

Homework Assignment 2
Modeling a Complete Drivetrain in Matlab
Due: Friday, September 7, 2007 on the hour before class

Description and Outcomes

In this assignment, you will create a first model for a complete drivetrain. The model combines an engine model with models for a transmission, a differential and the wheels. We will use this model to determine the velocities at which the driver should switch gears to maximize the power output of a car. In addition to learning about drivetrains, you will refresh your Matlab knowledge about functions and control structures.

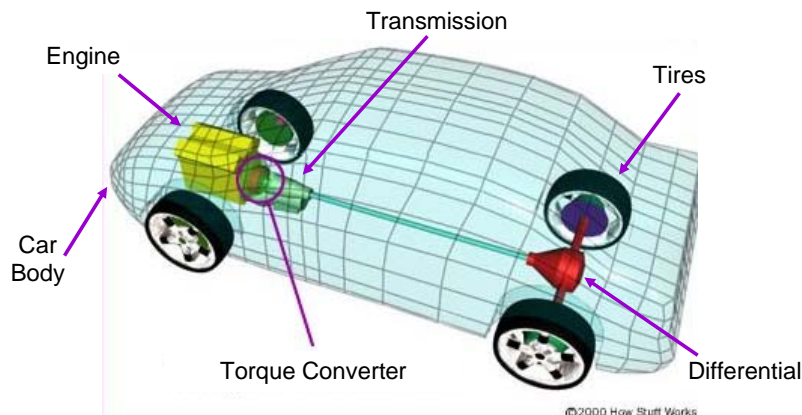
The learning objectives of this assignment are:

- to learn how to formulate, solve, and interpret an engineering problem
- to continue developing as an independent learner of Matlab features
- to learn the basics of Matlab variables functions and control structures
- to learn how to use Matlab to solve engineering problems

Background

In this homework assignment, we focus on the drivetrain of a car, specifically the drivetrain of a Ford Taurus V6 3L sedan. The goal of the assignment is to generate a plot that allows us to determine at which velocities to shift gears such that the maximum power of the engine is used.

The drivetrain consists of the engine, torque converter, transmission, differential, and wheels. Several of these components are pretty complex devices and modeling them accurately is a challenging problem. However, a simple model will be sufficient for the approximate simulations we perform in this class. Next, we discuss each drivetrain component in more detail.



Engine: The engine is modeled as a mapping from engine speed to engine torque. Typically there is a separate curve for each position of the accelerator, but since we are interested in taking advantage of the maximum power of the engine, we will simply assume that the engine runs at full throttle, i.e., we “floor it.” The speed-torque characteristic can be approximated by a sixth-order polynomial:

$$\tau = a_0 + a_1\omega + a_2\omega^2 + a_3\omega^3 + a_4\omega^4 + a_5\omega^5 + a_6\omega^6$$

where τ is the engine torque in [Nm], and ω is the engine speed in [rad/s]. The coefficients are:

$$\begin{aligned}
a_0 &= 170 \\
a_1 &= 0.76 \\
a_2 &= -5.5 \times 10^{-3} \\
a_3 &= 2.9 \times 10^{-5} \\
a_4 &= -8.3 \times 10^{-8} \\
a_5 &= 1.16 \times 10^{-10} \\
a_6 &= -6.4 \times 10^{-14}
\end{aligned}$$

Note: the polynomial relationship is only valid for engine speed between 500 and 6500RPM. Below 500RPM, the engine would stall, and above 6500RPM the engine would experience excessive wear and tear (it is electronically protected not to go above this red-line speed).

Torque Converter: In this assignment, we assume that the car is cruising at constant velocity – it is in steady-state. That means that the torque converter really serves no purpose and can be omitted from the drivetrain model.

Transmission: The model of the transmission is a lossless speed reduction with a ratio of $n:1$. The gear ratio, n , can take on 4 different values corresponding to 1st through 4th gear. (We are not modeling the reverse.) An ideal gear reduction is modeled by the following two equations for the rotation speed and torque:

$$\begin{cases} \omega_{out} = \omega_{in} / n \\ \tau_{out} = n\tau_{in} \end{cases}$$

where the subscript *in* refers to the torques and velocities for the shaft closest to the engine, and n is the gear ratio. For a Ford Taurus, the gear ratios are:

gear ratio 1 st gear:	2.77
gear ratio 2 nd gear:	1.54
gear ratio 3 rd gear:	1.00
gear ratio 4 th gear:	0.69

Differential: Since we assume that the car is driving in a straight line, we can model the differential using the exact same equations — it simply serves as another gear reduction with a gear ratio of 4.266 to 1.

Wheels: The wheels are modeled as a rigid cylinder rolling without slip over a flat road surface (notice the similarity with the equations for the transmission above):

$$\begin{cases} v_{car} = R\omega_{wheel} \\ F_{car} = \tau_{wheel} / R \end{cases}$$

where R is the radius of the wheel. The wheels of a Ford Taurus have a standard rim diameter of 16 inches with a 215/60 tire resulting in a wheel radius of 0.332m.

Based on these models, one can compute the power generated by the engine at different speeds in each of the gears. Since this is only the second homework assignment, we will still provide you with significant “scaffolding.” That is, we will lead you through the problem step by step and even show you what the end-result of your code should look like. In each of the future assignments, some of the scaffolding will be removed until you can solve the entire assignment by yourself. For instance, in this assignment we will no longer specify that you need to include a header in each of your m-files; you learned that in the previous assignment and are expected to carry that over in all future assignments (and beyond – even when you write programs for your coop or full-time job later, you should always include a header).

Tasks

Task 1: Create the function engine_model_XYZ (where XYZ are your initials)

The function engine_model_XYZ implements the sixth order polynomial model on the previous page. The function should have one input: a vector of engine speeds in [rad/s]. As an output, the function should return a vector of corresponding torques in [Nm], with the same size as the input. The function should verify that all the inputs are within the range over which the polynomial approximation is valid. If any of the input values are outside the range, a warning message should be generated.

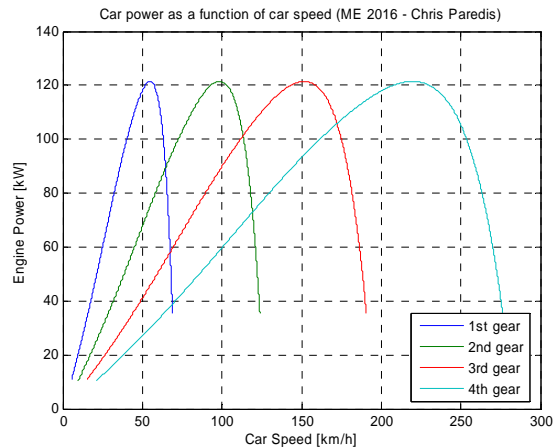
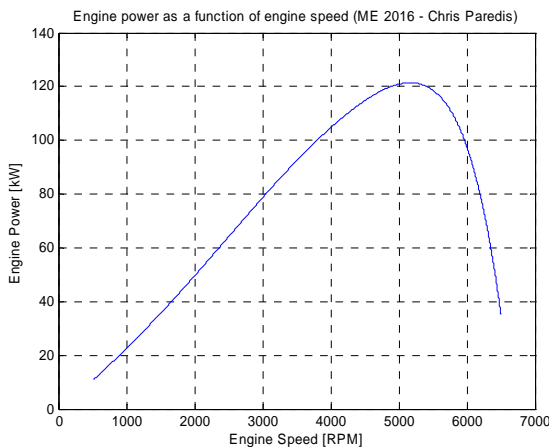
Task 2: Create the script plot_power_curves_XYZ (where XYZ are your initials)

This script should create two graphs as shown below. In a first graph, plot the engine characteristic, that is, engine power in [kW] as a function of engine speed in [RPM]. The second graph should plot a power curve for each of the 4 gear ratios listed above. These power curves should express the power as a function of the car velocity in [km/h].

Task 3: Interpretation of the plots

Once you have successfully completed Tasks 1 and 2, you need to use the resulting graphs to answer the following questions:

- Question 1:* At which engine speed does the engine produce the maximum power?
- Question 2:* When driving at 50 km/h in which gear does the engine produce the most power? Approximately how much power is that? Under which circumstances would you consider driving at 50 km/h using this gear? (Note: convert 50km/h to mph if you don't have a good sense for how fast 50 km/h is).
- Question 3:* If one would like to accelerate as quickly as possible by "flooring it," at which velocities should one shift gears? Explain. (Note we are assuming that the tires will not slip).
- Question 4:* When accelerating from 0 to 150 km/h in the fashion considered in question 3, what is the highest engine speed (in RPM) that you will reach? At which car velocity will you reach this maximum engine speed?



Report

Turn in a brief report in MS Word containing the following:

1. Your answers to all the questions.
2. A copy of all your Matlab code
3. A copy of all your figures (use the 'Edit / Copy Figure' in the figure window, and paste into your Word document).
4. A statement of collaboration (see below) – include this even if you did not collaborate with anybody

Evaluation Criteria

A detailed grade sheet for this assignment is provided as a separate file on the course web-site. Print out this sheet, fill in your name, and staple it to the front of your submission.

Submission

1. **Hardcopy in class:** At the *beginning* of class, hand in a hardcopy that includes the grade sheet and your report. Make sure you staple everything together so that we don't lose anything. (no staple = incorrect submission)
2. **T-square:** save all your files in a zip-file called HW2.FamilyName.FirstName.zip (replace FamilyName and FirstName with YOUR names) and submit this file in the Assignments section of T-square. The zip-file should contain: your Matlab function and script, and your report. The deadline for electronic submission is *on the hour before the beginning of class*. (For instance, if your class starts at 2:05PM, then the assignment is due at 2:00PM).

NOTE: it is best to use the "Save Draft" feature on t-square. This will allow you to resubmit as many times as you want anytime before the deadline. At the deadline, t-square will automatically submit the current draft — no action is required on your behalf.

Late Submission

Remember that the deadline for this assignment will be strictly enforced. After the deadline has passed you will receive a late-penalty. Don't wait until the last minute to get started! We repeat here the policy that is included in the syllabus:

Late Submission

T-square will be set up such that late submissions cannot be submitted electronically. We will accept late homework but with the following penalties. Submit by noon Saturday and receive 20% off of your grade. Submit by noon Sunday and receive 40% off. After noon on Sunday, no more partial credit will be awarded. If you are submitting late, e-mail the electronic version and bring a hardcopy to the office of your instructor (Section A: E-Jiang.Ding@ipst.gatech.edu, IPST 378; Sections C&D: chris.paredis@gatech.edu, MARC 256). If you plan on submitting late, a quick e-mail by the deadline would be appreciated so that we can make appropriate plans for grading your assignment.

Collaboration

We would like to re-emphasize the policy on collaboration. Collaboration is encouraged. Discussing the assignments with your peers will help you to develop a deeper understanding of the material. However, "discussing the assignment" does not mean solving it together; it does not mean asking your friend to debug your code for you. I encourage you to discuss how to approach the problem, which Matlab functions to use, or how to interpret the results, but I do expect each student to turn in a report and Matlab functions that reflect the student's individual work. Do not copy code from another student. Do not copy parts of other electronic documents. In general, an activity is acceptable if it promotes learning by you and your peers. For example, you learn from discussing alternate solution approaches with your friend, but you don't learn from blindly copying your friend's code. To avoid any confusion, each homework solution should explicitly identify the students with whom you collaborated and what the extent of the collaboration was. Any copying on homework and/or exams will be dealt with severely and reported to the Dean of Students – No exceptions. If you have questions about this collaboration policy, do not hesitate to ask your instructor.