f,arrival),...
               'RelTol', RT_Variation(i), 'AbsTol', 1*10^-16, 'MaxStep', 1000);
[t_2, f] = ode45(transit_1ODE, tspan_2, f0,options_2);
x_transit_1 = f(:,1)*cos(theta_motion)-3115.22e3-2884.998e3;
y_transit_1 = f(:,1)*sin(theta_motion)-10078.63e3+2992.34e3;
f2_storage {index}= f(end,2);
time_storage {index} = t(end);
labels{index} = sprintf('Arrival Velocity %.2f at Reltol e
%.2f',f(end,2),RT_Exp(i));
index = index +1;
end
figure;
hold on;
for i = 1:length(f2_storage)
   scatter( log(RT_Variation(i) * ones(size(f2_storage{i}))),f2_storage{i}, 50,
colors(mod(i-1, length(colors)) + 1), 'filled', ...
       'DisplayName', labels{i});
end
```

```
xlabel('log(RelTol)');
ylabel('Arrival Velocity [m/s]');
title('Arrival Time vs log(RelTol) for Convergence');
legend('show');
grid on;
hold off;
figure;
   plot(t_2/86400, f(:,1), 'LineWidth', 2);
   xlabel('Time [Days]');
   ylabel('Position [m]');
   title('Spacecraft Position Over Time for Stage 3');
   grid on
   hold on
figure;
   plot(t_2/86400, f(:,2), 'LineWidth', 2);
   xlabel('Time [Days]');
   ylabel('Velocity [m/s]');
   title('Spacecraft Velocity Over Time for Stage 3');
   grid on
%Now just need to plot stages 2 and 3 in 2d
x_all = [x; x_transit; x_transit_1];
y_all = [y_pos; y_transit; y_transit_1];
t_all = [t;t_1;t_2];
velo_all = [sqrt((9.81*((6400*10^3)^2)./(y(:,1))));z(:,2);f(:,2)];
pos_all = [y(:,1);z(:,1);f(:,1)];
figure;
   scatter(x_all/1e3, y_all/1e3, 5, t_all/86400, 'filled'); % Convert time to
days
   hold on;
   plot(10000,0, 'bo', 'MarkerSize', 5, 'MarkerFaceColor', 'k'); % Starship
   plot(0,0, 'bo', 'MarkerSize', 70, 'MarkerFaceColor', 'b'); %Earth
   xlabel('X coordinate [km]');
   ylabel('Y coordinate [km]');
   title('Spacecraft Trajectory from r_0 to Martian LEO');
   colorbar;
   colormap(jet);
   ylabel(colorbar, 'Time [days]');
   axis equal;
   grid on;
   t_min = 0;
   t_max = 18064.7712;
   t_new = (t_all >= t_min) & (t_all <= t_max);
   x_filtered = x_all(t_new);
   y_filtered = y_all(t_new);
   t_filtered = t_all(t_new);
figure;
   scatter(x_filtered/1e3, y_filtered/1e3, 5, t_filtered/3600, 'filled'); %
Convert time to days
   hold on;
```

```
   plot(10000, 0, 'bo', 'MarkerSize', 5, 'MarkerFaceColor', 'k'); % Starship
   plot(0, 0, 'bo', 'MarkerSize', 75, 'MarkerFaceColor', 'b'); % Earth
   xlabel('X coordinate [km]');
   ylabel('Y coordinate [km]');
   title('Filtered Spacecraft Trajectory');
   colorbar;
   colormap(jet);
   ylabel(colorbar, 'Time [Hours]');
   axis equal;
   grid on;
   t_min = 92.5664*86400;
   t_max = 92.5669*86400;
   t_new= (t_all >= t_min) & (t_all <= t_max);
   x_filtered = x_all(t_new);
   y_filtered = y_all(t_new);
   t_filtered = t_all(t_new);
figure;
   scatter(x_filtered/1e3, y_filtered/1e3, 5, t_filtered/86400, 'filled'); %
Convert time to days
   hold on;
   plot(10000, 0, 'bo', 'MarkerSize', 5, 'MarkerFaceColor', 'k'); % Starship
   plot(0, 0, 'bo', 'MarkerSize', 75, 'MarkerFaceColor', 'b'); % Earth
   plot(7.45268e7, 6.2747e6, 'bo', 'MarkerSize', 68, 'MarkerFaceColor', 'r'); %
Mars
   xlabel('X coordinate [km]');
   ylabel('Y coordinate [km]');
   title('Filtered Spacecraft Trajectory');
   colorbar;
   colormap(jet);
   ylabel(colorbar, 'Time [Days]');
   axis equal;
   grid on;
figure;
   plot(t_all/86400, velo_all, 'LineWidth', 2);
   hold on;
   xline(t(end)/86400, '--r', 't_{end}', 'LabelHorizontalAlignment', 'left',
'LabelVerticalAlignment', 'middle');
   xline(t_1(end)/86400, '--g', 't_{1,end}', 'LabelHorizontalAlignment',
'left', 'LabelVerticalAlignment', 'middle');
   xline(t_2(end)/86400, '--b', 't_{2,end}', 'LabelHorizontalAlignment',
'left', 'LabelVerticalAlignment', 'middle');
   xlabel('Time [Days]');
   ylabel('Velocity [m/s]');
   title('Spacecraft Velocity Over Time For Total Flight');
   grid on;
   hold off;
figure;
   plot(t_all/86400,pos_all, 'LineWidth', 2);
   xlabel('Time [Days]');
```

```
ylabel('Position [m]');
title('Spacecraft Position Over Time For Total Flight');
grid on
```