Michigan Tech
MEEM/EE 4295: Introduction to Propulsion Systems for Hybrid Electric Drive Vehicles

HW_2
Topics: Power Requirement, Introduction to Matlab and Model Based Design (Simulink)

Modeling and Matlab Exercise

Using the Matlab code from HW-1 as a starting point, add the following.

Part I: Matlab

1) Using the Matlab code from HW-1
   a) Put the time, velocity and road slope (seconds, MPH, degrees) in arrays. They will appear in the Workspace once you execute the .m file
   b) List the variables needed, writes to the Workspace.
   c) Enter the conversion factors you need.
   d) Add the Simulink "Callbacks" to execute the Matlab file that loads the initial values into the workspace.

Part II: Introduction to Simulink

Implement the same vehicle model from above using Simulink. The acceleration tables (arrays) from Part I may be used in Part II. This should save significant time in entering the data. If the model in Part I has been validated, it can be used to compare the results in Part II, but not the only validation.

1) Using the Simulink code, MTU_Basic_Drive_Cycle_1.mdl[1] shown in class, develop a Simulink model to the tractive force (think "required torque) for the drive cycle. Remember we have rolling resistance, wind drag and road slope.

2) Use your Simulink model to:
   a) Determine the tractive force needed to maintain the given speed.
   b) Determine the power needed as a function of time.
   c) Determine the power lost from aerodynamic drag.
   d) Determine the increase/decrease in F_t for the change in slope
3) Plot the results for tractive forces versus time.

[1] The Simulink model is posted on the web, you may "cut and paste" or use any portion you want.

4) Plot the power gained during regeneration.
5) If the power gained during regeneration was lost to heat, put the heat loss in terms of something a potential customer would grasp[2].

Code/Solution Validation

In homework 1, we asked for various plots of force and power given a specific drive cycle. Since the answers were not in the back of the book, you needed a method to validate your code or at least determine if the solution is reasonable. Using what we know about energy expended for portions of a drive cycle, determine if your CALCULATED external forces acting on the vehicle are reasonable. Do this for rolling resistance, wind drag, tractive force and losses due to slope.

Also check the power required for at least one of the above forces.

The information below is repeated from HW-1.

Figure 1 shown below is the velocity versus time of our drive cycle. The cycle is as follows

1) WOT from 0-60
2) Steady state at 60
3) Apply brakes and decelerate to 40 (now behind a slow driver)
4) Steady state at 40
5) WOT from 40-70 to pass
6) Steady state at 70 to complete the pass
7) Decelerate to 55
8) Steady state at 55
9) Maintain 55 while going uphill, the elevation curve (road slope) is shown in Figure 2.

    i) As we crest the hill, we maintain 55 to the bottom of the hill

    ii) Steady state at 55 to almost the end of the drive cycle, apply the brakes and stop the vehicle.

The drive cycle is being used to demonstrate basic math modeling methods and how to formulate those in Matlab. It is NOT representative of “reasonable” driving.

[2] The amount to toast bread, dry hair, etc.

During deceleration, we may recover 80% of the energy normally lost due to braking.

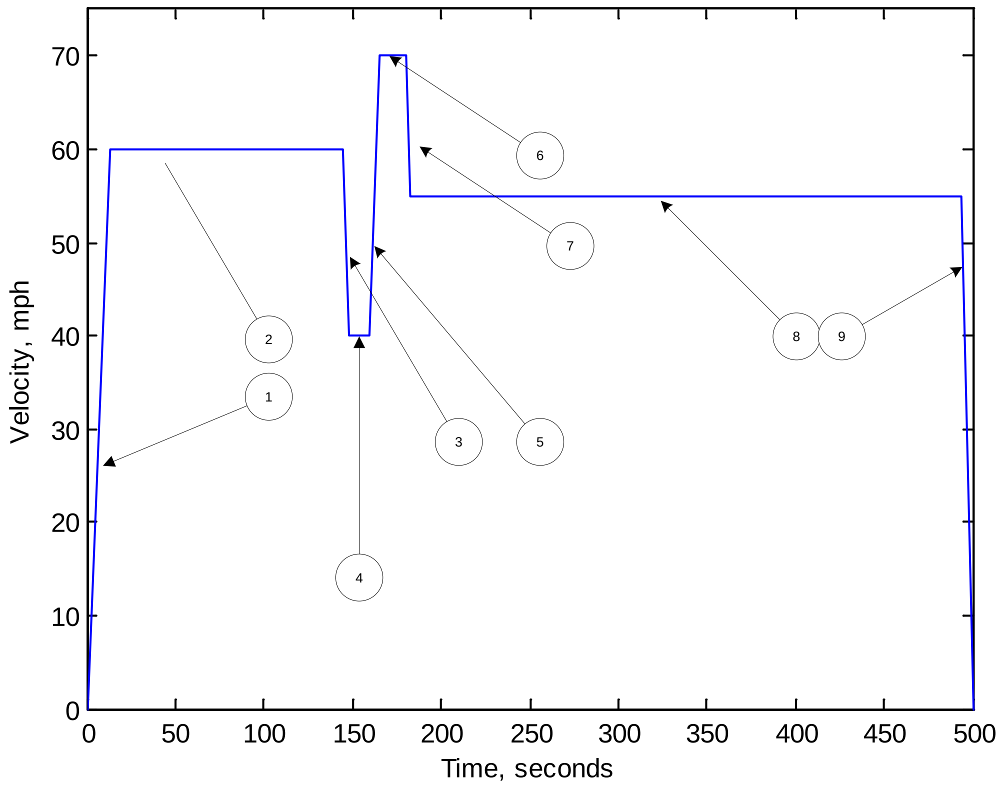

Figure 1: Vehicle velocity versus time for the drive cycle

Figure 2 shown below is the grade of road over our drive cycle. You may notice we are driving on level ground most of the time. At a time of 300 seconds, we start up an incline of 4.0 degrees. Once we reach the top of the hill the slope is now a -4.5 degrees. We maintain the 55 mph speed down the hill and by good use of our brakes and our magic regeneration system. Once we meet the bottom of the hill we maintain a constant speed for the remainder of the drive cycle until braking at the end. The entire drive cycle has taken 500 seconds.

For the given system we first model the vehicle. Figure 3 is our standard 2-D car model[3]. The forces acting on the vehicle are summed in the X-direction, our direction of motion. For most of the cycle the direction of travel is horizontal.

[3] Fundamentals of Vehicle Dynamics, T. D. Gillespie, SAE Publication, 1992.

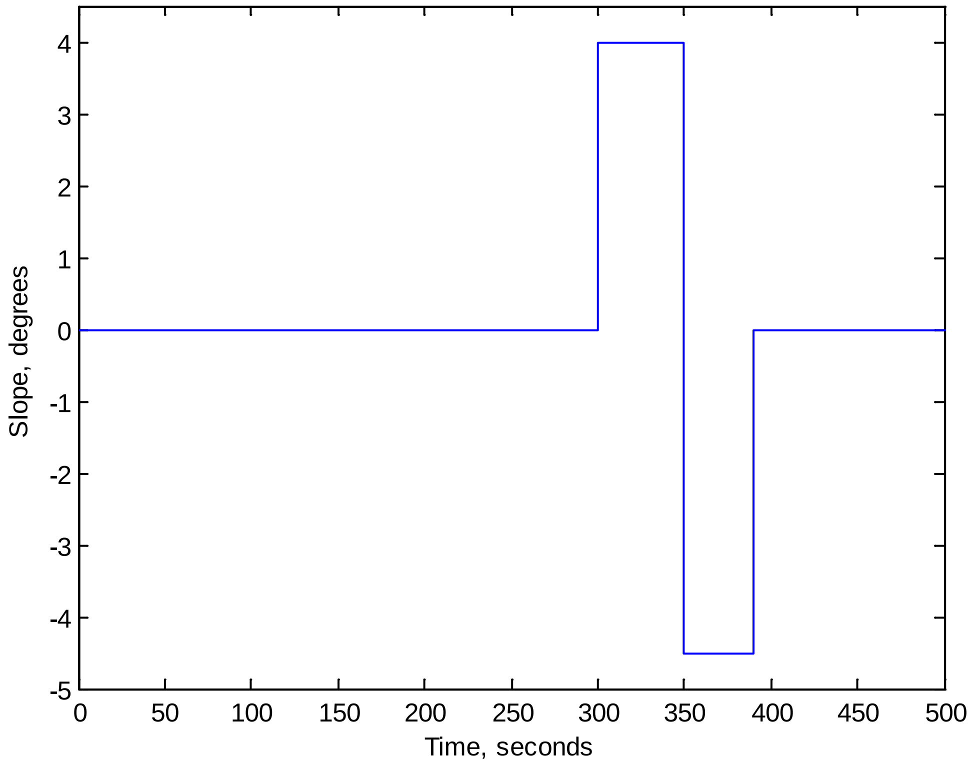

Figure 2: Road slope for the drive cycle.

For this problem include rolling resistance and wind drag, but neglect other power losses. The C_d for this model is 0.40. You may assume a constant temperature of 72^o F.

Time	Velocity, mph	Slope, degrees
0	0	0
13.0	60	0
145.0	60	0
148.0	40	0
160.0	40	0
165.5	70	0
180.0	70	0
183.0	55	0
300.0	55	Starts up the hill, slope of 4 degrees
350.0	55	Apex or top of hill, starts down
390.0	55	Bottom of hill, slope returns to zero
493.6	55	0, Start to brake
500.0	0.0	0, vehicle at rest

Table 1: Data use to generate Figure 1.

We are working this problem in SAE units, you may convert them if you choose.

Table 2:

Item	Value	Units
Weight	4,100	Lbf
ρ	0.00236	Lbf-sec^2/Ft^4
g	32.17	Ft/sec^2
C_d	0.4	Unit less
A	2.7	meters^2
θ	Given in table and figures	degrees

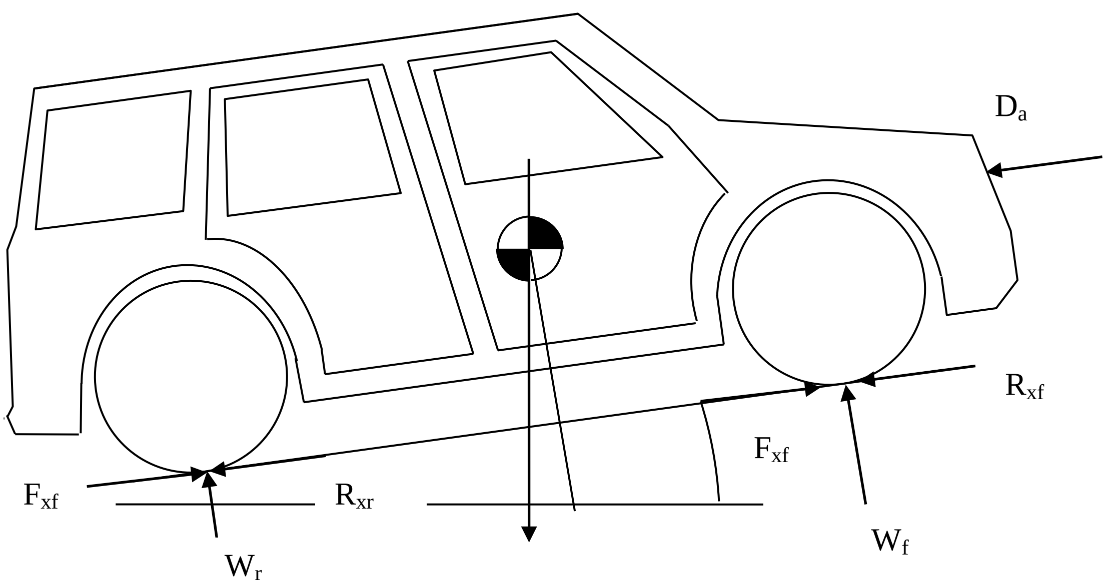

Figure 3: Basic model of the vehicle and the external forces.

Symbol	**Definition**	**Units**
$\mathbf{W_f}$	**Front wheel load**	
$\mathbf{W_r}$	**real wheel load**	
ha	**distance to location of drag forces**	
h	**distance to cg**	
L	**wheelbase**	
b	**distance to front wheels from cg**	
c	**distance to rear wheels from cg**	
$\mathbf{R_{xf}}$	**rolling resistance, front wheels**	

$\mathbf{R_{xr}}$	**rolling resistance, rear wheels**	
$\mathbf{F_{xf}}$	**tactive force, front wheels**	
$\mathbf{F_{xr}}$	**tractive force, rear wheels**	
θ	**Road slope**	

When we sum the forces in the X-direction we get the following equation.

$$\sum F_X = m\ddot{x} = F_t - R_f - D_a - mg\sin(\theta)$$

Rolling resistance may be approximated as follows if we use a function that approximates the friction losses as a linear function of speed. It is commonly written as:

$$R_f = f \cdot W\left(1 + \frac{V}{100}\right)$$

f=0.01 and W is the weight in Lbf, V is in mph. Since all of the calculations are in Ft and Lbf., convert the equation to the form

$$R_f = f \cdot W\left(1 + \frac{\dot{X}}{K_{fv}}\right)$$ and determine the appropriate value of K_{fv} for the velocity in Ft/sec. The variable K_{fv} is the conversion to allow you to use Ft/sec.

Wind drag may be approximated by the following.

$$D_a = \frac{1}{2}\rho C_d A\dot{X}^2$$

The variables are
ρ=density of air, Lbf-sec^2/Ft^3 or kg/meter^3
C_d=drag coefficient, unit less
A=cross-sectional area, meter squared or feet squared

Now we have a fairly complete model of the external force acting on the vehicle and we can approximate the tractive forces needed to meet the drive cycle. When we sum the forces in the X-direction we derived the following equation in class.

$$\sum F_X = m\ddot{x} = F_t - R_f - D_a - mg\sin(\theta)$$