

Cross-Cultural Bicycle Design at Cal Poly and the Munich University of Applied Sciences

Frank Owen, PhD
Associate Professor, Mechanical Engineering Department
California Polytechnic State University, San Luis Obispo, California, USA
fowen@calpoly.edu

George Leone, BA
Technician/Student Project Facilitator, Mechanical Engineering Department
California Polytechnic State University, San Luis Obispo, California, USA
gleone@calpoly.edu

Andrew Davol, PhD
Associate Professor, Mechanical Engineering Department
California Polytechnic State University, San Luis Obispo, California, USA
adavol@calpoly.edu

Georg Fey, Diplomarbeit Candidate
Student, Fachbereich 03
Fachhochschule München, Munich, Germany
georgfey@gmx.de

Abstract

Bicycles are ubiquitous and also globally a cornerstone of student transport and recreation. We have found that bicycles also serve as a transition vehicle of another sort. They serve as a technical platform that both encapsulates fundamental and interesting problems in mechanics, vehicle dynamics, stability, motive power, etc., and they are also something that university students have an intuitive, first-hand knowledge of from an early age. Thus they function well as a springboard for students headed into areas where they have no prior experience.

The bicycle industry is strong on the U.S. West Coast. For example, the “mountain” in mountain bike is Mt. Tamalpais in Marin County, north of the Golden Gate Bridge. In urban Germany the bicycle is an important cornerstone of personal transportation. The Mechanical Engineering Departments at Cal Poly and the Munich University of Applied Sciences (Fachhochschule München) have an exchange program involving both students and faculty. Both have curriculum ingredients that focus on bicycle science.

This mixing of students and professors and the study of bicycles has led to interesting projects, curriculum development, industry engagement and sponsorship, cross-cultural information exchange, and individual cross-cultural enrichment experiences for both faculty and students.

What has developed has not been planned from above. The individual pieces, like Cal Poly’s “Single Track Vehicle Design” course, have been methodically developed. But like most things involving bicycles, what has developed has grown from the bottom up without an overall plan, a grassroots effort. But the individual puzzle pieces form a larger whole with a story worth relating, a story that involves helicopters, fluid power, and a trip to Munich’s Oktoberfest along the way. This paper gives some of this history and experience in a sequence of vignettes.

Introduction – Bicycles in an Undergraduate M.E. Curriculum

As a cheap, convenient transportation medium for students in an urban environment or on college campuses where parking is always in short supply, the bicycle cannot be beat. Most students grew up on bicycles, so they have a long, innate association with this machine. The simplicity of the bicycle lends itself to easy maintenance and repair. For these reasons, we have found that the bicycle is a vehicle of another sort for mechanical engineering students. New technical material delivered in our curriculum can be affixed atop this strand of experience. Thus students have a ready platform for trying out what they learn about energy transfer (potential vs. kinetic), dynamics, structural strength, vibrations, stability, and control.

In former years automobiles often served as a technical playground for engineering students. How many fledgling technophiles cut their teeth (or rather busted their knuckles) on cheap, old, undependable, chipless cars? It often astounds us engineering professors how little our students know about the cars they drive. The dependability of modern automobiles as well as the automation and control under the hood have combined to make the automobile much more of a black box than it was just a generation ago. Often the hood stays closed. But with a bicycle, the hood is always up. It is mechanically naked and hides nothing from view.

We use both automobiles and bicycles in class to illustrate practical applications of technical concepts. Automobile examples resonate less with our students than do examples from the world of bicycles, probably for the reasons mentioned above. The bicycle's simplicity makes it technically accessible even to beginning students. It embodies many mechanical engineering fundamentals. But the simplicity hides deeper complexity, which lies not far below the surface. For example, one of our master's students took as his thesis the task of answering a question that has been asked and answered ad infinitum and ad nausea in the recent bicycling press: which is better, an aluminum or a carbon fiber frame¹?

Though bicycles lend themselves readily to inclusion in an ME curriculum, their use is not without disadvantages. There is no clear-cut, definitive text on bicycles (but see (2) and (3)). In fact, since bicycles are so accessible technically, much of what is written about them in the technical press is of questionable quality. There is no big money behind bicycles, so funding to support academic projects and research in this area is lacking. We have been involved in development work for bicycle companies, some of it as academic projects. But the motivation behind this has been more intellectual interest and the pursuit of technical questions in an area of interest to our students. (An example of successful academic pursuit of bicycle-related research can be seen at the website of Dr. Eric Wang, University of Nevada-Reno, <http://biomech.me.unr.edu/>.)

Besides the obvious mechanical aspects of a bicycle, the study of bicycles also can involve thermodynamics, biomechanics, structural analysis, manufacturing processes, computational fluid dynamics, mechatronics, fluid power, system dynamics and modeling, etc. I.e. the technology is not one-dimensional and involves technologies that overlap into other engineering disciplines. The specific project descriptions below illustrate how broad-based bicycle study can be.

A Grass-Roots, Bottom-Up Evolution of Interests and Activity

For the reasons mentioned above, bicycles often find their way into mechanical engineering curricula as design or senior projects. The bicycling thread is woven deep into the academic fabric at Cal Poly. Geographically the university is situated favorably for year-round road and mountain biking. The Cal Poly Wheelmen bicycle racing team regularly scores well in national competitions. Mechanical engineering students are often participants on this team. This has led to putting into competitive practice what we preach in the classroom.

Engineering students at Cal Poly have been involved in racing faired two-wheelers since 1978. That year, a senior mechanical engineering student, Marshall Saville, started the Cal Poly Human Powered Vehicle (HPV) team as part of his senior project. He participated in the second World Human Powered Speed Championships, which was held at Ontario Motor Speedway in Southern California. The next year a club and team was formed to compete in the World Championships. This team continued to compete at the World Championship events and even raced in England in 1982. In 1983, the first ASME Student Human Powered Vehicle Challenge was held in Davis, California, and the team shifted its focus to that event. Cal Poly HPV has competed in every annual ASME Collegiate HPV Challenge held since then. The Team has raced at the World Human Powered Speed Challenge, a straight line speed event

for the last two years, placing fifth and reaching 59.89 mph (96.38 kph). Further information on Cal Poly's HPV efforts is given below.

Besides this competitive impetus, bicycling found its way as an elective into the ME curriculum at Cal Poly with the introduction of ME 441 – Single Track Vehicle Design class by Professor Bill Patterson in 1997.

Patterson, a helicopter pilot in Vietnam, also spearheaded the development of a human-powered helicopter at Cal Poly between 1981 and 1989. Three helicopters were developed. The last one, Leonardo da Vinci III, flew in December 1989 and was the first human-powered helicopter in the world to fly. As can be seen in Figure 1, this machine borrowed heavily from bicycle technology.



Figure 1: Leonardo III, first successful human powered helicopter

A Clash of Cultures – Europe vs. the United States

An added advantage to using bicycles in the curriculum is that they are ubiquitous and overlap international boundaries. The ME department at Cal Poly has active international exchange programs with Chalmers University in Gothenburg, Sweden and the Munich University of Applied Sciences. Students from both European schools have been active participants in Cal Poly's Single Track Vehicle Design course. And one author of this paper has been actively involved in bicycle-related design projects in Munich.

As much as bicycle technology overlaps these international barriers, the differences between how bicycles are used in the U.S. and in Europe are striking. Though many people use bicycles to commute to work in the U.S., there a bicycle is much more of a recreational vehicle and sports appliance than it is in Europe. In Europe bicycles are a mainstay of urban commuting. This difference is reflected in the type of projects students get involved in at Cal Poly and in Munich.

Most bicycle projects at Cal Poly, for example, involve mountain bikes or racing bikes. In Munich the projects involve bicycles for urban transport. Another difference that runs somewhat parallel to this is that in the United States the bicycle is not regulated, like an automobile is, for safety. Thus there are no government standards which students must design to. In Germany, however, there is the STVZO (Straßenverkehrszulassungsordnung⁴), which gives specifications for all street vehicles as well as specific rules for bicycle safety equipment. So though bicycle technology is similar across these two cultures, the end uses of bicycles differ sharply, providing a different design environment for students working in each.

Projects

The following section contains information about some of the significant bicycle projects we have been involved with at Cal Poly and the Munich University of Applied Sciences.

ASME-HPV (Human Powered Vehicle) Competition – Cal Poly

Cal Poly has competed in every ASME HPV competition since its inception in 1983. Every year either completely new vehicles are built or the vehicle from the previous year is extensively reworked. One student's task one year, for example, was to lighten the aluminum frame from the previous year. He became a hole engineer. His entire project was to drill as many holes as possible in the frame to lighten the vehicle. Too many of the wrong size and the vehicle would fail. Not enough and the vehicle would weigh too much.

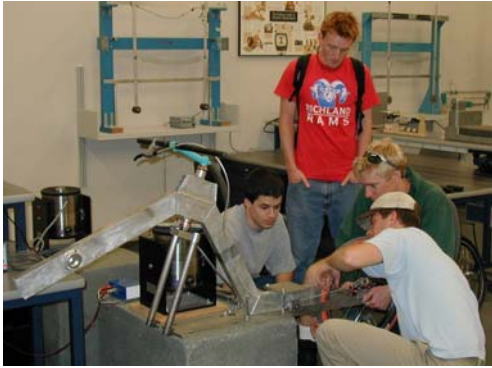


Figure 2: Vibration testing on HPV frame



Figure 3: Fairing lay-up for HPV

Students have almost always built the entire vehicle, rarely is work ever contracted out. Burt Rutan's company, Scaled Composites, CNC-machined the molds with student participation in 1995-96. Every HPV since the 1981 "Phoenix" has used advanced composites in their fairings, and numerous ones have used composite materials as structural members. CAD design, CNC machining, FEA, laser cutting, vacuum bagging, and numerous other advanced design and manufacturing techniques have been actively sought out and used by the team since the early 1980s. Teams have ranged in size from three to 35 members. No school credit was given for team participation, with the exception of some sporadic Senior Projects, until last year when elements were included in advanced design classes. The team has regularly placed well in the Western Region.



Figure 4: A scarred HPV rolls to a win

Single-Track Vehicle Design Class – Cal Poly

This class was started by Professor Bill Patterson in 1997. It is taught once a year and is always fully booked. The class covers bicycle dynamics and handling, parameterization of handling characteristics, sensitivity of bike handling to parameter change, frame structural strength, etc. The class is project-based. Students work individually or in teams to design and build a prototype bicycle during the course. Past projects have included a number of “chopper” bicycles, all sorts of trick bikes, bicycles with unusual configurations, purposefully unrideable bicycles, swing bikes (bicycles with steering front and rear), cargo-carrying bicycles, etc (see Figures 5 and 6).



Figure 5: Double-up bike



Figure 6: Chopper bike

At the conclusion of the class, all bicycles developed are on display and available for trial rides. The class has also developed several devices that can be used to further study bicycles, such as a bicycle with adjustable geometry, to demonstrate the effect of geometry changes on vehicle handling, and a bicycle pendulum, on which the entire bicycle and rider can be mounted to determine the bike/riders center of mass and the roll mass moment of inertia (see Figure 7).



Figure 7: Bike pendulum to determine CG and I_M

“Pimp My Bike – 50+” – Munich University of Applied Sciences

Meanwhile at the Munich University of Applied Sciences one is more likely to find mainstream bicycle projects rather than projects related to racing or recreational use. In the fall of 2005 the mechanical engineering department was involved in a group project to develop accessories for making commuter bicycles more convenient for the over-50 age group. This project was conducted under the auspices of the Strascheg Center for Entrepreneurship, which encourages the development of entrepreneurial projects from their conception to a marketable prototype phase. Five projects were developed: two flexible consumer goods/cargo carriers, a braking system to make braking accessible from all hand positions on the figure-8 handlebar commonly used on street bikes in Germany, an ergonomic saddle that pivots at the hip joint, and a safety pedal with built-in LEDs and generator (see Figure 8). These projects involved both ME students and students from Economics Engineering, which most closely resembles Industrial Engineering in the United States.



Figure 8: “Pimp My Bike – 50+” safety pedal

Frontloader Rickshaw – Munich University of Applied Sciences

Of course cycle rickshaws are found primarily in Asia but they also see commercial use in European metropolitan areas, serving tourists as an alternative to taxis or tourist busses. Not only is the people-carrying important, their use as rolling billboards is also commercially viable. The rickshaws most commonly used are heavy and have the passenger compartment behind the driver. This impedes the passengers’ view and also inhibits the communication between the passengers and the driver, who doubles as a tour guide.



Figure 9: Tourist transport in downtown Munich

In Munich these rickshaws are used year-round, but business booms during the city's Oktoberfest (see Figure 9). An enterprising ME senior, Georg Fey, operates a rickshaw as a side business to earn money for school. Fey bought two Indonesian rickshaws from eBay but quickly became aware of their limitations for this traffic and decided to design his own.

The result is a new, lighter-weight, front-loading rickshaw, where the passengers sit forward of the driver, with an unobstructed view and with unimpeded communication with the driver. The design was a series of compromises involving the vehicle's frame configuration, steering options, drivetrain options, and braking options. The resulting prototype is currently under construction (see Figure 10).

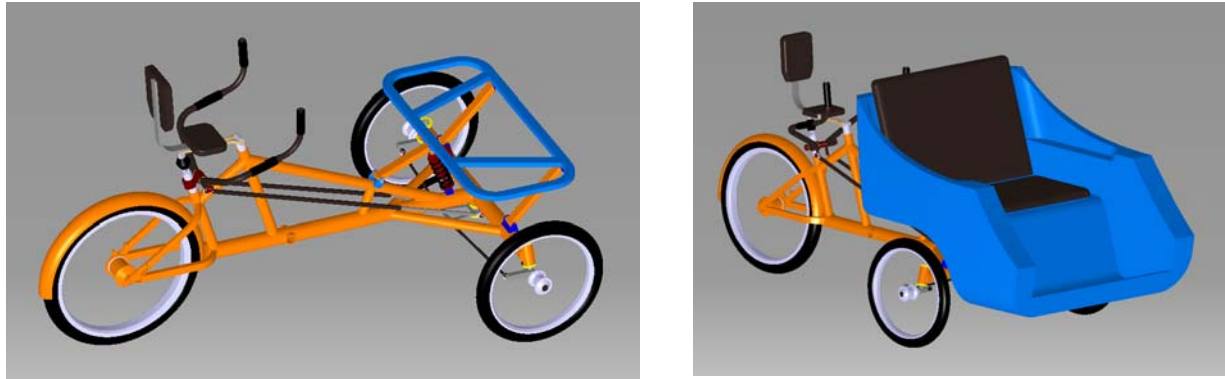


Figure 10: Georg Fey's front-loader rickshaw

Hydraulic Bicycle – Cal Poly

Cal Poly has a close relationship with Parker Hannifin Corporation, which has promoted the study of hydraulic and pneumatic motion control at a number of universities in the United States. Also recognizing the student appeal of bicycles, Parker staged "The Chainless Challenge" in the 2004-5 academic year⁵. The project involved student teams from nine universities. The challenge was to develop a bicycle with a hydraulic or pneumatic drive. Sponsorship money was provided for the development. The resulting bicycles were then transported to Cleveland for a face-off. The activity and result were so pleasing to Parker that it has decided to fund a rematch for the current academic year.

The Cal Poly student team realized that a hydraulic-drive bike could never compete with a mechanical-drive bike from the standpoint of efficiency. But a hydraulic drive allows possibilities that are hard to achieve with a mechanical drive. A continuously variable transmission and a regenerative braking system using a hydraulic accumulator were designed.



Figure 11: Drive system on Cal Poly hydraulic bike

Spin-Offs

Cal Poly students have wound up doing work in the bicycle industry. The two chief engineers of Kestrel Bicycles, a pioneer in molded carbon bike frames, are former Cal Poly HPV team members, for example. (The owner is a former UC Davis HPV Team member.) They commonly hire Cal Poly HPV members for co-ops. BikeE (formerly of Corvallis, OR) hired a Cal Poly graduate from the Single Track Vehicle Design course to design its tandem, which was put into production.

Suggested Bicycle-Related Projects

Besides the above projects, other areas of suggested research/design activity are given below.

The Cal Poly ME Department has a close relationship with our Kinesiology Department in producing devices to enable the disabled to participate in recreational activity. So far these have not included developing specialized bicycles for particular disabilities, but this has been done successfully at other universities (see the ME webpage at the University of Wyoming:

<http://www.eng.uwyo.edu/mechanical/undergrad/design/>, for example). We should move into this area.

Also, reference 6 contains a detailed list of bicycle-related project suggestions. Actually Wilson describes in detail four projects. They are cantilever-brake action after wear, the effect of wheel wobble on drag, the heat transfer and drag of whirling feet, improved fastening and connections. This is followed by a list of 50 suggested projects submitted by readers of the publication. They are organized under 13 topic areas: aerodynamics, brakes/shifters/components, cranks/hubs/alternative drives, frames, heat transfer, instruments, mechanics, psychology, physiology and performance, suspensions, tires, training, wheels, and wheelchairs.

Conclusions

Bicycles are well suited as a vehicle in an ME curriculum to illustrate fundamental principles throughout the broad scope of mechanical engineering. The apparent simplicity hides a deeper complexity that can engage students in study and research beyond the bachelors degree. But research money and technical literature regarding bicycles is lacking.

Besides this, bicycles are appealing to students. Since cars have become more complex and dependable, students' hands-on involvement with automobiles is much less widespread today than it was in the past. Most students have a hands-on, intuitive relationship with bicycles from an early age. And many college students ride bicycles daily. This intuitive feel can be exploited by relating ME topics to something that they are already very familiar with.

And bicycles are ubiquitous. They cross international boundaries. So the appeal of technical material related to bicycles is universal. But there are differences in the ways bicycles are used in different parts of the world. In the U.S., bicycles are primarily recreational and racing machines. In Europe they are primarily mainstays of urban transport. In Asia, bicycles also play a large role in cargo carrying. These differences are interesting features to exchange students.

For all these reasons, bicycles are very useful as vehicles for conveying the knowledge that forms the core of a mechanical engineering curriculum.

References

1. Jang, Andrew, "Quantification of Comfort Relative to Road Vibration in Racing Bicycles: An Experimental Approach", Masters Thesis, Cal Poly, 2005.
2. Wilson, David Gordon, Bicycling Science, 3rd Edition, MIT Press, 2004.
3. Patterson, William, Lords of the Chainring, 3rd Edition, self-published, 2002.
4. German Federal Government, Straßenverkehrszulassungsordnung, http://www.verkehrportal.de/stvzo/stvzo_67.php and <http://www.advev.de/fahrradcheck.htm>, 2005.
5. Gannon, Mary C., "An Uphill Battle", Hydraulic & Pneumatics, Penton Publishing, September 2005.

6. Wilson, David Gordon, "Research and Development Projects for Bicycles", Cycling Science, Volume 3 Number 2, Cycling Science Publications, June 1991.