MAE 3100 – Spring 2012 (Smith)

Computer Project 2 – Vehicle Performance Analysis and Design Optimization

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Summary:

While analyzing the design and performance of a Honda 1600 cubic centimeter engine, Newton's second law was used in order to computer difference dynamic variables. Because Newton's second law is a second order differential equation, `ode45,` was used in order to compute acceleration, velocity, distance, and time for different acceleration events. Five gears were also part of the computation as the engine was made to shift when 7500 revolutions per minute were reached.

Problems encountered during computation included deriving equations based on results from the system of ordinary differential equations (Newton's 2^{nd}). Discerning which values are from linear equations was easier to see when plotted that while deriving formulas. Another issue included difficulty passing the time value while a shift delay occurred in task four. Lastly optimizing for shift points and rpm values was difficult.

Ultimately, challenges were overcome through methodical and analytical means. Using Matlab's debugging feature made it possible to locate exact location where errors or miscomputations were occurring.

Table A.1 shows the computed values for max gear, time, distance, speed, maximum rpm, and the maximum acceleration in g's (where g = 9.81 m?s^2) while the turbo is off. If compared to the computed values in Table A.2, it's obvious that the turbocharger increases the engines performance during the three events 1) accelerating from 0.1 to 60mph, 2) accelerating from 0.1 mph through 0.25mi, and 3) accelerating from 0.1 to maximum speed. All calculations were performed through the main calling m-file "CP2.m" [C.1] , which uses the ode45 function along with the m-file "htc1600_ode.m" [C.5]. In order to calculate the velocity from the rpm and vice versa, m-files RPMtoV.m [C.3], and VtoRPM.m [C.4], were created and used the horse power value approximated with interpolation used by the spline function in get_HP.m [C.2].

The figures for tasks 2-3 [B.1-B.4] it is easy to visualize the fact the only linear function is that of the distance based on time, as it should be. The other three nonlinear functions for speed, max rpm, and max acceleration can be used to make a few observations. In task 3, a function was including that acted as a transmission for the engine computation; shifting gears at 7500rpm. During tasks 3 and 4 something interesting occurs while calculating the maximum velocity. While the vehicle increases its speed, the force of drag F_d also

increases. The maximum velocity of the car occurs when the acceleration becomes constant or when $F_d = F_t$. As the force of drag increases, the vehicles acceleration rate decreases. A graphical representation of this can be seen in figures B.4.d and B.7.d. Acceleration is not the only value affected as the velocity [B.4.b] and thus rpm [B.7.b] are related.

From the figures produced in Figs. [B.4 – B.7], one can compare the calculated values graphically with and without the turbocharger engaged. It is interesting to notice that when the engines performance is increased (turbocharger on), the linearity of the figures drastically decreases. This would also be the case with the internal dynamic forces within the engine. Also, although there is a shift delay of 0.4 seconds imposed during task 4 computations, the values found were not drastically different [A.1]. While the shift delay is occurring, the acceleration becomes negative as the car coasts with no traction force, $F_t = 0$. Although the values are similar shift delay seems to cause an increase in the linearity of the maximum rpm, velocity, and maximum acceleration [B.4 vs. B.7].

The final portion of the project posed the greatest number of issues during this project. Optimizing values based on the system of nonlinear constraints through fmincon was not completed. The two design variables that we were trying to optimize were the rpm shift point and the overall gear ratio R. For part A) minimizing acceleration time to 60mph would be done by maximizing the overall velocity while decreasing distance. The main issue was the fact that the input for fmincon was not data type double thus could not be used with both. An attempt was made, but from researching the subject it seems that the fminsearch command may be the only way to obtain a solution. A higher RPM with increase the velocity thus decreasing the time of the acceleration event so the optimum RPM value is toward the upper bounds. While the overall gear ratio will decrease the velocity thus increasing the total time. Thus, staying in a lower gear and shifting at a higher RPM will decrease total time by maximizing velocity and acceleration .

Appendix A – OUTPUT Values

A.1 – Output values **without** turbo

Task	Max. Gear	Time (s)	Distance (mi)	Speed (mph)	Max. RPM (revs/min)	Max. Acceleration (g's)
2	1	3	0.010241	24.817782	5009.812343	0.409638
3(i)	2	8.873160	0.070873	60.000000	7114.302350	0.237168
3(ii)	3	12.539328	0.250000	71.774180	5572.542566	0.131891
3(iii)	4	41.029207	1.213872	114.724652	6477.326247	0.057286
4(i)	2	9.273160	0.154553	60.000000	7114.302350	0.237168
4(ii)	3	12.810497	0.250000	70.254884	5454.584528	0.131891
4(iii)	4	40.600026	1.280306	113.524589	6409.570967	0.057286

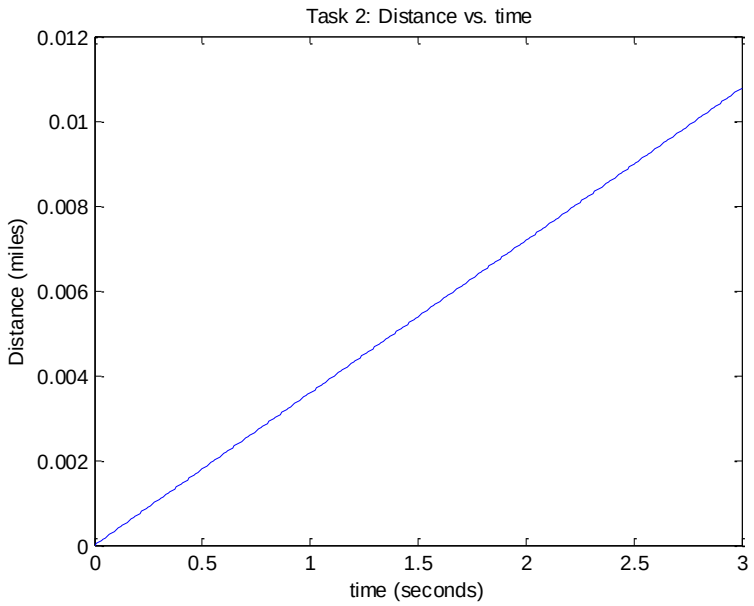
A.2 – Output values **with** turbo

Task	Max. Gear	Time (s)	Distance (mi)	Speed (mph)	Max. RPM (revs/min)	Max. Acceleration (g's)
2	1	3.000000	0.010781	36.783043	7425.165886	1.363130
3(i)	2	4.516901	0.035808	60.000000	7114.302350	0.788673
3(ii)	4	8.910371	0.250000	101.005898	5702.768695	0.317058
3(iii)	5	34.896193	1.527683	172.008145	7500.000000	0.176931
4(i)	2	4.916901	0.081948	60.000000	7114.302350	0.788673
4(ii)	4	15.900489	0.586719	132.837973	7500.000000	0.317058
4(iii)	5	36.496193	1.743790	172.008145	7500.000000	0.176931

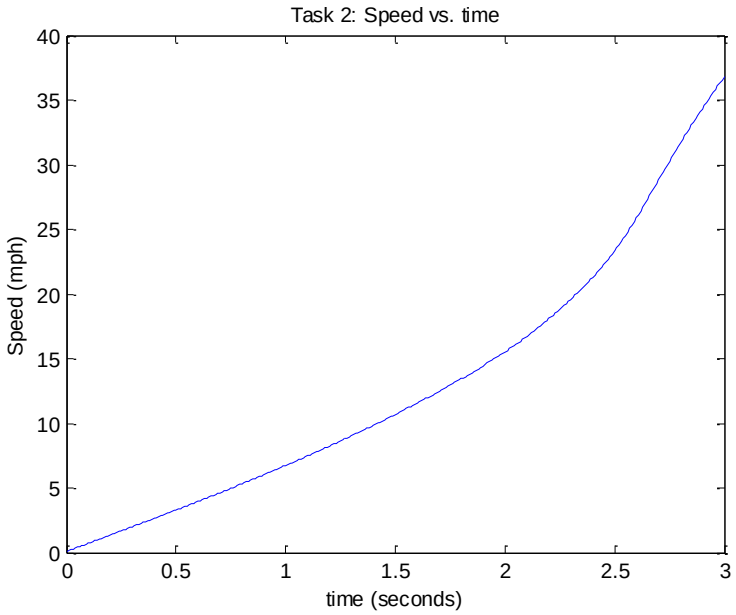
Appendix B – Plots

Fig. B.1 – Task 2 Figures: With Turbo

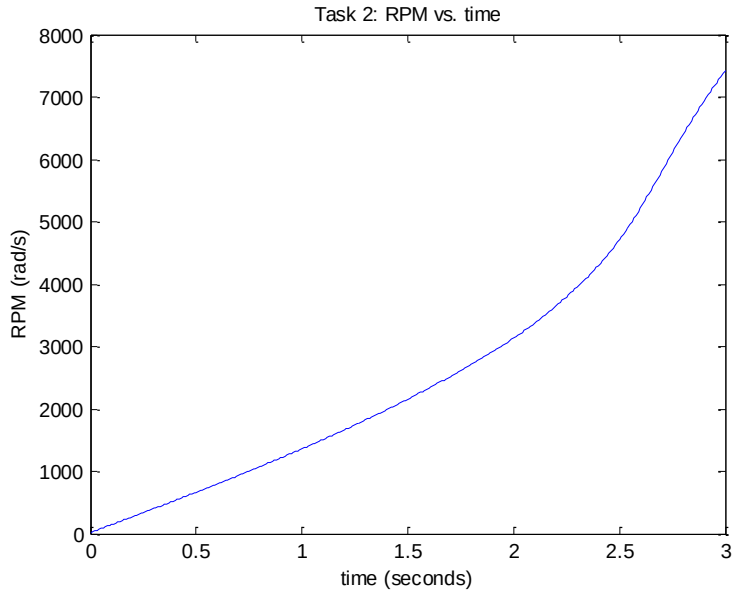
B.1.a – Distance vs. Time



B.1.b –Velocity vs. Time



B.1.c – RPM vs. Time



B.1.d –Acceleration vs. Time

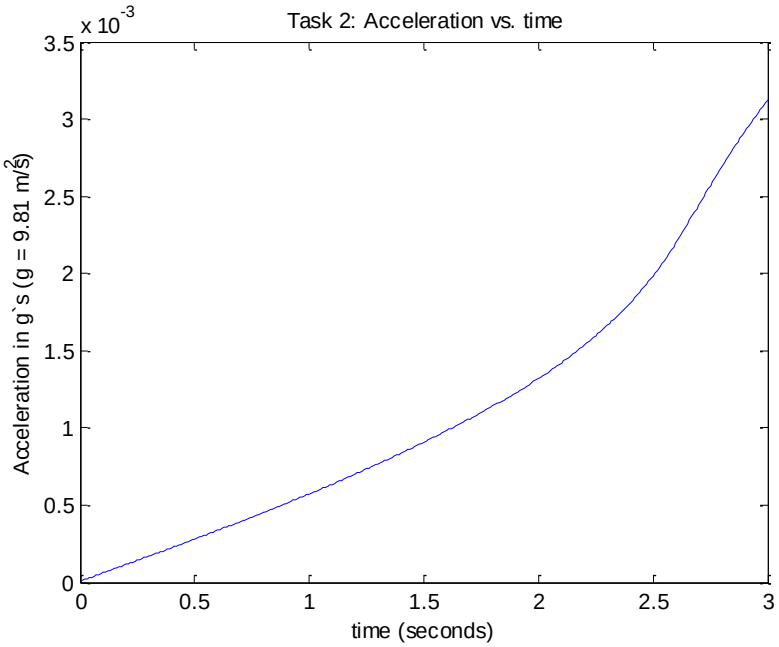
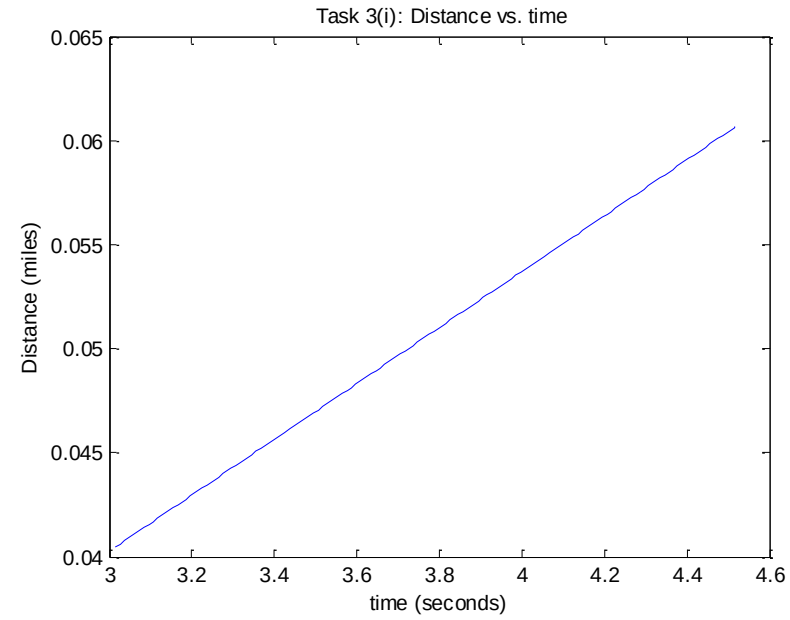
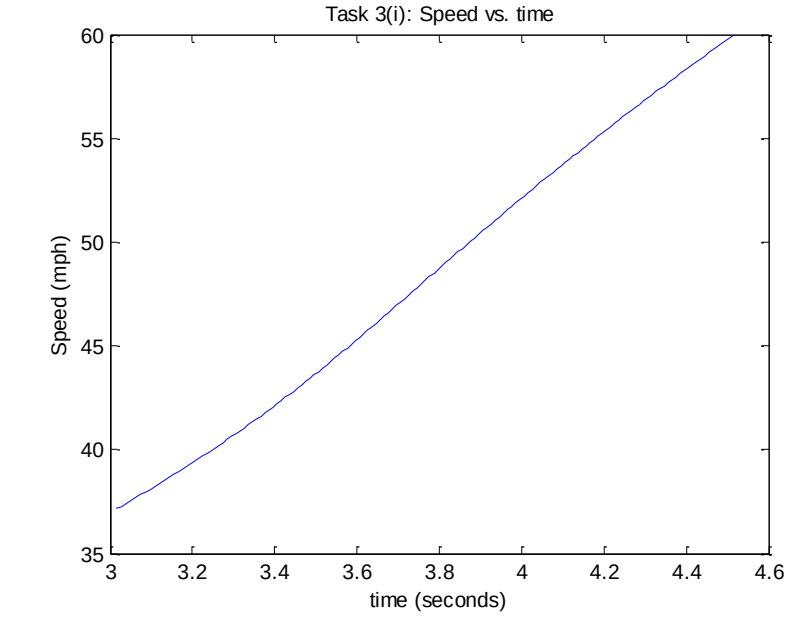


Fig. B.2 – Task 3(i) Figures: With Turbo

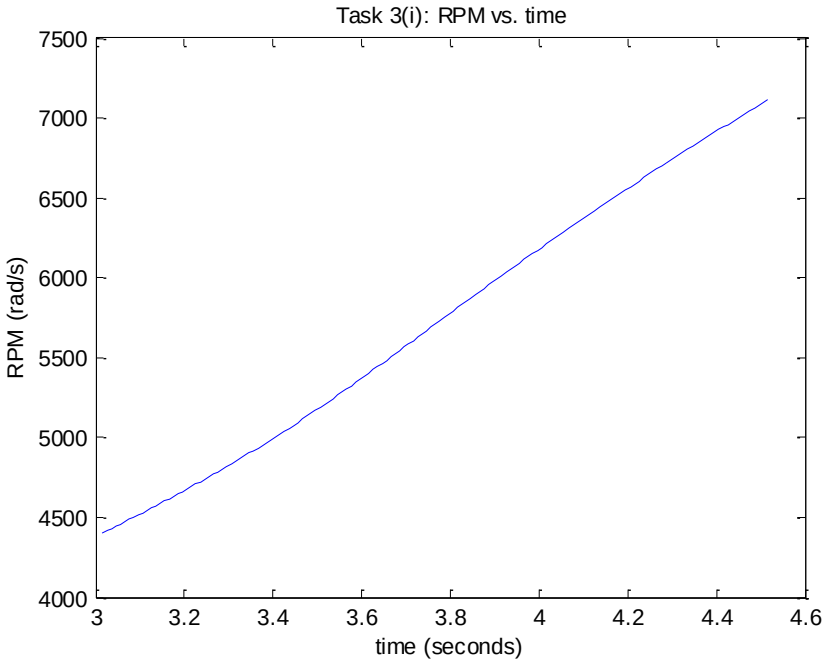
B.2.a –Distance vs. Time



B.2.b –Velocity vs. Time



B.2.c –RPM vs. Time



B.2.d –Acceleration vs. Time

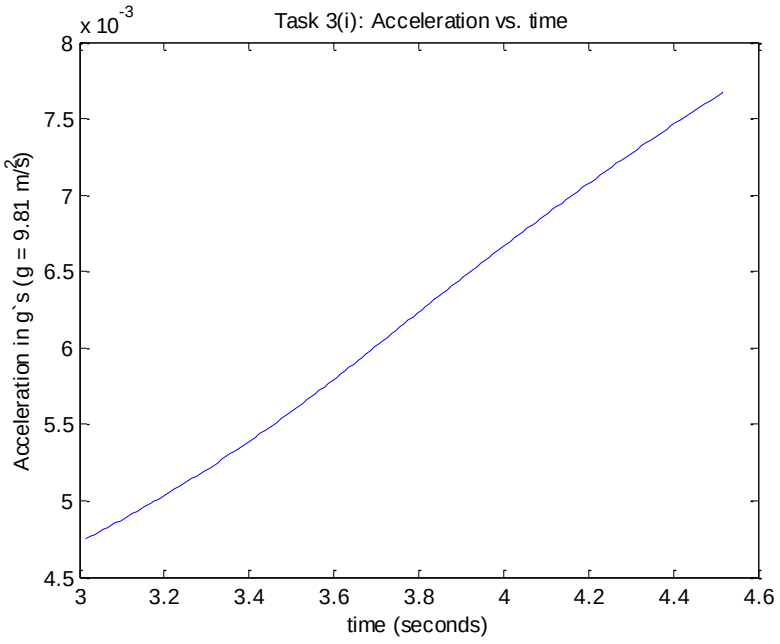
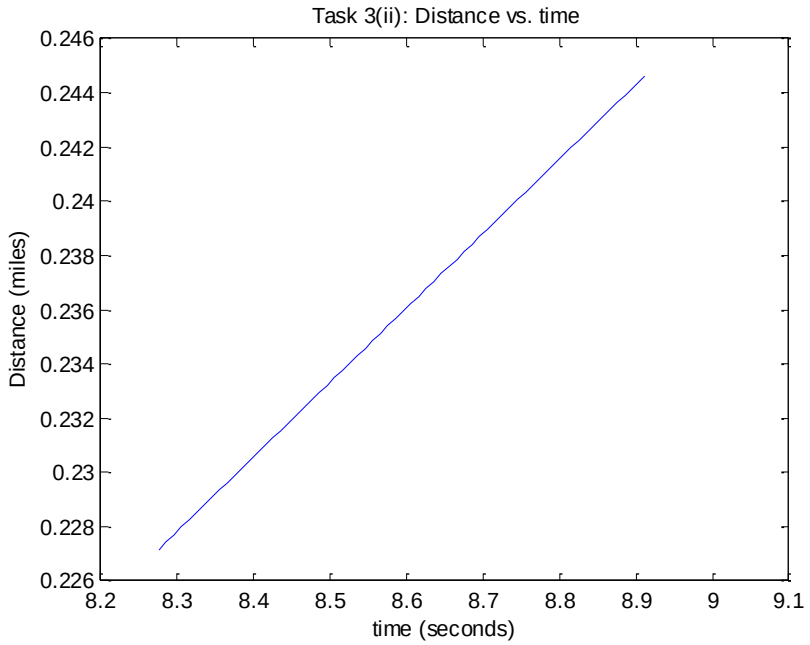
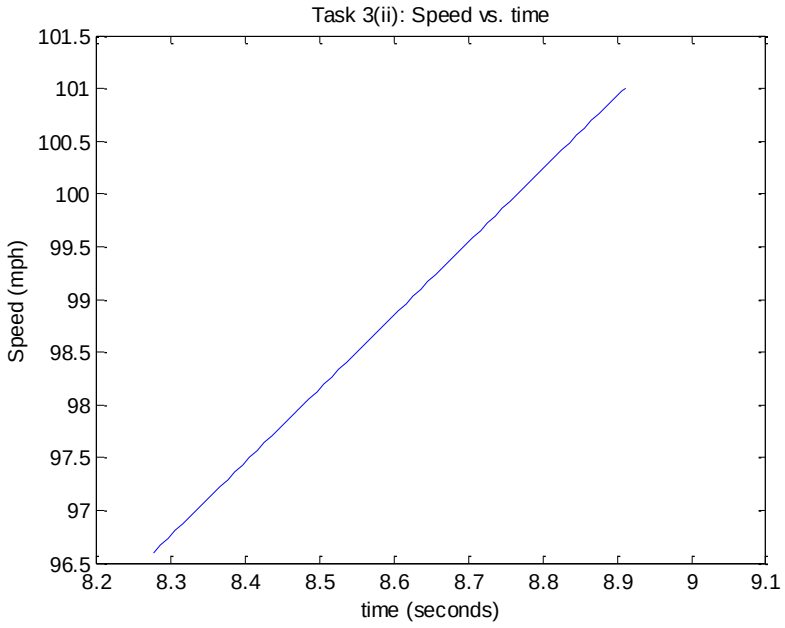


Fig. B.3 –3(ii) Figures: With Turbo

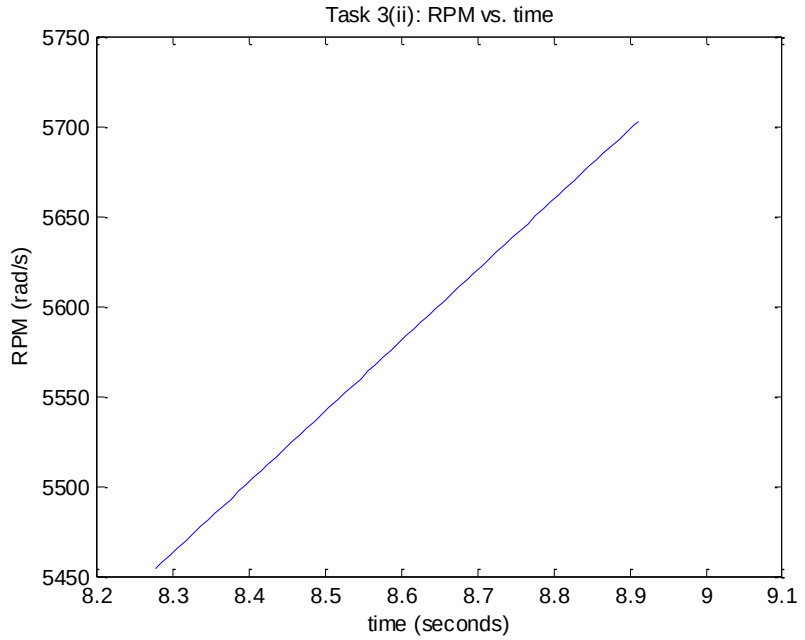
B.3.a –Distance vs. Time



B.3.b –Velocity vs. Time



B.3.c –RPM vs. Time



B.3.d –Acceleration vs. Time

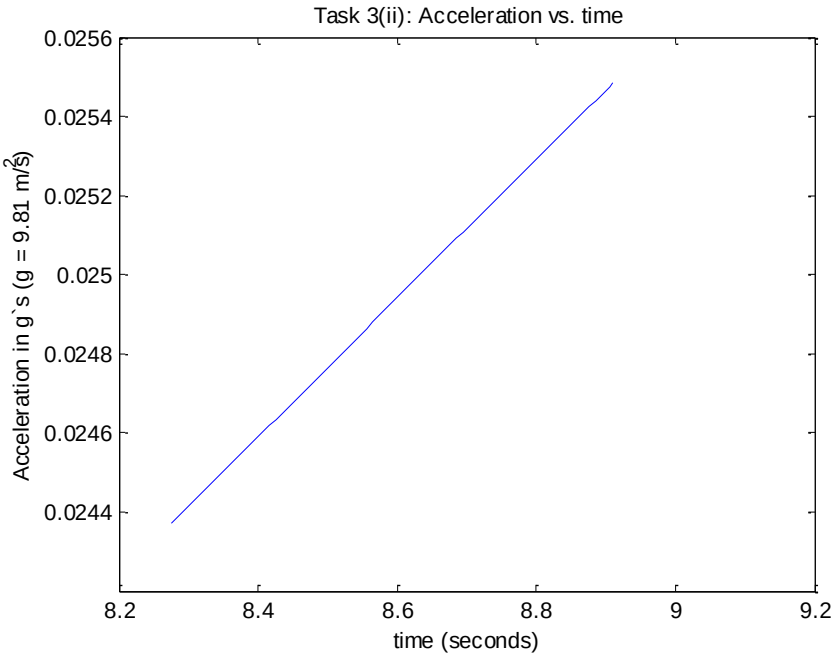
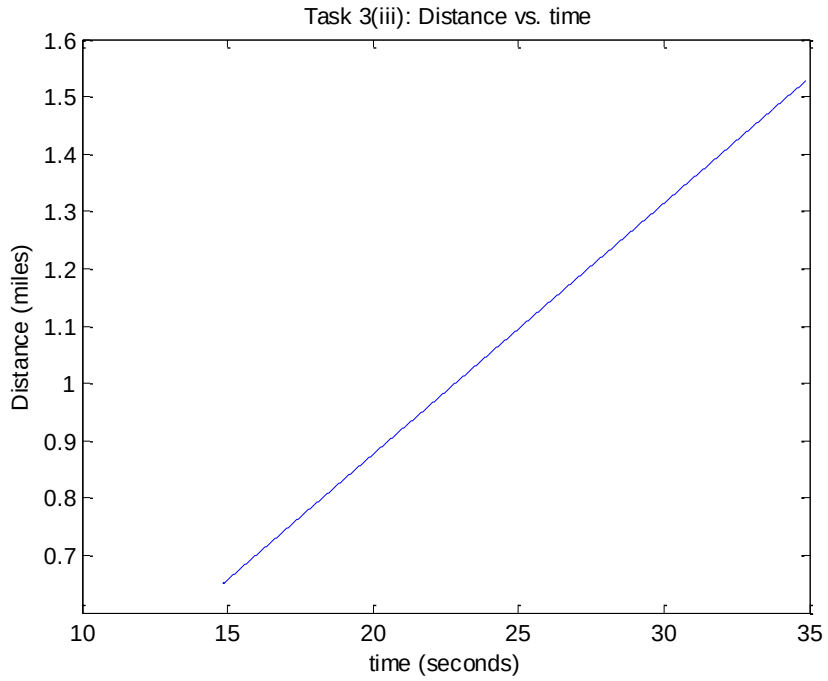
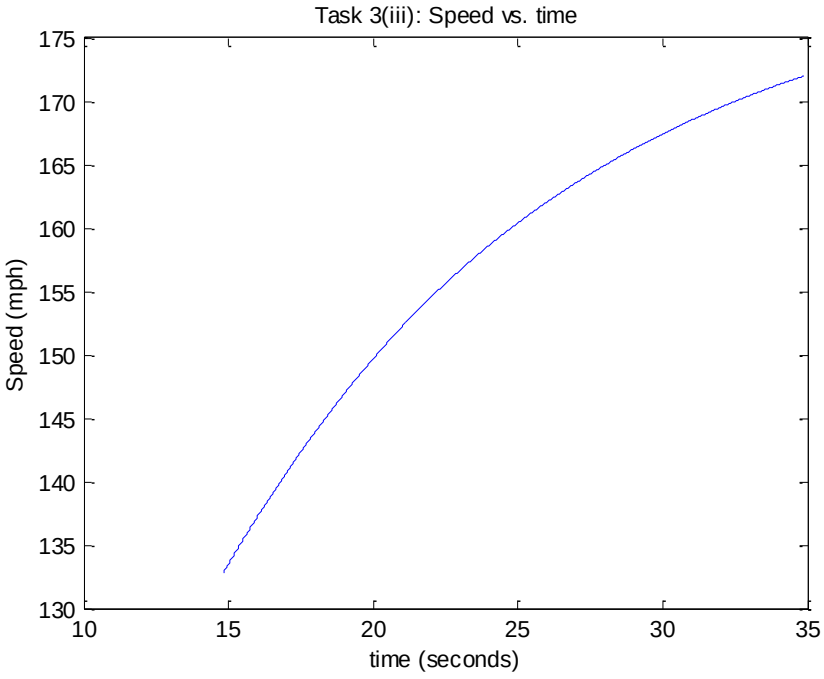


Fig. B.4 –3(iii) Figures: With Turbo

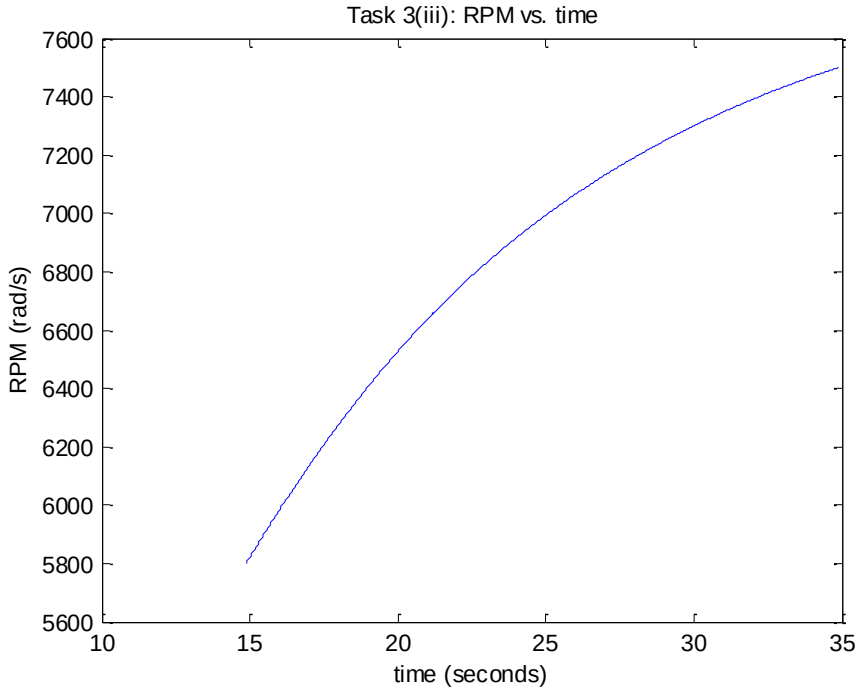
B.4.a –Distance vs. Time



B.4.b –Velocity vs. Time



B.4.c –RPM vs. Time



B.4.d –Acceleration vs. Time

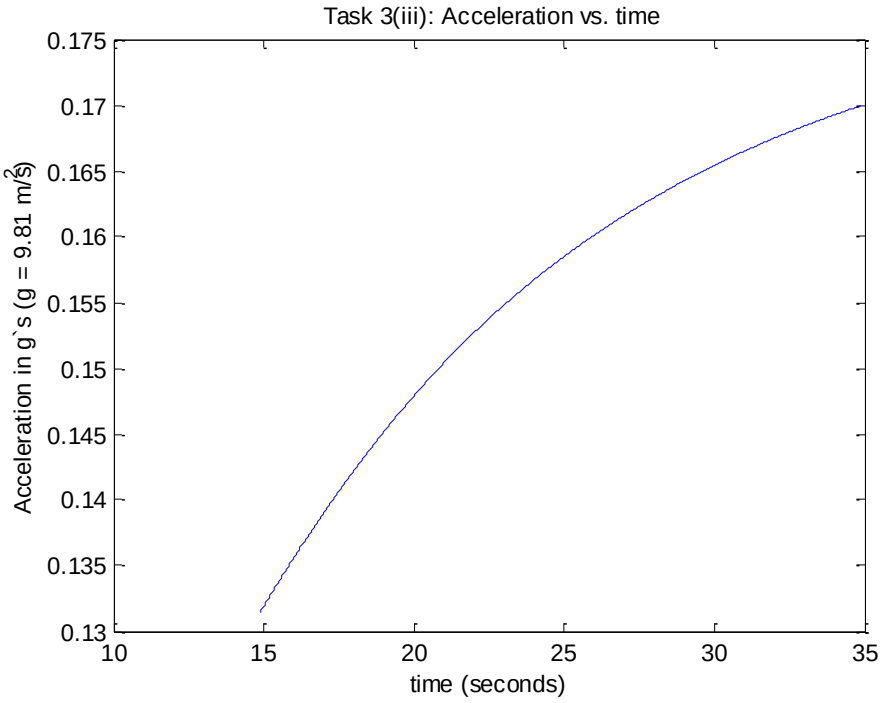
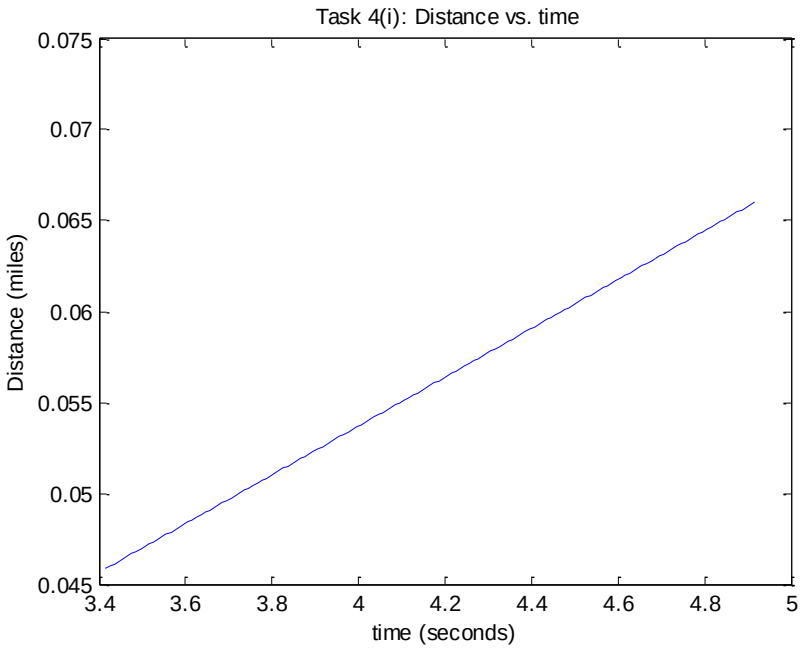
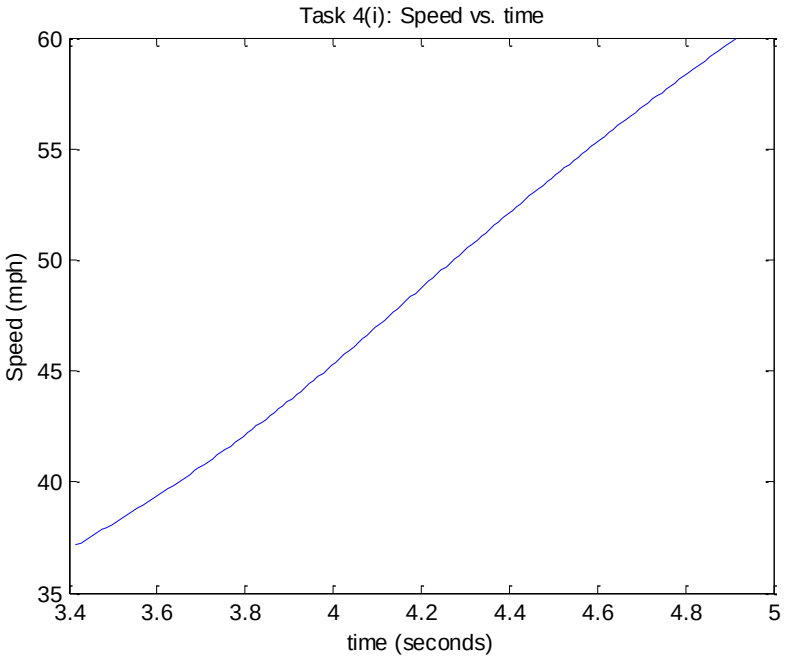


Fig. B.5– 4(i) Figures: With Turbo and Without

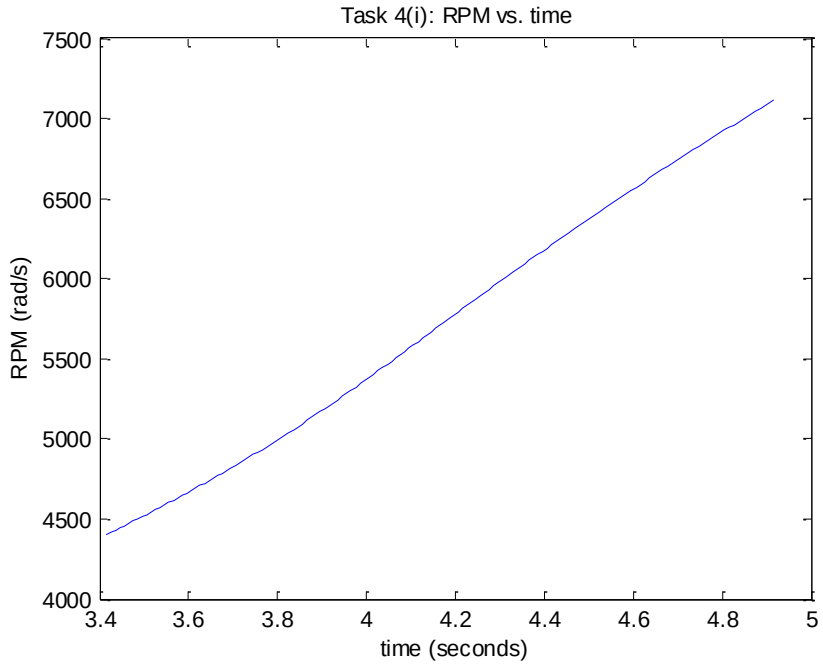
B.5.a –Distance vs. Time



B.5.b –Velocity vs. Time



B.5.c –RPM vs. Time



B.5.d –Acceleration vs. Time

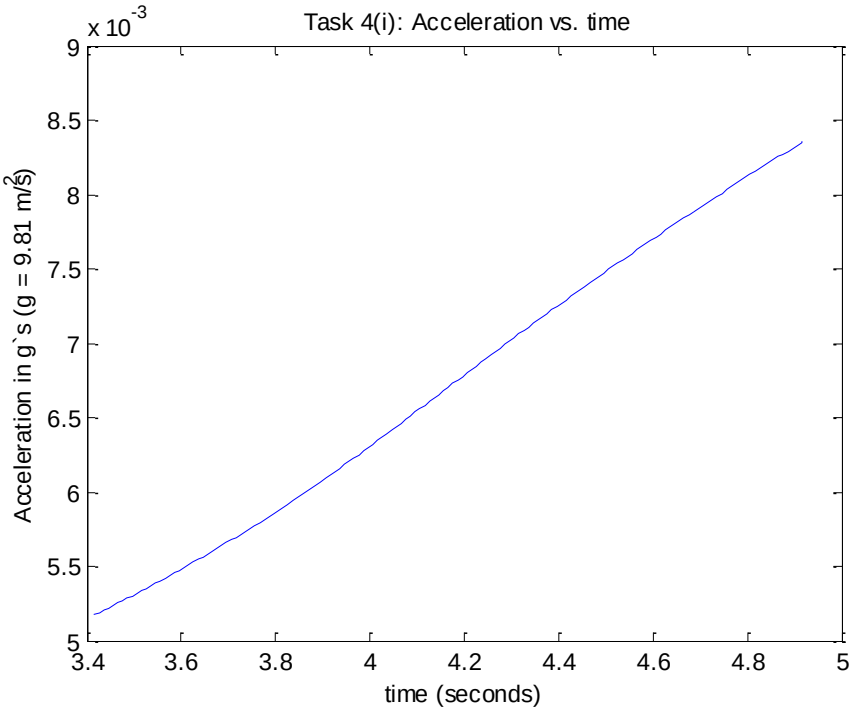
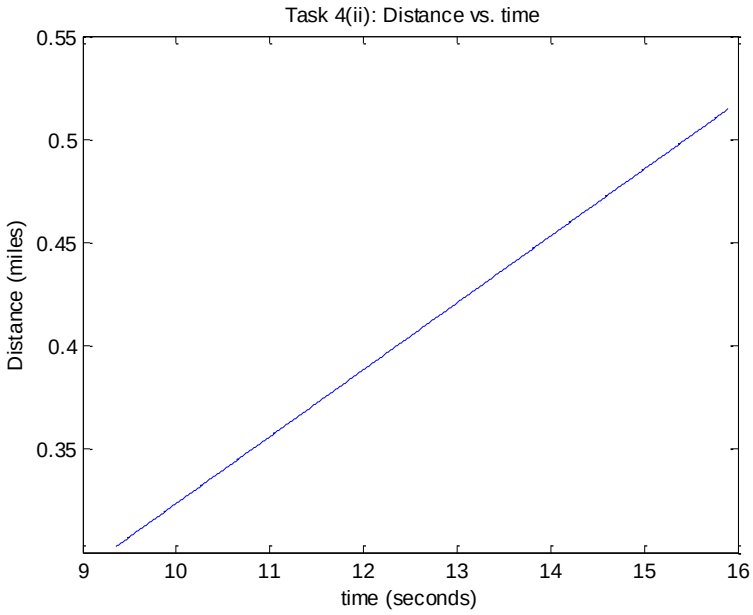
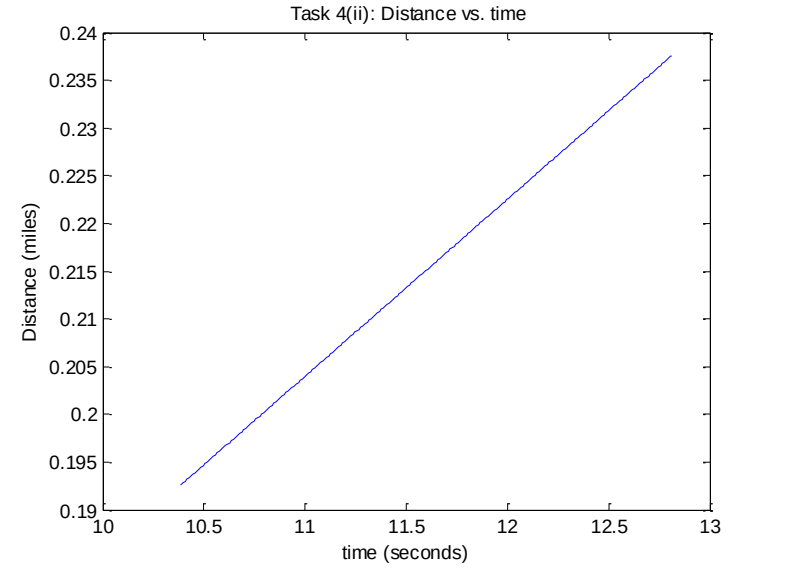


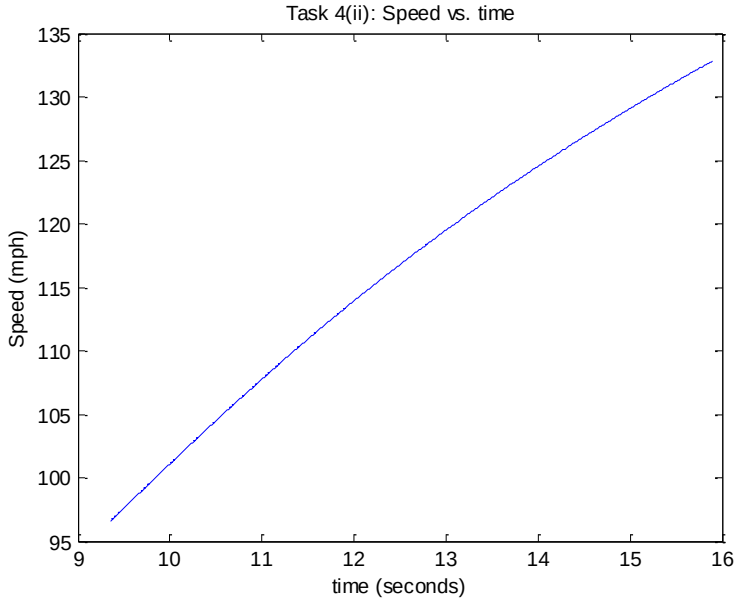
Fig. B.6 – 4(ii) Figures: With Turbo and Without Respectively

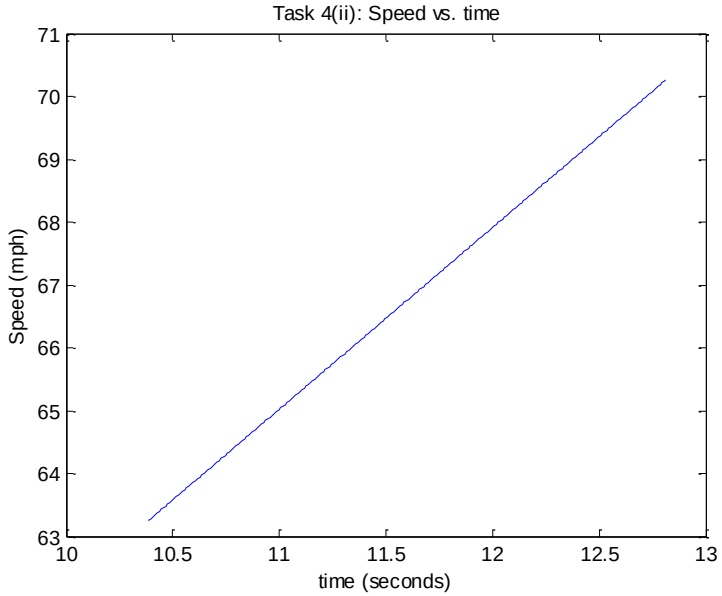
B.6.a –Distance vs. Time



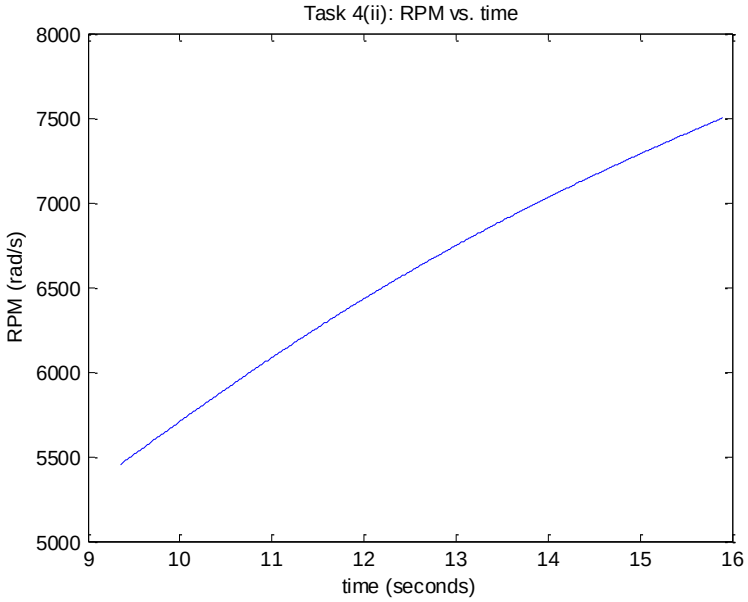


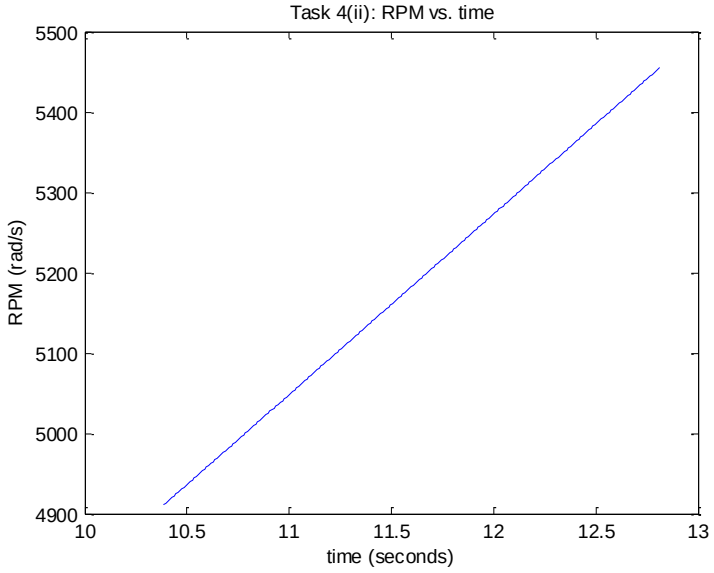
B.6.b –Velocity vs. Time



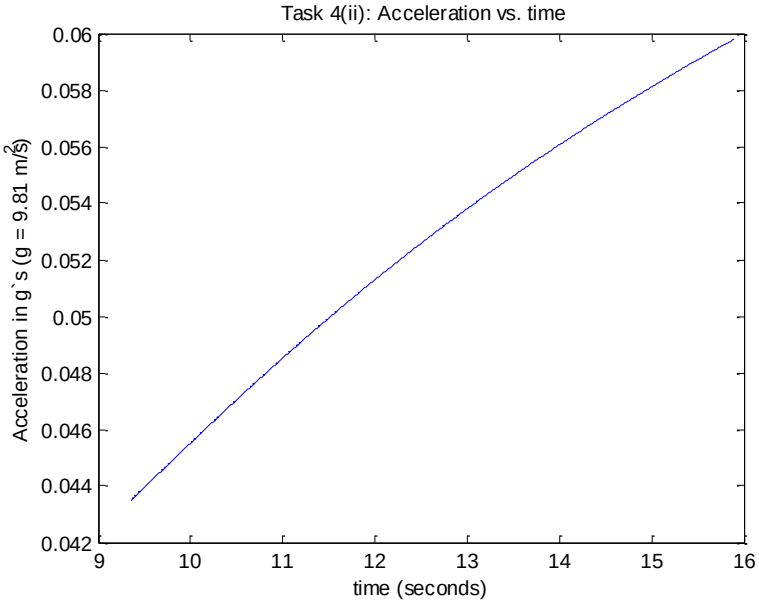


B.6.c –RPM vs. Time





B.6.d –Acceleration vs. Time



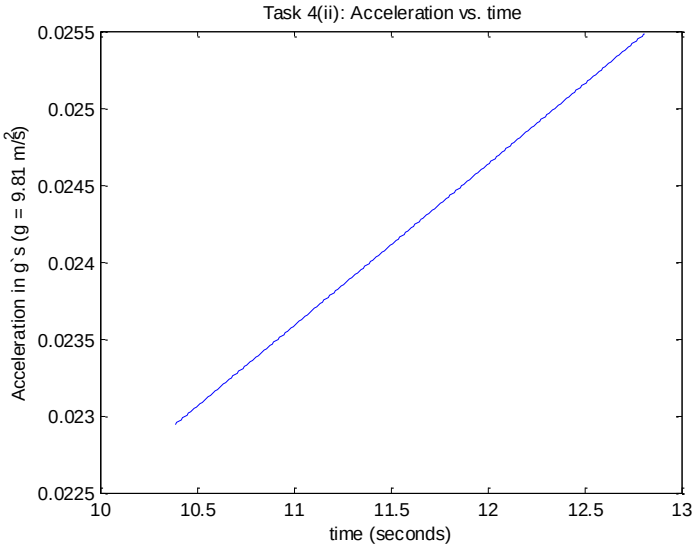
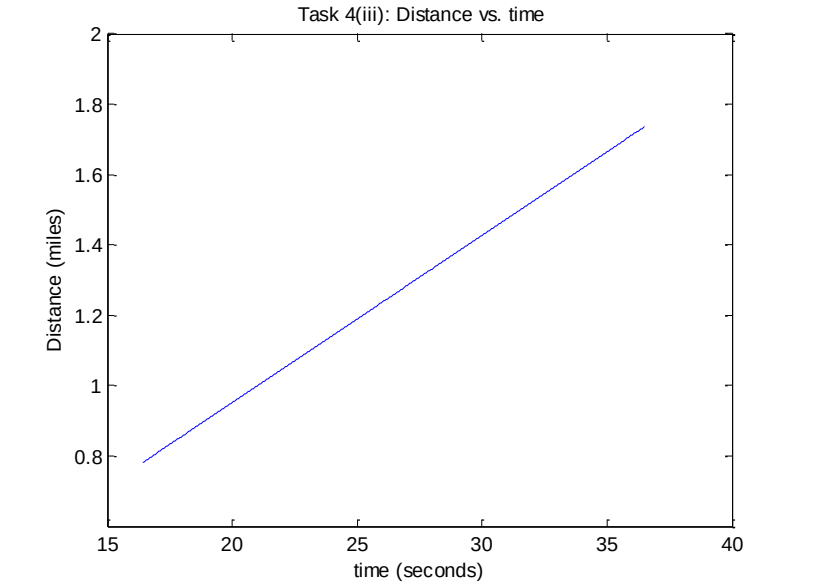
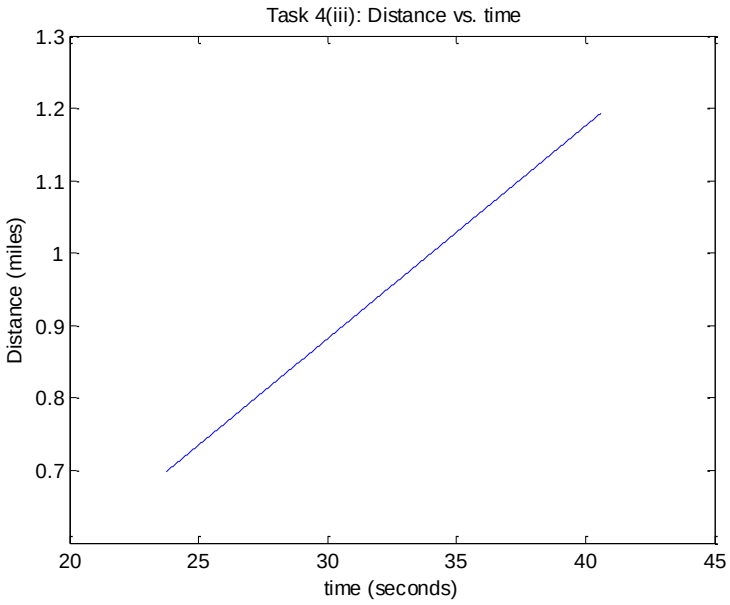


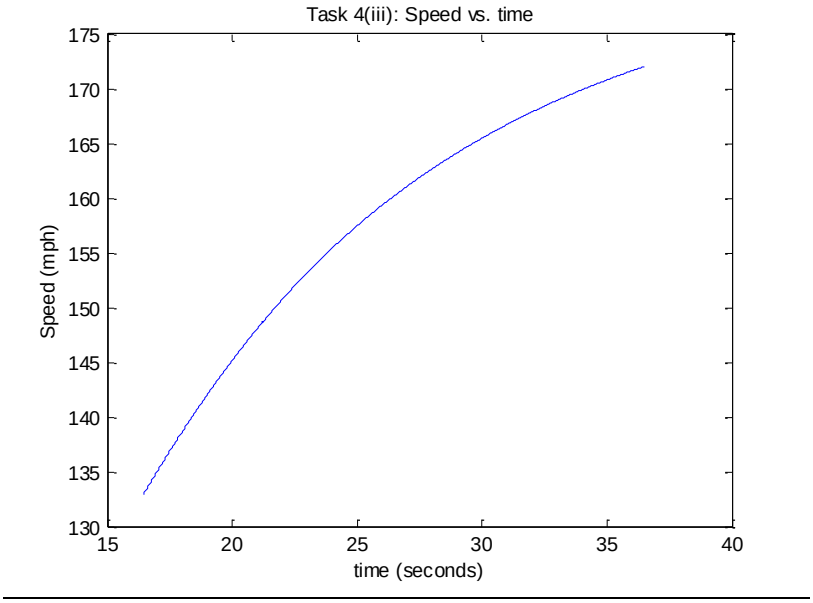
Fig. B.7 – 4(iii) Figures: With Turbo and Without Respectively

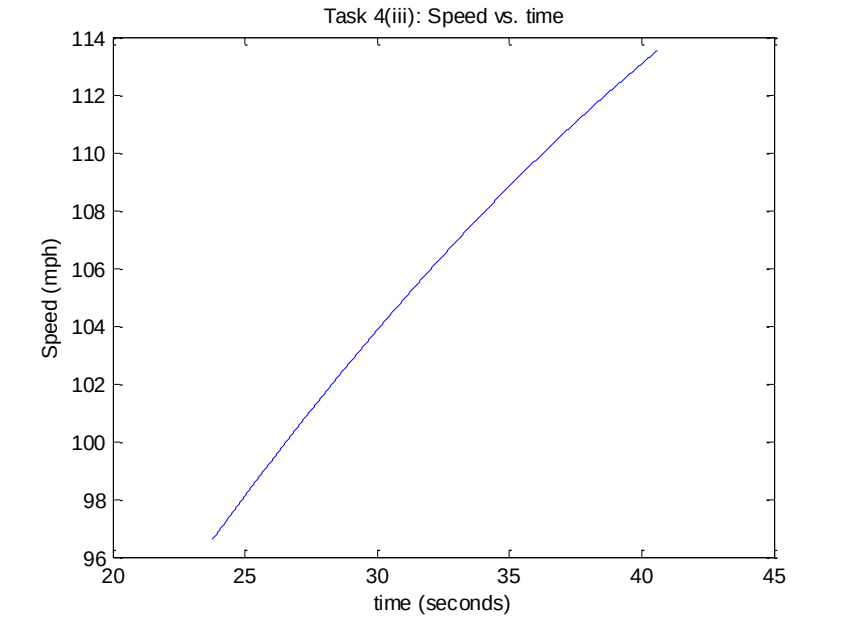
B.7.a –Distance vs. Time



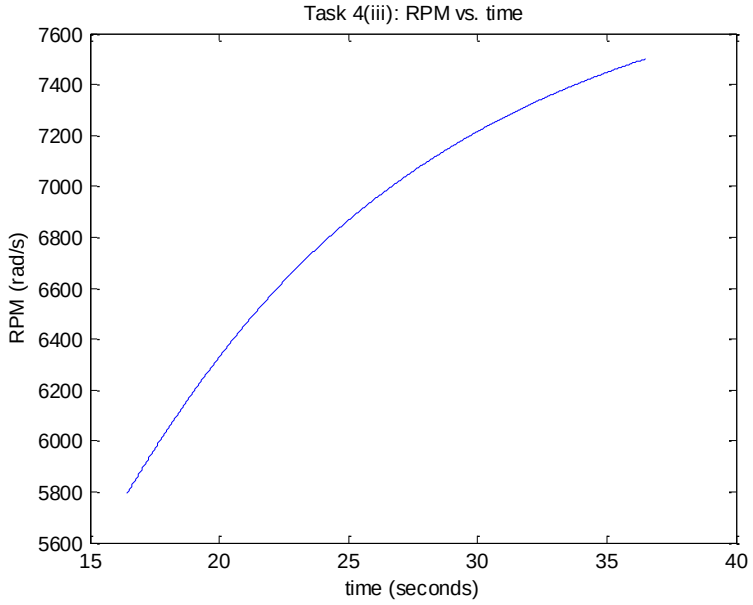


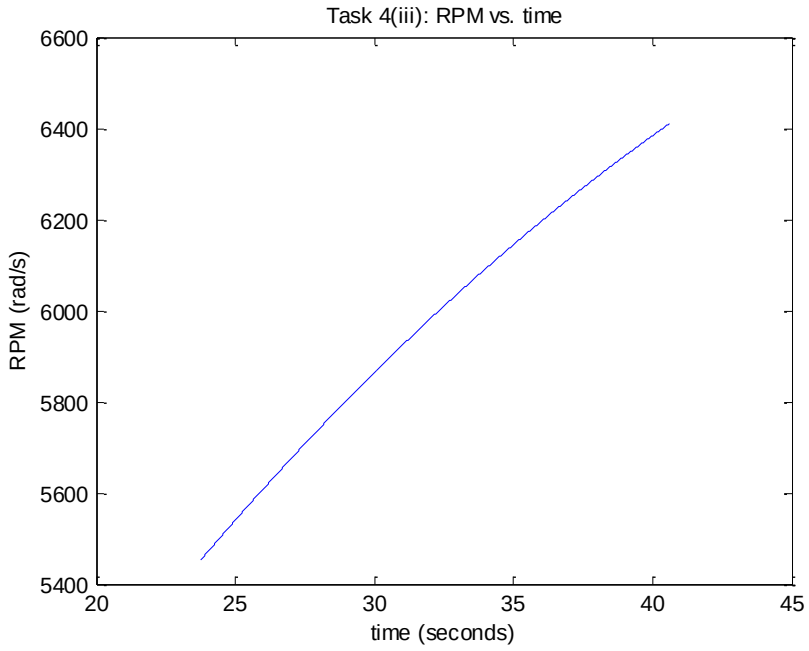
B.7.b –Velocity vs. Time



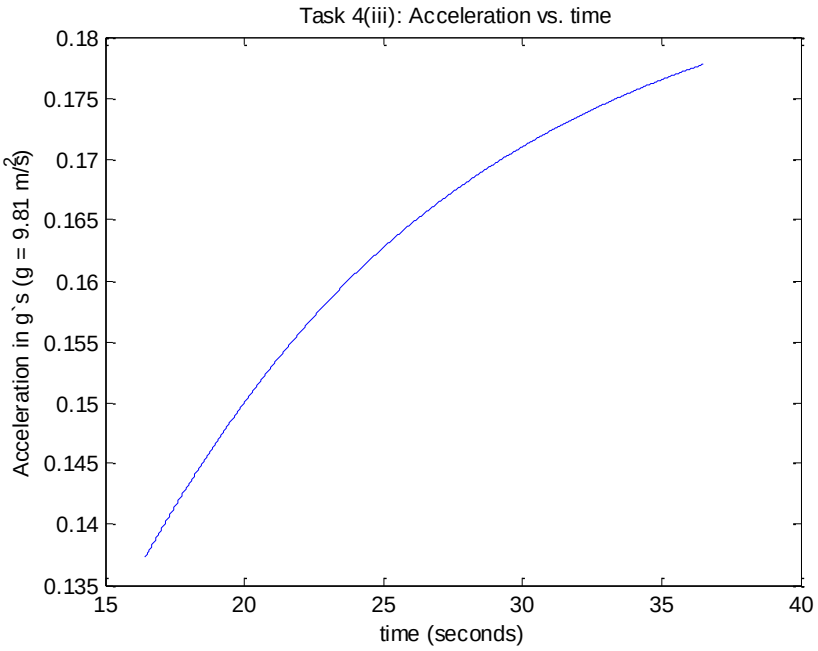


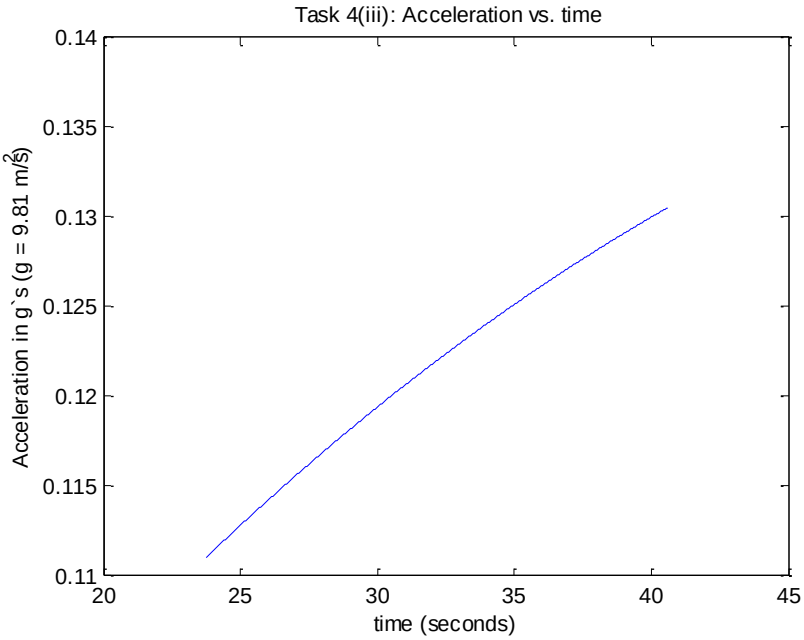
B.7.c –RPM vs. Time





B.7.d –Acceleration vs. Time





Appendix C – Matlab M-files

C.1 – CP2.m

```
%% CP2: Vehicle Performance Analysis and Design Optimization
%
%  _INPUT:_____________________________________________________________
% |          w = 2498;        % Weight (lbs)                           |
% |          A = 19.9;        % Frontal area (ft^2)                    |
% |          r = 11.5;        % Tire rolling radius (inches)           |
% |          rho = 1.25;      % Air density (kg/m^3)                   |
% |          Cd = 0.32;       % Drag coefficient                       |
% |          alpha = 0.826;   % Drivetrain loss coefficient            |
% |          Rf = 4.250;      % Final drive                            |
% |          Rt = [3.250 1.909 1.250 0.909 0.702]; % Trans. Reduction  |
% |          R = Rt*Rf;       % Overall gear ratio                     |
% |          mass = w/32.2;   % Mass (slug)                           |
% |                                                                    |
% |                                                                    |
% |     'turbo' = 0 or 1 sets the turbocharger on or off respectively  |
% |      'gear' = 1, 2, 3, 4, or 5 - transmission gear number          |
% |____________________________________________________________________|

%  __ CONVERSION FACTORS: _____________________________________________
% |                                                                    |
% | 1 lbf = 0.45359237 kg (at 1 g acceleration)                        |
% | 1 m/s = 2.2369362921 mph                                           |
% | 1 ft-lb = 1.355817952 N-m                                          |
% | 1 m = 0.00062137119224 miles                                       |
% | 1 lb = 0.0310809502 slug                                           |
% | 1 kg / (m^3) = 0.0624279606 pound / (ft^3)                         |
% | 1 ft^2 = 0.09290304 m^2                                            |
% |____________________________________________________________________|
function [OUTPUT] = CP2(D,task)
format compact;format shortg;clear all;clc;
global Honda
disp(' Turbo? ');
disp('(1)YES ');
disp('(0) NO ');
TBO = input('');
disp(' ========== MENU ============');
disp('|___Input__________Task_____|');
disp('|     2      -        2      |');
disp('|    3.1     -      3(i)     |');
disp('|    3.2     -     3(ii)     |');
disp('|    3.3     -    3(iii)     |');
disp('|    4.1     -      4(i)     |');
disp('|    4.2     -     4(ii)     |');
disp('|    4.3     -    4(iii)     |');
disp('|_____________________________|');
task = input('Choose task:');
% _____________________ [SET UP DATA STRUCTUREs ]____________________
if task == 2
D = struct('w',{2498},'A',{(19.9)*0.09290304},'r',{(11.5)*0.0254},...
           'Rt',{[3.250 1.909 1.250 0.909 0.702]},'rho',{1.25},...
           'Cd',{0.32},'alpha',{0.826},'Rf',{4.250},...
           'turbo',{TBO},'gear',{1});
end
% ======================= Acceleration Analysis ======================
switch task
% ============================ [ Task 2 ] ==============================
    case 2
```

```
% ========================================================================
disp('========================== [TASK 2] ============================');

tspan = 0:0.01:3.0;
v0 = (0.1/2.2369362921);
options = odeset('MaxStep',0.02,'RelTol',1E-9);
[t X] = ode45(@htc1600_ode,tspan,[v0;0],options,D);
rpm = VtoRPM(X(:,1),D);
tc = max(t);  % time of accleration event
% ========== OUTPUT ===============
OUTPUT.velocity = X(:,1);
OUTPUT.acceleration = diff(X(:,1))/(t(2)-t(1));
OUTPUT.time = t;
OUTPUT.rpm = rpm;
OUTPUT.position = (mean(X(:,1))*tc);
% ================================
fprintf('(a) Time = %f seconds\n',tc);
distance = OUTPUT.position*0.00062137119224;   % distance travelled [mi]
fprintf('(b) Distance = %f miles\n',distance);
maxvel = max(OUTPUT.velocity)*2.23693629205;    % max velocity [m/s]
fprintf('(c) Max. Speed = %f mph\n',maxvel);
maxrpm = max(rpm);       % max rpm
fprintf('(d) Max. RPM = %f\n',maxrpm);
maxaccelgs = max(OUTPUT.acceleration);
gforce = maxaccelgs/9.80665;  % in g's
fprintf('(e) Max. Acceleration = %f g`s (where g = 9.81 m/s^2)\n',gforce);
figure(1),plot(t,(OUTPUT.velocity*tc)*0.00062137119224);
    figure(2),plot(t,mean(X(:,1))*t*0.00062137119224);
    title('Task 2: Distance vs. time');xlabel('time (seconds)');ylabel('Distance
(miles)');
    figure(3),plot(t,OUTPUT.velocity*2.23693629205);
    title('Task 2: Speed vs. time');xlabel('time (seconds)');ylabel('Speed (mph)');
    figure(4),plot(t,VtoRPM(OUTPUT.velocity,D));
    title('Task 2: RPM vs. time');xlabel('time (seconds)');ylabel('RPM (rad/s)');
    figure(5),plot(t,((OUTPUT.velocity*tc)*0.00062137119224)/9.81)
    title('Task 2: Acceleration vs. time');xlabel('time (seconds)');ylabel('Acceleration
in g`s (g = 9.81 m/s^2)');
% ============================ [ Task 3i ] ==============================
    case 3.1
% ========================================================================
disp(' ======================== TASK 3(i) ============================');
v0 = (0.1/2.2369362921);   % [m/s]
current_velocity = v0;  % [m/s]
tc = 0;tf = 100; % [s]
distance = 0; % [m]
for i = 1:5;
options = odeset('Events',@Event_shift,'MaxStep',0.02,'RelTol',1E-9);
D = struct('w',{2498},'A',{(19.9)*0.09290304},'r',{(11.5)*0.0254},'Rt',{[3.250 1.909
1.250 0.909
0.702]},'rho',{1.25},'Cd',{0.32},'alpha',{0.826},'Rf',{4.250},'turbo',{TBO},'gear',{i});
[t X] = ode45(@htc1600_ode,tc:0.01:tf,[current_velocity distance],options,D);
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
rpm = VtoRPM(X(:,1),D);
% ========== OUTPUT ===============
V = []; T = [];
    Vmax(i) = max(X(:,1));
    V = [V X(:,1)];
    T =[T t];
current_velocity = max(RPMtoV(rpm,D));
tc = max(t);
OUTPUT.velocity = X(:,1);
OUTPUT.acceleration = diff(X(:,1))/(t(2)-t(1));
OUTPUT.time = t;
```

```
OUTPUT.rpm = rpm;
OUTPUT.position = (mean(X(:,1))*tc);
distance(i) = (mean(X(:,1)))*(tc);
distance = mean(distance);
% ==========================================
maxrpm = max(rpm);       % max rpm
Max_ACCELERATION = max(diff(X(:,1))/(t(2)-t(1)));
gforce = Max_ACCELERATION/9.80665;  % in g's
if current_velocity >= (60/2.2369362921);
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
fprintf('(a) Time = %f seconds\n',tc);
fprintf('(b) Distance = %f miles\n',distance*0.00062137119224);
fprintf('(c) Max. Speed = %f mph\n',current_velocity*2.23693629205);
fprintf('(d) Max. RPM = %f\n',maxrpm);
fprintf('(e) Max. Acceleration = %f g`s (where g = 9.81 m/s^2)\n',gforce);
    figure(2),plot(t,mean(X(:,1))*t*0.00062137119224);
    title('Task 3(i): Distance vs. time');xlabel('time (seconds)');ylabel('Distance
(miles)');
    figure(3),plot(t,OUTPUT.velocity*2.23693629205);
    title('Task 3(i): Speed vs. time');xlabel('time (seconds)');ylabel('Speed (mph)');
    figure(4),plot(t,VtoRPM(OUTPUT.velocity,D));
    title('Task 3(i): RPM vs. time');xlabel('time (seconds)');ylabel('RPM (rad/s)');
    figure(5),plot(t,((OUTPUT.velocity*tc)*0.00062137119224)/9.81)
    title('Task 3(i): Acceleration vs. time');xlabel('time
(seconds)');ylabel('Acceleration in g`s (g = 9.81 m/s^2)');
   break
end
end
% ============================== TASK 3ii ==============================
    case 3.2
% ======================================================================
disp(' ======================== TASK 3(ii) ==========================');
v0 = (0.1/2.2369362921); % Initial velocity 0.1 [ft/s -> m/s]
current_velocity = v0;  % Current velocity [m/s]
tc = 0;tf = 30; % tspan [s]
distance = 0;
for i = 1:5;
D = struct('w',{2498},'A',{(19.9)*0.09290304},'r',{(11.5)*0.0254},...
           'Rt',{[3.250 1.909 1.250 0.909 0.702]},'rho',{1.25},...
           'Cd',{0.32},'alpha',{0.826},'Rf',{4.250},...
           'turbo',{TBO},'gear',{i});
options = odeset('Events',@Event_qrtmile,'MaxStep',0.02,'RelTol',1E-9);
[t X] = ode45(@htc1600_ode,tc:0.01:tf,[current_velocity 0],options,D);
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
rpm = VtoRPM(X(:,1),D);
% ========== OUTPUT ==============
V = []; T = [];
    Vmax(i) = max(X(:,1));
    V = [V X(:,1)];
    T =[T t];
current_velocity = max(RPMtoV(rpm,D));
tc = max(t);
OUTPUT.velocity = X(:,1);
OUTPUT.acceleration = diff(X(:,1))/(t(2)-t(1));
OUTPUT.time = t;
OUTPUT.rpm = rpm;
OUTPUT.position = (mean(X(:,1))*tc);
distance(i) = (mean(current_velocity))*tc;
maxrpm = max(rpm);
Max_ACCELERATION = max(diff(X(:,1))/(t(2)-t(1)));
gforce = Max_ACCELERATION/9.80665;  % in g's
if distance(i) >= (0.25/0.00062137119224);
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
```

```
fprintf('(a) Time = %f seconds\n',tc);
fprintf('(b) Distance = %f miles\n',distance(i(length(i)))*0.00062137119224);
fprintf('(c) Max. Speed = %f mph\n',current_velocity*2.23693629205);
fprintf('(d) Max. RPM = %f\n',maxrpm);
fprintf('(e) Max. Acceleration = %f g`s (where g = 9.81 m/s^2)\n',gforce);
    figure(2),plot(t,mean(X(:,1))*t*0.00062137119224);
    title('Task 3(ii): Distance vs. time');xlabel('time (seconds)');ylabel('Distance
(miles)');
    figure(3),plot(t,OUTPUT.velocity*2.23693629205);
    title('Task 3(ii): Speed vs. time');xlabel('time (seconds)');ylabel('Speed (mph)');
    figure(4),plot(t,VtoRPM(OUTPUT.velocity,D));
    title('Task 3(ii): RPM vs. time');xlabel('time (seconds)');ylabel('RPM (rad/s)');
    figure(5),plot(t,((OUTPUT.velocity*tc)*0.00062137119224)/9.81)
    title('Task 3(ii): Acceleration vs. time');xlabel('time
(seconds)');ylabel('Acceleration in g`s (g = 9.81 m/s^2)');
   break
end  % "if distance >= 0.25"
end  % "for i = 1:5"
% ============================== TASK 3iii ==============================
    case 3.3
disp(' ======================== TASK 3(iii) ==========================');
% ===================================================================
v0 = (0.1/2.2369362921);   % [m/s]
current_velocity = v0;  % [m/s]
tc = 0;tf = 300; % [s]
distance = 0;

for i = 1:5;
D = struct('w',{2498},'A',{(19.9)*0.09290304},'r',{(11.5)*0.0254},...
           'Rt',{[3.250 1.909 1.250 0.909 0.702]},'rho',{1.25},...
           'Cd',{0.32},'alpha',{0.826},'Rf',{4.250},...
           'turbo',{TBO},'gear',{i});
options = odeset('Events',@Event_maxvel,'MaxStep',0.02,'RelTol',1E-9);
[t X] = ode45(@htc1600_ode,tc:0.01:tf,[current_velocity 0],options,D);
current_velocity = max((X(:,1)));
rpm = VtoRPM(current_velocity,D);
% ========== OUTPUT ===============
V = []; T = [];
    Vmax(i) = max(X(:,1));
    V = [V X(:,1)];
    T =[T t];
tc = max(t);
OUTPUT.velocity = X(:,1);
OUTPUT.acceleration = diff(X(:,1))/(t(2)-t(1));
OUTPUT.time = t;
OUTPUT.rpm = rpm;
distance(i) = (mean(X(:,1)))*(tc);
maxvel = max(Vmax);    % max velocity
maxrpm = max(rpm);       % max rpm
Max_ACCELERATION = max(OUTPUT.acceleration);
gforce = Max_ACCELERATION/9.80665;  % in g's
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
fprintf('(a) Time = %f seconds\n',tc);
fprintf('(b) Distance = %f miles\n',distance(i(length(i)))*0.00062137119224);
fprintf('(c) Max. Speed = %f mph\n',maxvel*2.23693629205);
fprintf('(d) Max. RPM = %f\n',maxrpm);
fprintf('(e) Max. Acceleration = %f g`s (where g = 9.81 m/s^2)\n',gforce);

if max(X(:,1)/t) - 1.25 <= 0
    disp('REACHED')
    break
end
end
```

```
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
fprintf('(a) Time = %f seconds\n',tc);
fprintf('(b) Distance = %f miles\n',distance(i(length(i)))*0.00062137119224);
fprintf('(c) Max. Speed = %f mph\n',maxvel*2.23693629205);
fprintf('(d) Max. RPM = %f\n',maxrpm);
fprintf('(e) Max. Acceleration = %f g`s (where g = 9.81 m/s^2)\n',gforce);
    figure(2),plot(t,mean(X(:,1))*t*0.00062137119224);
    title('Task 3(iii): Distance vs. time');xlabel('time (seconds)');ylabel('Distance
(miles)');
    figure(3),plot(t,OUTPUT.velocity*2.23693629205);
    title('Task 3(iii): Speed vs. time');xlabel('time (seconds)');ylabel('Speed (mph)');
    figure(4),plot(t,VtoRPM(OUTPUT.velocity,D));
    title('Task 3(iii): RPM vs. time');xlabel('time (seconds)');ylabel('RPM (rad/s)');
figure(5),plot(t,((OUTPUT.velocity*tc)*0.00062137119224)/9.81)
title('Task 3(iii): Acceleration vs. time');xlabel('time (seconds)');ylabel('Acceleration
in g`s (g = 9.81 m/s^2)');



    case 4.1
% ============================== 4i ================================
disp(' ======================== TASK 4(i) ==========================');
% ==================================================================
v0 = (0.1/2.2369362921);   % [m/s]
current_velocity = v0;  % [m/s]
ti = 0;tf = 100; % [s]
distance = 0;
tdelay = 0;
for i = 1:5;
options = odeset('Events',@Event_shift,'MaxStep',0.02,'RelTol',1E-9);
D = struct('w',{2498},'A',{(19.9)*0.09290304},'r',{(11.5)*0.0254},...
           'Rt',{[3.250 1.909 1.250 0.909 0.702]},'rho',{1.25},...
           'Cd',{0.32},'alpha',{0.826},'Rf',{4.250},...
           'turbo',{TBO},'gear',{i});
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
[t X] = ode45(@htc1600_ode,max(tdelay):0.01:tf,[current_velocity 0],options,D);
OUTPUT.Rt = D.Rt(D.gear)*D.Rf;
rpm = VtoRPM(max(X(:,1)),D);
tc = max(t);
OUTPUT.velocity = X(:,1);
OUTPUT.acceleration = diff(X(:,1))/(t(2)-t(1));
OUTPUT.time = t;
OUTPUT.rpm = rpm;
OUTPUT.GearR = D.Rt(D.gear)*D.Rf;
current_velocity = max(X(:,1));
distance(i) = (mean(current_velocity))*tc;
maxvel = max(X(:,1));    % max velocity
maxrpm = max(rpm);       % max rpm
Max_ACCELERATION = max(diff(X(:,1))/(t(2)-t(1)));
gforce = Max_ACCELERATION/9.80665;  % in g's
if current_velocity >= (60/2.2369362921);
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
fprintf('(a) Time = %f seconds\n',tc);
fprintf('(b) Distance = %f miles\n',distance(i(length(i)))*0.00062137119224);
fprintf('(c) Max. Speed = %f mph\n',maxvel*2.23693629205);
fprintf('(d) Max. RPM = %f\n',maxrpm);
fprintf('(e) Max. Acceleration = %f g`s (where g = 9.81 m/s^2)\n',gforce);
    figure(2),plot(t,mean(X(:,1))*t*0.00062137119224);
    title('Task 4(i): Distance vs. time');xlabel('time (seconds)');ylabel('Distance
(miles)');
    figure(3),plot(t,OUTPUT.velocity*2.23693629205);
```

```
    title('Task 4(i): Speed vs. time');xlabel('time (seconds)');ylabel('Speed (mph)');
    figure(4),plot(t,VtoRPM(OUTPUT.velocity,D));
    title('Task 4(i): RPM vs. time');xlabel('time (seconds)');ylabel('RPM (rad/s)');
    figure(5),plot(t,(OUTPUT.velocity*tc*0.00062137119224)/9.81)
    title('Task 4(i): Acceleration vs. time');xlabel('time
(seconds)');ylabel('Acceleration in g`s (g = 9.81 m/s^2)');
   break
end

[tdelay X] = ode45(@htc1600_shiftdelay,tc:0.01:tc+0.4,[current_velocity 0],options,D);
end
% ============================== TASK 4ii ============================
    case 4.2
% ====================================================================
disp(' ======================= TASK 4(ii) ========================');
v0 = (0.1/2.2369362921);   % [m/s]
current_velocity = v0;  % [m/s]
tf = 100; % [s]
distance = 0;
tdelay = 0;
tc = 0;
for i = 1:5;
options = odeset('Events',@Event_qrtmile,'MaxStep',0.02,'RelTol',1E-9);
D = struct('w',{2498},'A',{(19.9)*0.09290304},'r',{(11.5)*0.0254},...
           'Rt',{[3.250 1.909 1.250 0.909 0.702]},'rho',{1.25},...
           'Cd',{0.32},'alpha',{0.826},'Rf',{4.250},...
           'turbo',{TBO},'gear',{i});
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
[t X] = ode45(@htc1600_ode,max(tdelay):0.01:tf,[current_velocity 0],options,D);
rpm = VtoRPM(max(X(:,1)),D);
tc = max(t);
OUTPUT.velocity = X(:,1);
OUTPUT.acceleration = diff(X(:,1))/(t(2)-t(1));
OUTPUT.time = t;
OUTPUT.rpm = rpm;
current_velocity = max(X(:,1));
distance(i) = (mean(current_velocity))*tc;
maxvel = max(X(:,1));     % max velocity
maxrpm = max(rpm);        % max rpm
Max_ACCELERATION = max(diff(X(:,1))/(t(2)-t(1)));
gforce = Max_ACCELERATION/9.80665;  % in g's
if distance(i) >= (0.25/0.00062137119224);
    figure(2),plot(t,mean(X(:,1))*t*0.00062137119224);
    title('Task 4(ii): Distance vs. time');xlabel('time (seconds)');ylabel('Distance
(miles)');
    figure(3),plot(t,OUTPUT.velocity*2.23693629205);
    title('Task 4(ii): Speed vs. time');xlabel('time (seconds)');ylabel('Speed (mph)');
    figure(4),plot(t,VtoRPM(OUTPUT.velocity,D));
    title('Task 4(ii): RPM vs. time');xlabel('time (seconds)');ylabel('RPM (rad/s)');
    figure(5),plot(t,(OUTPUT.velocity*tc*0.00062137119224)/9.81)
    title('Task 4(ii): Acceleration vs. time');xlabel('time
(seconds)');ylabel('Acceleration in g`s (g = 9.81 m/s^2)');
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
fprintf('(a) Time = %f seconds\n',tc);
fprintf('(b) Distance = %f miles\n',distance(i(length(i)))*0.00062137119224);
fprintf('(c) Max. Speed = %f mph\n',maxvel*2.23693629205);
fprintf('(d) Max. RPM = %f\n',maxrpm);
fprintf('(e) Max. Acceleration = %f g`s (where g = 9.81 m/s^2)\n',gforce);
   break
end
[tdelay X] = ode45(@htc1600_shiftdelay,tc:0.01:tc+0.4,[current_velocity 0],options,D);
end
% ============================== TASK 4iii ===========================
```

```
    case 4.3
disp(' ======================= TASK 4(iii) ==========================');
% ============================================================================
v0 = (0.1/2.2369362921);    % [m/s]
current_velocity = v0;  % [m/s]
tc = 0;tf = 1000; % [s]
tdelay = 0;
distance = 0;
for i = 1:5;
options = odeset('Events',@Event_maxvel,'MaxStep',0.02,'RelTol',1E-9);
D = struct('w',{2498},'A',{(19.9)*0.09290304},'r',{(11.5)*0.0254},...
           'Rt',{[3.250 1.909 1.250 0.909 0.702]},'rho',{1.25},...
           'Cd',{0.32},'alpha',{0.826},'Rf',{4.250},...
           'turbo',{TBO},'gear',{i});
[t X] = ode45(@htc1600_ode,max(tdelay):0.01:tf,[current_velocity 0],options,D);
rpm = VtoRPM(max(X(:,1)),D);
tc = max(t);
OUTPUT.velocity = X(:,1);
OUTPUT.acceleration = diff(X(:,1))/(t(2)-t(1));
OUTPUT.time = t;
OUTPUT.rpm = rpm;
current_velocity = max(X(:,1));
distance(i) = (mean(current_velocity))*tc;
maxvel = max(X(:,1));     % max velocity
maxrpm = max(rpm);        % max rpm
Max_ACCELERATION = max(diff(X(:,1))/(t(2)-t(1)));
gforce = Max_ACCELERATION/9.80665;  % in g's
fprintf('\n ------->>> GEAR NUMBER: %f\n',i);
fprintf('(a) Time = %f seconds\n',tc);
fprintf('(b) Distance = %f miles\n',distance(i(length(i)))*0.00062137119224);
fprintf('(c) Max. Speed = %f mph\n',maxvel*2.23693629205);
fprintf('(d) Max. RPM = %f\n',maxrpm);
fprintf('(e) Max. Acceleration = %f g`s (where g = 9.81 m/s^2)\n',gforce);
if max(X(:,1)/t) - 1.25 <= 0
    disp('REACHED')
    break
end
[tdelay X] = ode45(@htc1600_shiftdelay,tc:0.01:tc+0.4,[current_velocity 0],options,D);

end
    figure(2),plot(t,mean(X(:,1))*t*0.00062137119224);
    title('Task 4(iii): Distance vs. time');xlabel('time (seconds)');ylabel('Distance
(miles)');
    figure(3),plot(t,OUTPUT.velocity*2.23693629205);
    title('Task 4(iii): Speed vs. time');xlabel('time (seconds)');ylabel('Speed (mph)');
    figure(4),plot(t,VtoRPM(OUTPUT.velocity,D));
    title('Task 4(iii): RPM vs. time');xlabel('time (seconds)');ylabel('RPM (rad/s)');
    figure(5),plot(t,(OUTPUT.velocity*tc*0.00062137119224)/9.81)
    title('Task 4(iii): Acceleration vs. time');xlabel('time
(seconds)');ylabel('Acceleration in g`s (g = 9.81 m/s^2)');
end
end
```

C.2 – get_HP.m

```
%% M-file: get_HP.m
function [HP] = get_HP(rpm,D)
% ==================  Values from Honda_HP.txt ========================
% RPM values
get_HPrpm = [0,1500,2000,2500,3000,3500,4000,4500,5000,5500,6000,...
             6500,7000,7500,8000,10000];
```

```
% Horsepower 'without' turbo
HPwoT = [0,21.992,29.703,37.605,45.354,53.913,60.548,70.602,82.635,...
         93.936,103.39,111.39,115.69,115.1,107.24,28.561];
% Horsepower 'with' turbo
 HPwT = [0,20.449,30.274,42.412,58.892,85.901,118.74,167.68,234.77,...
         298.14,320.56,324.88,322.28,321.31,317.44,257.04];
switch D.turbo
    case 0 % Without turbo
        HP = spline(get_HPrpm,HPwoT,rpm);
    case 1 % With turbo
        HP = spline(get_HPrpm,HPwT,rpm);
end
end
```

C.3 – RPMtoV.m

```
%% M-file: RPMtoV.m
function [velocity] = RPMtoV(rpm,D)
R = D.Rt(D.gear)*D.Rf;
velocity = (rpm*2*pi*D.r)/(60*R);
end
```

C.4 – VtoRPM.m

```
%% M-file: VtoRPM.m
function [rpm] = VtoRPM(velocity,D)
R = D.Rt(D.gear)*D.Rf;
rpm = (60*velocity*R)/(2*pi*D.r);
end
```

C.5 – htc1600_ode.m

```
function [dv] = htc1600_ode(t,v,D)
global Honda
Honda.Velocity = v(1);                    % Store new velocity [m/s]
Honda.Position = v(2);                    % Store Position [m]
Honda.Time = t;                           % Elapsed time [s]
Honda.Mass = D.w*0.45359237;              % Mass [kg]
Honda.Ft = get_Ft(v(1),D);                % Traction force [N]
Honda.Fd = get_Fd(v(1),D);                % Drag force [N]
dv(1,1) = (Honda.Ft - Honda.Fd)./Honda.Mass;    % Newton's 2nd law of motion [m/s^2]
dv(2,1) = v(1);                                 % Speed of the car [m/s]
return
```

C.6 – Event_shift.m

```
%% M-file: Event_shift.m
function [ value, isterminal, direction ] = Event_shift(~,x,D
value = [(VtoRPM(x(1),D))-7500;max(x(1))-(60/2.2369362921)];
isterminal =  [1;1];
direction = [1;1];
```

C.7 – Event_qrtmile.m

```
%% M-file: Event_qrtmile.m
% optimset - event function for (a) 7500 rpm and (b) 60 mph
function [value,isterminal,direction] = Event_qrtmile(t,x,D)
```

```
value = [(VtoRPM(x(1),D))-7500;(mean(x(1))*max(t))-(0.25/0.00062137119224)];
isterminal = [1;1];
direction = [1;1]
```

C.8 – Event_maxvel.m

```
%% M-file: Event_maxvel.m
%   (i) 'Events' function to shift gears @ 7500 RPM
function [value,isterminal,direction] = Event_maxvel(t,x,D)
a = x(1)/t;
value = [(VtoRPM(x(1),D))-7500;a-1.25];
isterminal = [1;1];
direction = [1;-1];
end
```