Gearhead Moments of Zen: Using Real-World Examples Of Supercar Design to Teach Introductory Design and Manufacturing

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Abstract

This paper gives three case-study examples of design lessons in the introductory Mechanical Engineering Design and Manufacturing class. These brief lessons, named "Gearhead Moments of Zen", relate the lecture concepts to the design of supercars through simple calculations and analysis. The "Moments of Zen" provide a break from the normal lecture format of the class, show how first-order calculations can elucidate important information about design specifications, and allow the students to relate to the lecture material in a different way. This paper covers examples of three engineering concepts and the associated Moments of Zen: torque, power, and couplings. Evaluations of learning outcomes are ongoing and initial review based on course reviews indicates success.

Introduction

Teaching an introductory class is a complicated balance between giving students fundamental and basic concepts, while still motivating the concepts with applications that are realistic and approachable. There has been a recent trend to improve introductory mechanical engineering classes to show students immediately the applications of the knowledge they are acquiring in the classes early in their department [1] [2]. Such identity with the material has been shown to increase persistence in engineering [3] [4].

This paper illustrates a thematic method of examples threaded throughout a semester-long class at the Massachusetts Institute of Technology that tie together introductory concepts that the students are leaning and real-world examples from the automotive industry. These examples, which often include video, sound or music, pictures, and real-world specifications, break up the normal lecture-format class and show immediate applications for the concepts covered in class. The examples are called "Gearhead Moments of Zen" and this paper will present the material for Torque, Power, and Couplings/Fasteners. These Moments of Zen are a new addition to the class and initial evaluation was based on number of times students unpromptedly mentioned them in course evaluations at the end of the semester.

Background

The introductory design and manufacturing class taught in Mechanical Engineering at MIT has been a project-based class for more than 40 years, however, there is always a goal to improve the connection between lecture material and the lab assignments and to better show the applications of the information communicated in lecture. Two years ago, the course instructors began an over-arching theme for lecture examples based on the auto industry.

The automotive industry was chosen for these lecture examples for a variety of reasons. All of the students have seen a car, nearly all of the students have ridden in a car, and many have driven a car. This experience gives all the students a level of familiarity with the examples.

Additionally, some students are intimidated by the association that all mechanical engineers like cars because the students might not know much about cars. By using cars in the examples, we give all the students more background and also show how they can analyze problems, even ones they aren't familiar with, using the basic engineering techniques covered in the class. Also, car performance is well-described and much information is publicly accessible. This decreases the burden on the course staff when creating more examples because it is easy to find statistics and data on various cars and their performance, as well as videos to illustrate interesting behavior (such as burnouts, pit stops, and drag races) on websites such as Wikipedia and Youtube.

In order to create a break in the traditional lecture format and make a sense of anticipation during the lecture, the automotive examples were named "Gearhead Moments of Zen", with accompanying fun graphics and text. They usually occur halfway or later through the lecture, and are a distinctive style from other examples given in class, often accompanied by videos.

The following sections illustrate three Gearhead Moments of Zen examples for torque, power, and couplings.

Gearhead Moments of Zen: Torque

One of the first Gearhead Moment of Zens that the students encounter is an example to illustrate torque. This example is presented early in the semester, where most of the torque concepts and problems are abstract balancing and beam-bending examples and do not show much association to more complex mechanical engineering systems. Two videos are shown, illustrating a 0-100 mph speed test for both a turbo-charged sports car (in this case, a Porsche 911), and a Top Fuel dragster. The students are asked, "Why do these two cars behave differently? What are the different design considerations for each of these cars?" After some initial class discussion, the specifications of both cars are presented (Figure 1). The lecturer leads the students towards a discussion around the different shapes of the vehicles. Soon the students discover the problem of tipping over backwards if there is too much power driving the rear wheels. So, how is the top fuel dragster stable? A simple force balance shows the students the point of the long nose of the dragster is to stabilize it as it applies its large torque to the wheels and accelerates. Torque, which had previously been applied to only abstract and obscure systems now answers a specific and visible question in the students' minds.

Comparison

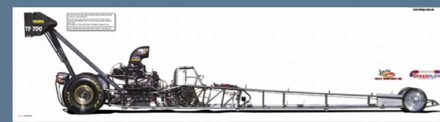
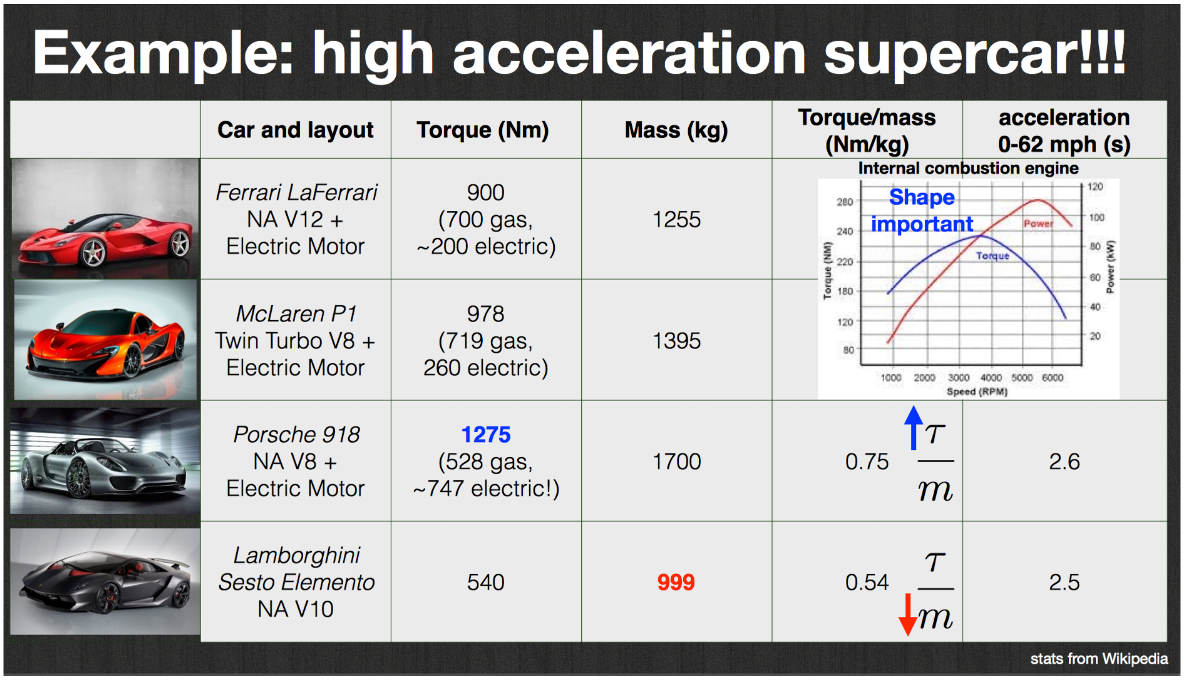
	 Porsche 911 Turbo S	 Top Fuel Dragster
Power	560 hp	8,500-10,000 hp
Weight	3516 lbs	2320 lbs (min)
0-100 mph	6.8 s	0.8 s

Figure 1: Comparison of power, weight, and 1-100mph speed for a Porsche 911 Turbo S and a Top Fuel Dragster, all parameters via Wikipedia

Gearhead Moments of Zen: Power

The next example of a Gearhead Moment of Zen looks into the power specifications of cars focused on high-end supercars. After a discussion of torque-speed curves, students are asked how such information can be used by a car designer to maximize the car's acceleration in a speed test. Several videos are shown of supercars doing acceleration tests (with the volume included for added effect). Then the students are asked to predict what the changes in performance would be for a hybrid gas-electric supercar. After some class discussion, the lecturer slowly reveals the specifications for hybrid cars (Figure 2). The students review both torque-speed curves and Newton's second law of motion, F=ma. Assuming all the tires are approximately the same diameter, acceleration scales as the torque divided by the mass. Therefore, to maximize acceleration, a car designer either needs to increase torque or decrease mass. Different brands have taken different design tactics, focusing either on mass or acceleration, but their results are the same: increased acceleration.



Example: high acceleration supercar!!!

	Car and layout	Torque (Nm)	Mass (kg)	Torque/mass (Nm/kg)	acceleration 0-62 mph (s)
	Ferrari LaFerrari NA V12 + Electric Motor	900 (700 gas, ~200 electric)	1255		
	McLaren P1 Twin Turbo V8 + Electric Motor	978 (719 gas, 260 electric)	1395		
	Porsche 918 NA V8 + Electric Motor	**1275** (528 gas, ~747 electric!)	1700	0.75 $\frac{\tau}{m}$	2.6
	Lamborghini Sesto Elemento NA V10	540	**999**	0.54 $\frac{\tau}{m}$	2.5

Figure 2: Comparison of acceleration for hybrid supercars, all parameters via Wikipedia

Gearhead Moments of Zen: Couplings

The final example of a Gearhead Moment of Zen is from the midpoint of the introductory design and manufacturing class. By this time in the semester, the students are learning about more focused engineering topics and have moved away from general physics-based problems. During the lecture on couplings and constraints, students are introduced to the idea of perfectly constrained shafts and learn how to avoid overconstrained systems. Once again, the automotive industry provides excellent examples of constraint in their products. The discussion begins with the crankshaft in an engine. Where are the constraints? How are the engines produced so that the shaft isn't overconstrained? Then the real fun begins by showing the students videos of dune buggies driving over extremely rough terrain. The student discussion focuses on how are the dune buggies able to have such large range of motion in their suspensions without the shafts binding up. Once again, simple calculations based on the mass of the dune buggy and the shape of the suspension joint (Figure 3) illustrate for the students the importance of using the correct couplings and constraining the correct number of degrees of freedom.

Figure 3: Examples of well-supported shafts with various forms of constraint and coupling. Video of off-road vehicle is available at [5].

Discussion and Conclusions

The Gearhead Moments of Zen have been an extremely useful tool in tying together various examples throughout the semester of MIT Mechanical Engineering's introductory Design and Manufacturing class. They provide a break from the usual lecture format, show real-world applications of the topics covered in lecture, and reinforce the theory presented in class. The Gearhead Moments of Zen were the most-mentioned lecture example in course evaluations in 2014. Based on this information, further work is ongoing to quantify the student learning outcomes based on the inclusion of Gearhead Moments of Zen, which are now included in approximately 30% of lectures. The authors hope that these examples inspire other lecturers to use similar material in their lectures or seek out fun and approachable examples for their own classes. Providing visualizations and examples on a variety of topics will help solidify students' knowledge and hopefully lead to increased understanding in subsequent classes that build upon these introductory topics.

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