Use of Automotive Related Examples in Teaching Undergraduate Engineering Curriculum

David Che

Department of Engineering and Computer Science

Geneva College, Beaver Falls, PA 15010

Email: dcche@geneva.edu

Abstract

Engineering students in general are interested in and familiar with cars. The mere fact that these students end up in the mechanical engineering program indicated that they had interests in building things like machinery, and one of the most commonly used machinery is certainly automobiles. There are literatures demonstrating the effectiveness of using automotive related examples in stimulating student interests in engineering courses[1]. In this paper, several automotive related examples are shared in the context of teaching engineering statics, dynamics, and mechanical component design courses of an undergraduate curriculum.

One example involves a hands-on lab on steering system analysis and verification of the Ackermann angle. Another example discusses vehicle cornering and braking analysis that can be used in teaching dry friction in engineering statics. The third example is the use of automotive hang-on panels in teaching a center of gravity lab in statics and spring design in mechanical component design course.

From students' feedback, it clearly shows the enthusiasm they had towards these topics.

Keywords: engineering education, automotive examples, experiential learning

The Steering Lab

Every family has at least 1-2 vehicles and somehow somewhere the students were already exposed to the maintenance and inner workings of at least some parts of the vehicle. So using automobiles as examples is a great way to connect with them and stoke their interests in learning more theory. The textbook we used in mechanical component design[2] actually was heavily littered with automotive examples. Even if one has no automotive work experience, today with the internet sites like Wikipedia.org, HowStuffWorks.com, You-tube, etc. it is very easy to figure out how different car components or systems work.

Having worked in the automotive industry for many years, the author delivered a lecture on automotive steering system in the mechanical component design course and also the deformable body mechanics course. The lecture used a mixture of computer animation and engineering theory to introduce students to the fundamentals of vehicle steering, especially the Ackermann angle geometry. For homework assignment, students were asked to study their own cars or trucks and identify the steering components and explain how they work together. If they don’t have a car on campus, they are encouraged to look at their friend’s car or truck. They needed to measure the steering wheel angle and the angles turned at the tires/wheels to determine steering ratio and verify the Ackermann geometry as discussed in class (see Figure 1). They were required to take pictures of these steering components and identify what types of steering components and systems they are (see Figure 2 for example). The main text of reference for the theory part was J. Y. Wong’s Theory of Ground Vehicles[3].

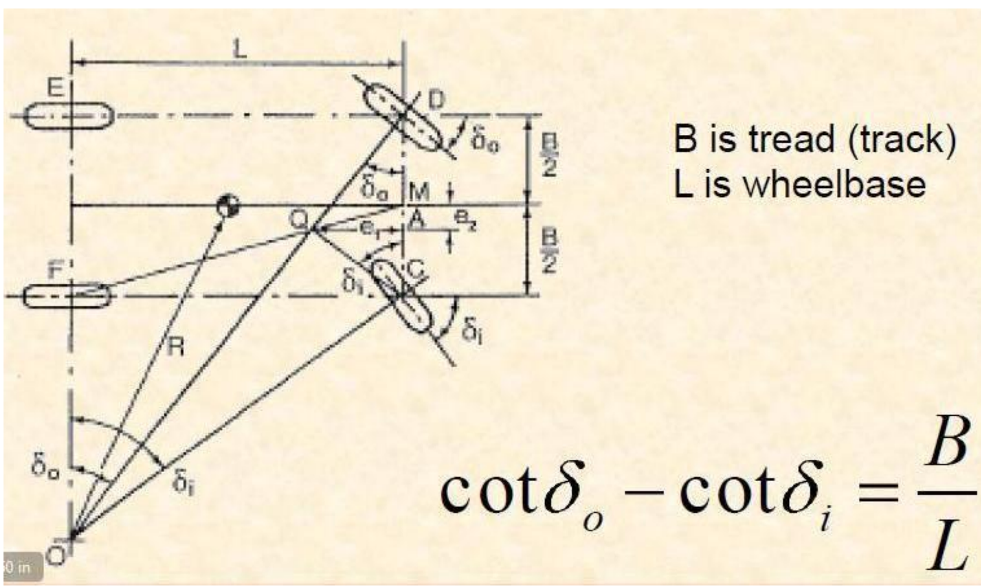

Figure 1 Steering Geometry and Ackermann Angle[3]

where δ_o is the angle of the exterior wheel, δ_i is the angle of the interior wheel, B is the tread or track, and L is the wheel base.

$$steering\ ratio = \frac{steering\ wheel\ turns\ (\text{deg})}{front\ wheel\ deflection\ (\text{deg})}$$

After the students are done with the project, what they found was kind of surprise to them. The measurements of the steering systems did not always match the equation of Ackermann's geometry from theory. This would be the perfect occasion for the instructor to introduce them to the concept of deformable body mechanics - cars and trucks on the road today rarely use pure Ackermann linkages because there are a lot of compliance in the vehicle due to the deformable nature of the mechanical components used in today's vehicle. Thus it would not be wise to design or model today's vehicle using rigid body assumptions.

Several advantages of this lab are:

1. It is relatively easy to do. No extensive equipment is needed. All you need are a ruler, a protractor and a measuring tape. Some students devised clever ways of measuring the steering angle – they first lay a piece of very smooth cardboard on the road, then park the front wheels on the cardboard. At the turning of the steering wheel they can easily measure the angle of turn at the wheel/tire by marking on the cardboard.
2. It is relatively fun to do. Instead of staying in a lab, they now need to go outside and work by the street or on a driveway. They get to interact with a real car. They need to get their hands dirty. And it takes some thinking to figure out a convenient way to measure the parameters. They will need to climb under the car to study the mechanical components on a steering linkage. This really helps drive home the theoretical things discussed in class.
3. The results will vary. And there are plenty of things to discuss based on these various results.

Some safety warnings are needed though. Make sure they park the vehicle on a leveled ground, and in case it is by the street, they need to watch for traffic or make sure their body are protected in and out of the underside of the car or truck.

Here are some sample comments from the students at the end of the semester,

> *"Even though it was really cold out, the steering components of cars lab was one of my favorite. I was raised working on dirt bikes and have a decent knowledge of engines and such, but I didn't know too much about how cars steer. It was great to explore the different concepts to steer a car and why they are used. I did not know that Ackerman's equation existed; it completely makes sense now how a car must use a parallelogram shape to make the inside wheels turn sharper than the outer wheels to keep friction down."*

Another student wrote,

> *"Over the past semester I feel that I have learned a fair amount of information that is vital for my future as an engineer. Some things that really intrigued me were the lectures and the lab done with steering. I really enjoy cars and things that move. I also love hands on material, so the car lab was fun for me …"*

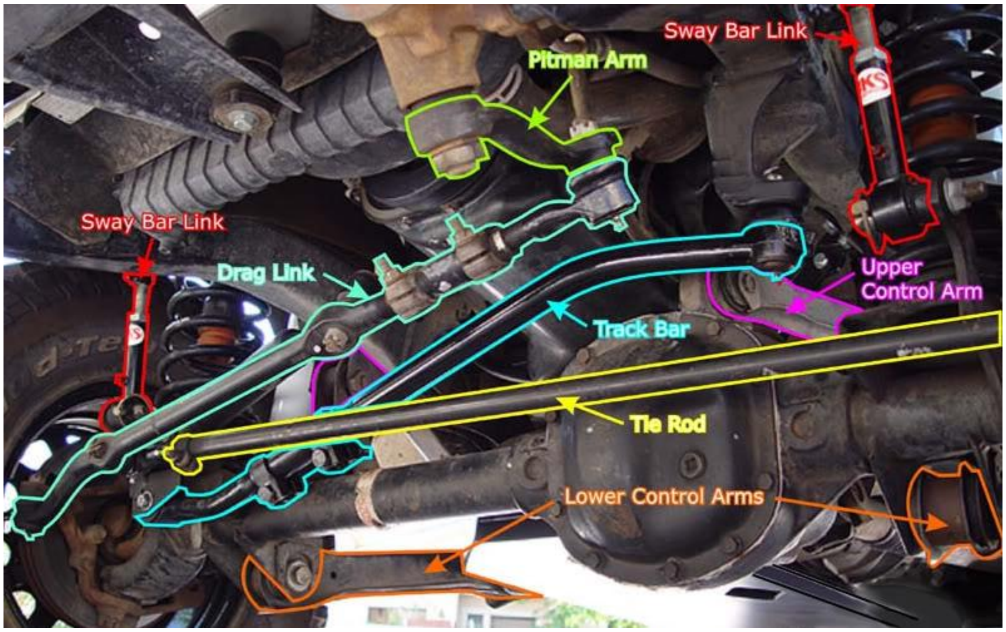

Figure 2 Identification of Steering System Components on a 1997 Jeep Wrangler Sahara[4]

Still another said,

> *"The section we did on the steering systems of vehicles was really interesting to me too, because first of all I love cars, and secondly I had no idea that the two front wheels turned different amounts because of the trapezoidal linkage, but now that I know that it makes a lot of sense. I also enjoyed the lab that we had to take pictures of the steering system on our cars because it made me more aware of what is actually going on in my car and how it works."*

Why It Is Not a Good Idea Hard Braking while Turning

One of the tips of driving I learned from a former engineering colleague was, try to avoid hard braking while turning around a corner. I never fully thought about the "why", until I started teaching statics. While teaching the friction section, it dawned on me that cornering puts a lot of lateral force on the tire. The amount of lateral force available to the vehicle depends on two things: (1) the weight of the vehicle, serving as the normal force N, and (2) the static frictional coefficient μ_s of the interfacing two surfaces. This relationship is well known:

$$\mathbf{F} \leq \mu_s \mathbf{N}$$

If driving force and braking force both present, they take away the amount of friction available to cornering (lateral force), since the maximum frictional force is like the radius of the half circle – it is fixed. So accelerating or braking during cornering is not a good idea, and could lead to slipping or squealing of the wheels. Discussion of these topics fascinates students, as this is something they probably never thought about, nevertheless highly relevant to the topic of friction analysis. If time allows, at the discretion of the instructor, the topic of slip angle in vehicle dynamics can also be brought to the students.

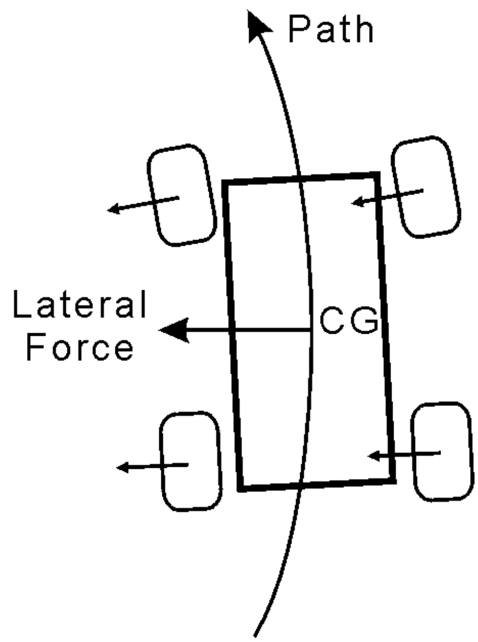

Figure 3 Lateral force needed to turn a corner[5]

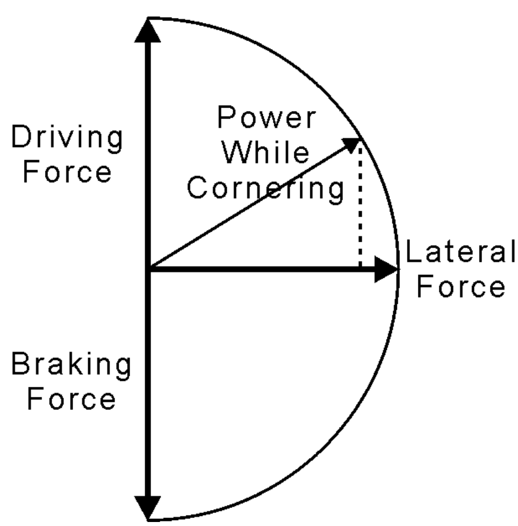

Figure 4 Friction Circle[5]

Automotive Hang-on Panels Lab

In engineering statics, there is always the need to teach students how to find the center of gravity (CG) of objects of irregular shapes. As discussed in the textbook[6], the CG of a two dimensional shape can be located using the property of two-force members. As shown in Figure 5, hanging the plate from two different points of the object and then draw plum lines, the intersection point would have to be the center of gravity of the object.

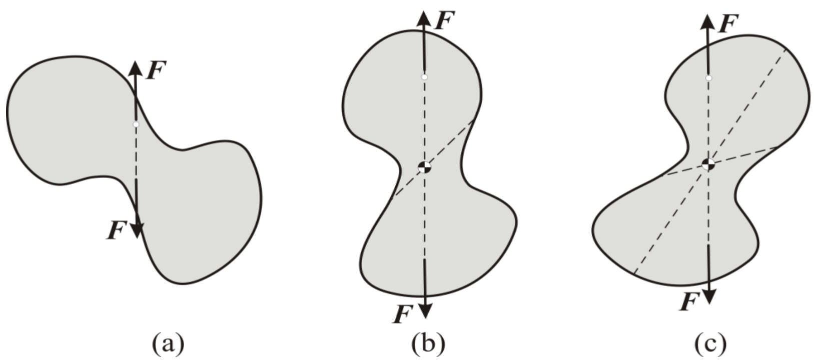

Figure 5 Locating the CG of a Two-dimensional Plate[6]

Similarly, CG of a 3D object can be found using the principle of three-force members, as shown in Figure 6. Repeating this procedure more than the minimum number of tries and then finding an average of these intersection points would only increase the measurement accuracy.

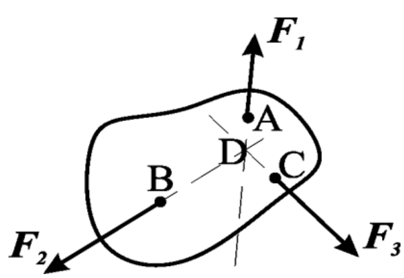

Figure 6 Locating the CG of a Three-dimensional Object[6]

In this lab, the major hang-on panels of a car, namely, a hood, a decklid, and four doors, were disassembled from the donated car. Students work in groups and each group is assigned to work on one of the panels. The goals of the lab are:

- Be able to use tools to disassemble a vehicle and measure weight, center of gravity (CG), dimensions and distances, etc. and conduct force/moment analysis on the chosen subsystem.
- Describe assumptions used.
- Draw a schematic diagram of the structure or mechanism, and a free body diagram of the panel itself at both closed and open positions.
- Estimate the spring rate of hood if you are studying hood (AutoCAD maybe used to come up with geometry for the hood mechanism at various positions).

Figure 7 is an example of a student group's FBD.

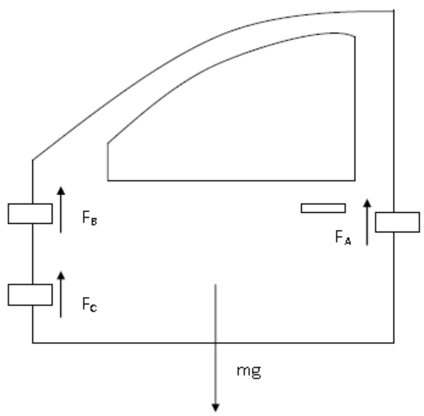

Figure 7 FBD of a Door for In-vehicle Position

During the lab, students drilled approximately ½" holes in the corners of the panels so as to be able to suspend it from a hook. These holes were used to suspend the hood from a scaffold off the ground, as shown in Figure 8. Once the panel was hanging freely, a plumb bob was suspended from the same hole and allowed to hang straight down. The position of the string along the hood was marked. This process of suspension was repeated by attaching the panel to the scaffold by a different hole in another corner of the panel. Again the plumb bob was used and its position was marked on the panel. The center of gravity was determined to be the intersection point of the two lines from the two plumb bobs.

Figure 8 Center of Gravity Measurement

In Mechanical Component Design course (MEE 403), we used the same panels for different studies. In the decklid and hood assembly, two different types of springs were used. The decklid uses a torsion bar spring, while the hood uses a spiral torsion spring (Figure 9).

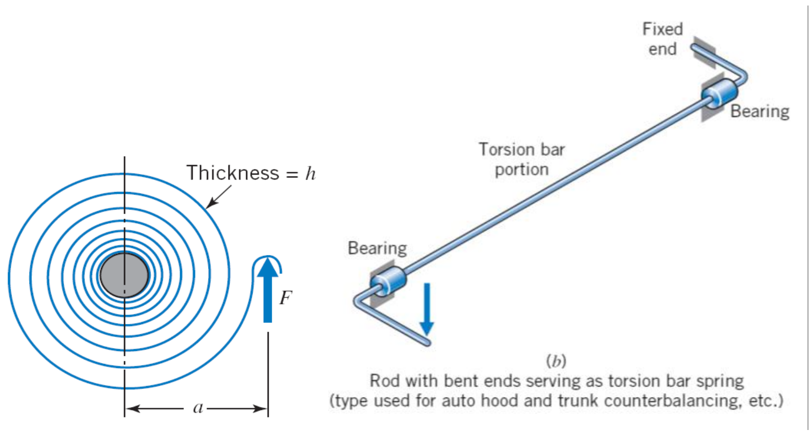

Figure 9 Two types of springs used in the decklid and hood assembly[2]

The following questions were also asked of the students in this lab:

1. What kind of mechanism is used? Draw a schematic diagram of the mechanism.
2. What are the properties of this mechanical component (material used, spring rate, etc.)?

3. Calculate the change in shear stress in this mechanical component and the change in torque when it goes from one end to the other end.
4. What is the torque supplied by the mechanism at the two end positions?
5. What percent of the door weight would the mechanism counterbalance at close position?
6. What torque would it provide at the other extreme holding the decklid open?
7. Make a graph showing gravity torque, spring torque, and net torque all plotted against the door open angle.

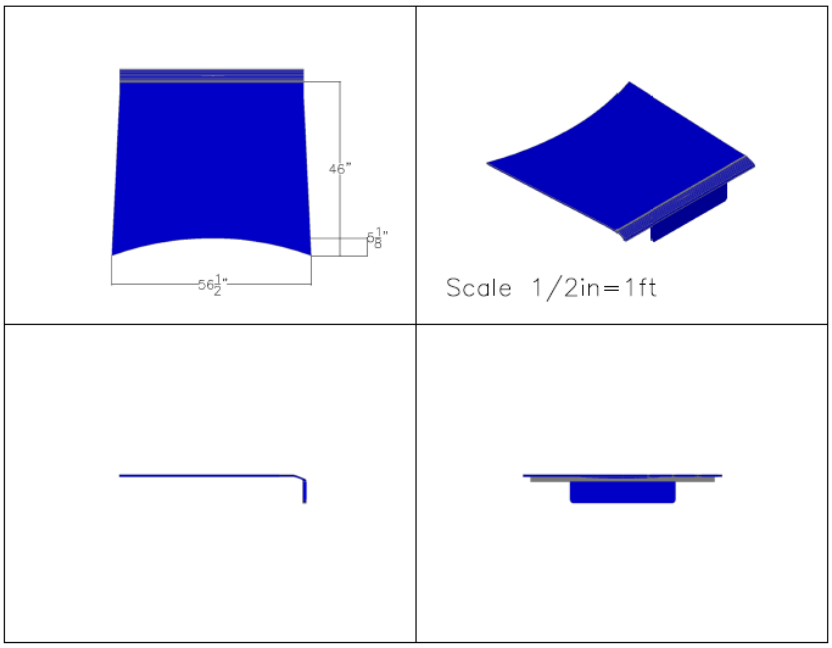

Figure 10 AutoCAD Drawings of the Hood[7]

Conclusions

Automotive related examples, when properly used in selected undergraduate engineering courses, can prove to be stimulating and inspiring. It helps fascinate students about the wonders of engineering design and analysis. It helps connect theory with engineering practice.

References

1. Stimulating Student Interest Using Automotive Systems, Olakunle Harrison, *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*
2. Fundamentals of Machine Component Design, Robert C. Juvinall, Kurt M. Marshek, John Wiley & Sons, 4th edition

3. Theory of Ground Vehicles, J. Y. Wong, John Wiley & Sons, 2008
4. Vehicle Steering Design, MEE 403 class presentation on 1997 Jeep Wrangler Sahara, Brad Mutschler, September 30, 2010, Geneva College, Beaver Falls, PA.
5. The Racing & High-Performance Tire, Chapter 6: Tire Behavior, *Sports Car* magazine, February 2004, http://insideracingtechnology.com/tirebkexerpt2.htm (accessed on March 11, 2013)
6. Engineering Statics, 3rd edition, pp. 194-197, SDC Publications, 2009.
7. Force and Moment Analysis of the Hood of an Automobile, EGR 211 Project Report, Jake Terpstra, Joan Kowalski, Ray Smith, October, 2010, Geneva College, Beaver Falls, PA.