AC 2007-35: STUDENT AUTOMOBILE ENGINES USED IN APPLIED THERMODYNAMICS LABORATORY

Alberto Gomez-Rivas, University of Houston-Downtown

Alberto Gomez-Rivas is Professor of Structural Analysis and Design and Chair of Engineering Technology, University of Houston-Downtown. Dr. Gomez-Rivas received two Ph.D. degrees: from the University of Texas, Austin, Texas, in Civil Engineering and from Rice University, Houston, Texas, in Economics. He received the Ingeniero Civil degree, with Honors, from the Universidad Javeriana in Bogotá, Colombia. He also served as Chief of Colombia's Department of Transportation Highway Bridge Division and is a Registered Professional Engineer. He is the author of over 30 journal articles.

George Pincus, University of Houston-Downtown

George Pincus is Dean of the College of Sciences and Technology, and Professor at the University of Houston-Downtown (1986-date). Prior service includes Dean of the Newark College of Engineering and Professor, New Jersey Institute of Technology (1986-1994). Dean Pincus received the Ph.D. degree from Cornell University and the M.B.A degree from the University of Houston. Dr. Pincus has published over 40 journal articles, 2 books and is a Registered Professional Engineer.

Student Automobile Engines Used in Applied Thermodynamics Laboratory

Introduction

This paper describes the experience of a professor with extensive testing background teaching a Thermodynamics course that was unpopular with students because of lack of tangible concepts and applications. He compared the experience that students had in courses in structural design where students were building and testing beams and had the opportunity to see cracks and deformations of structures at failure with the one of students in thermodynamics, an esoteric field that includes difficult to understand concepts such as enthalpy and entropy. The thermodynamics course offered in the past lacked practical laboratory experiences to illustrate application of theoretical principles that may provide lasting scientific student comprehension. He knew that engineering *technology* requires that applied thermodynamics courses include real world applications. Furthermore, courses on the subject must provide students with useful, lasting, and practical knowledge.

The problem presented to this professor was that laboratories with operating engines, turbines, and heat exchangers, are difficult and expensive to maintain and operate by a small engineering technology department. He had confronted a similar situation in a research university, during his graduate years, testing real structures and lacking testing equipment. However, nearby was a warehouse full of Navy equipment from the Second World War. Using cranes, gun turrets and jacks he developed the necessary testing equipment. The professor was also a car nut and expended many hours in the garage and was very active in automotive organizations. One morning going to school preoccupied with the lack of laboratories for his thermodynamics class, he went to the garage and saw his dream laboratory shown in Figure 1. At that moment, he realized that he had a full thermodynamics laboratory with engines, superchargers, heat exchangers, and instrumentation. Furthermore, he had all necessary technical manuals and specifications. On the other hand, in a class of fifteen to twenty students there are the same number of engines found in the vehicles owned by the students and the instructor that can be used to provide a practical and interesting laboratory for teaching applied thermodynamics.

Analysis of student course evaluations and exit interviews of graduates indicated great dissatisfaction with the Thermodynamics course offered in the past due to lack of applied laboratory work. This was the main motivation for the use of automobiles to provide working laboratory experiences. The same evaluation instruments indicated great satisfaction with the new course described in this paper.

The engineering aspects of the automobile have been lost under the cover imposed by body designers and outstanding operational characteristics make it unnecessary to open the hood or check the oil level. Furthermore, the complex computer systems used for operation and diagnostics keep users away from the mechanical systems of the car. The course opens the eyes of engineering technology students to the operation of this machine that is of great importance in modern society.

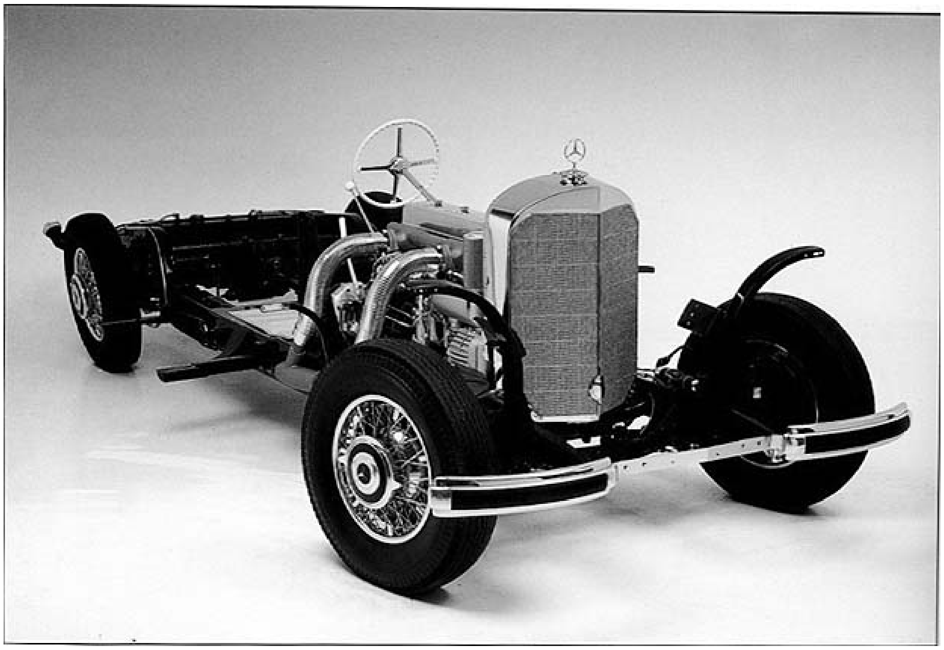

Figure 1. The thermodynamics laboratory that the professor saw in his garage. Notice the engine, exhaust system and the enormous heat exchanger in front of the car.

Creating the Thermodynamics Laboratory

The idea for the laboratory came at a moment in which the professor was contemplating a group of students lacking motivation and bored with theoretical concepts of enthalpy and entropy[1]. When he started asking students what kind of car or truck they had, sparkles came to their eyes. Some spent ten or more minutes describing the technical characteristics of their vehicles to other students without realizing that this information was part of the thermodynamics course.

Using student automobile engines instantly created interest in the discipline and provided a proper environment for understanding difficult energy concepts. To start with, students are required to compile all thermodynamic significant characteristics of their vehicles such as engine type, horsepower, torque, displacement, and information about turbo and superchargers if the engine has these devices. Search of this information for students' vehicles and questions to the instructor creates and ideal environment for comprehension of applied thermodynamics.

Students were organized in groups to select the vehicle that they wanted to study, analyze, and present results. Cars selected included Otto engines, popularly called gasoline engines, Diesel engines, normally aspired engines, and supercharged engines. Cars were classified also by the configuration of their heat exchangers, popularly called radiators. A total of eight different cars were studied but this paper presents and discusses the results for several different cars that are considered sufficient for the purpose of the paper.

Perhaps the most memorable moment in the course was when a girl discovered that her car was a real Diesel. Some students that had not been interested in cars became interested and aware of the environmental aspect and consequences of transportation equipment. The pollution aspects of engines were part of the course making it part of the social awareness core of courses in engineering technology.

Figure 2. Engine of one of the cars included in the thermodynamics laboratory.

Engine Analysis and Testing

Car engines can be classified into four groups: Otto and Diesel engines; normally aspired and supercharged engines. Representatives of all groups were found among the vehicles of the members of the class. Table 1 presents the representative vehicles with their engine characteristics.

Vehicle	Engine	Displacemet	Number of	Engine	Compression	Power	Torque
Make	Cycle	C. C.	Cylinders	Aspiration	Ratio	HP	Ft-Lbs
Chevrolet Silverado	Otto	4161	8	Normal	9.5;1	295	325
Chevrolet Tahoe	Otto	5328	8	Normal	9.5:1	285	325
Dodge Ram 1500	Otto	4700	8	Normal	9.3:1	235	300
Ford Taurus	Otto	2934	4	Normal	9.7:1	155	185
Mercedes C230 Kompressor	Otto	2300	4	Supercharger	8.8:1	185	200
Mercedes E320 CDI	Diesel	3200	6	Supercharger	16.5:1	208	388
Toyota Cambry	Otto	2362	4	Normal	9.8:1	158	161
Toyota Corolla	Otto	1795	4	Normal	10.0:1	126	122

Table 1. Vehicles included in the thermodynamics laboratory. A variety of engine cycles and aspiration methods were included.

The main characteristic studied in internal combustion engines is the cycle. There are two different cycles used in modern vehicles. The Otto cycle that uses gasoline for fuel and requires spark plugs for ignition. The Diesel cycle that uses Diesel fuel and do not need spark plugs because the very high compression ration makes the fuel explode at the proper time. Study of the operational characteristics of engines through the different stages of the cycle and computation of pressures temperatures and energy transformation from fuel to movement are important concepts to be learned by students.

Figure 2 presents a view of one of the vehicles included in the study. It is interesting to observe that although the components of the engine are hidden by covers all operational characteristics required for analysis are available through the diagnostics and operations terminal attached to the onboard computer. This a great advantage for educational purposes of modern cars because it is not necessary to have additional and expensive testing equipment for data acquisition.

	A–C	D	E	F	G	H	I
1	TOYOTA CAMRY 2007		Otto engine simulation using standard air method				
2							
3	Type of Engine	2.4L DOHC					
4	Number of Cylinders	4					
5	Horsepower	158	hp	@ 6000	rpm		
6	Power/cylinder	29455.15	W				
7	Bore	0.0885	m				
8	Stroke	0.096	m				
9	Total Displacement	0.002362	m^3				
10	Displacement/cylinder	0.00059054	m^3				
11	Compression ratio - r	9.8					
12	Gas Constant Air- R	0.287	kJ/kg *K				
13	Revolutions per second	100.00					
14	Time for a revolution	0.01	sec				
15	Time for a cycle	0.02	sec				
16	Specific heat ratio air - k	1.4	kJ/kg *K				
17	Constant vol. specific heat C_v	0.717	kJ/kg *K				
18	Constant p. specific heat C_p	1.004	kJ/kg *K				
19	Atmospheric pressure	100000	Pa				
20	T1	300	K				
21	Work=Power x time	589.103	J				
22							
23	Formulas:	$p*V=m*R*T$			$T_2=T_1*r^{k-1}$		Isentropic Process
24		$r=V_{max}/V_{min}$			$n= 1 - T_L/T_H$		
25		$p_1*V_1/T_1=p_2*V_2/T_2$			$W_{net}=n*Q_{in}$		
26		$W_{net}=Q_{in}-Q_{out}$			$k=Cp/Cv$		
27		1hp = 745.7 W			$W=C_v*((T_3-T_4)-(T_2-T_1))$		
28		Horsepower = work/time					
29		$s=s_2-s_1=s°_2-s°_1-R*ln(P_2/P_1)$					

Figure 3. Vehicle data used for the engine cycle analysis of a Toyota Camry

Figure 3 includes all data required for the Otto cycle analysis of the Toyota Camry owned by a student. The data presented in the figure, Excel rows 4 to 15, was obtained from the manufacture's publications. The student owner of this car was impressed by the amount of technical information that he was able to collect from Toyota and of the willingness of the manufacturer representatives to help locate the information and collaboration in discussion of the results. All other values in the figure were computed by students using the thermodynamic formulas presented.

Using the data and thermodynamics formulas presented in Figure 1, a model for Otto cycle analysis was developed using Excel. It is interesting to observe that the "what if" tools of Excel provide excellent tools for analysis of the engine cycles. Figure 3 presents all values of pressure temperature, volume and heat required for the cycle analysis.

The heat and energy characteristics of gases are non linear properties typically presented in extensive tables that used to require very time consuming interpolations for analysis. Figure 2 presents the automatic interpolation tools developed in Excel for manipulation of the gas characteristics required for engine analysis.

	A	B	C	D	E	F	G	H	I	J	K	L
30												
31	TOYOTA CAMRY 2007				Otto engine simulation using standard air method							
32	Point				1	p1-p2	2	p2-p3	3	p3-p4	4	p4-p1
33	Volume m^3											
34	Vr relative specific volume				621.20	A-21	63.39	=Vr1/r	3.2953	interpolation	41.797	interpolation
35	Pressure kPa				100	given	2383.99	$=p_1*V_1*T_2/(T_1*V$	6207	$=R*T_3/V_3$	280.129	$=R*T_4/V_4$
36	Temperature K				300	given	729.79	interpolation	1899.95	interpolation	840.39	interpolation
37	u specific internal energy kJ/kg				214.07	A-21	535.91	interpolation	1536.21	$=Q_H+u_2$	625.27	$=Q_{sal}U_1$
38	true volume m^3/kg				0.861	=R*T/P	0.088	$=R*T_2/P_2$	0.088	=V2	0.861	$=V_1$
39	s° - kJ/kg*K				1.70203	A-21	2.61772	interpolation	2.6036	interpolation	2.7722	interpolation
40	s kJ/kg*K				0.00551		0.00551		1.0578		1.0578	
41	Process type				1-2 isentropic process				3-4 isentropic process			
42												
43												
44	Interpolations											
45	Table A-21 p 1111	p1-p2						p2-p3				
46	Given vr, find T and u	vr	T	u	s°			vr	T	u	s°	
47	high	64.53	730	536.07	2.61803			3.295	1900	1582.6	2.61803	
48	value	63.39	729.79	535.91	2.62	725.24065	532.2958	3.295	1899.95	1536.21	2.6036	
49	low	62.13	720	528.14	2.60319			3.601	1850	1534.9	2.60319	
50	high- low	2.4	10	7.93	0.01484			-0.306	50	47.7	0.01484	
51	high - value	1.142244898						0.000				
52		p2-p3										
53	Given u, find T and vr	u	T	vr	s°							
54	high	641.4	860	39.12	2.79783	16.45	20	x	19.61178499			
55	value	625.269	840.388	41.7970087	2.7722	16.130693	x					
56	low	624.95	840	41.85	2.7717				error T	87.4252842	percent	
57	High - low	16.45	20	-2.73	0.02613	Tvalue	840.3882		error vr	-85.386514	percent	
58	high - value	16.13069315										
59												
60												
61												

Figure 4. Otto cycle analysis of results for a Toyota Camry. The figure also presents the gas table interpolation tools used in engine analysis.

Figure 5 presents the results of the Otto cycle analysis of the Toyota Camry. The analysis was performed under the standard-air assumptions commonly used in the thermodynamics course. At the beginning of the compression process air is at standard atmospheric conditions (100 kPa and 17 C or the measured values) and the volume is known, after that, there are isentropic compressions and expansions that allow for determination of the other corners of the Otto cycle. The heat addition is computed from the volume of the cylinder and the gasoline content of the mix[2]. The graphs show the results in a graphical way. The areas inside of the curves presented in the graphs represent the energy produced by the engine during the cycle.

The energy produced by the cycle was transformed into power at the a rpm specified by the manufacturer, in this case 6000 rpm, and includes consideration of the efficiency of the cycle. A power output of 160 HP was computed that compares well with the 158 HP shown in Figure 3.

The same analysis was performed for all vehicles in the group with very active and enthusiastic participation of the students performing computations and checking results with the data that they had obtained. The results were highly satisfactory due to the interest that students placed in obtaining correct data for their own vehicles. This active participation was the most important educational characteristic of the course.

Students took pride in their own vehicles and made an extraordinary effort collecting correct technical data in some cases through several interactions with sources. The analytical part of the analysis was considered as a challenge to match science with the data that they had obtained but there was an additional pride effect because the students were performing the analysis on their own vehicles.

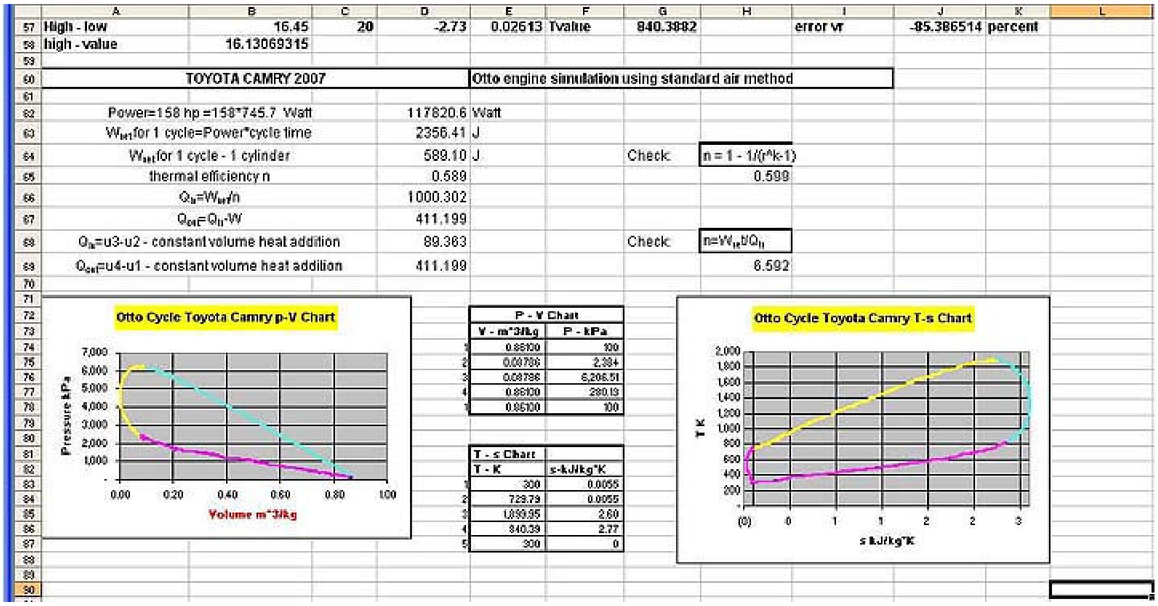

Figure 5. Otto cycle graphs presenting the p-V and T-s Charts for a Toyota Camry

Heat Exchangers

Analysis and design of heat exchangers are important parts of thermodynamics dealing with the component of an energy conversion system that keeps temperatures within operational limits. The different types of engines used in cars generate very high amounts of heat requiring cooling systems to avoid bearing seizure due to lubricant failure at high temperatures.

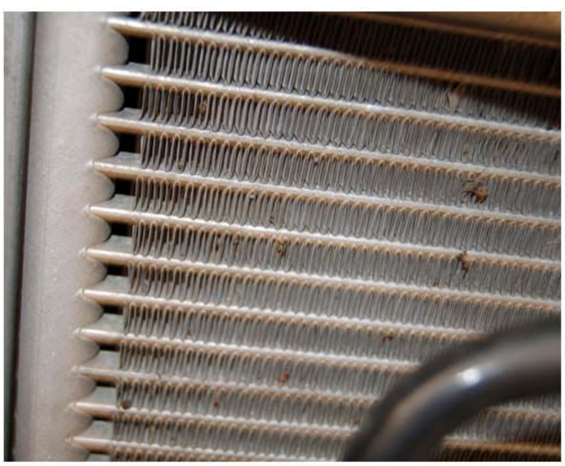

Figure 6 Heat exchanger details and instrumentation of a Mercedes C230 Kompressor analyzed in the thermodynamics course.

The heat exchanger of automobiles is one of its most important and part of the propulsion system that is well known to drivers for several reasons. It was for many years a trouble causing component when the car over heated. The style of the heat exchanger still dominates the appearance of the vehicle although it is covered by the grill. However, in luxury cars such as the

Rolls-Royce and the Mercedes Benz, the most distinctive characteristic is the heat exchanger or radiator.

In the historical development of the car, as we know it today, improvement of the cooling was a crucial step for achieving a practical vehicle. Early attempts, before the invention of the radiator by Karl Benz, required an operator collecting buckets full of water to cool the engine that were immediately wasted due to the lack of a cooling and recirculation system[3]. Many car historians associate the invention of the automobile with the invention of the radiator.

In modern times the heat exchanger of the car has assumed another task as part of the air conditioning system of the vehicle. From these considerations it is possible to conclude that car radiators are ideal to study the theoretical and practical aspects of heat exchangers in thermodynamics. Figure 6 shows the heat exchanger of a Mercedes C230 Kompressor together with the instruments to measure air and water temperatures. The figure illustrated the structural details of the radiator that are critical for heat exchange analysis. The digital thermometer indicates air temperature and the analog one refrigerant temperature inside of the heat exchanger.

Analysis of the heat exchanger involved determination of the structural characteristics of the exchanger, determination of the refrigerant flow rate, computation of the heat dissipated by the engine and finally temperatures of the air before and after the heat exchanger. Measurement of air temperatures after the exchanger agreed within ten percent with the theoretical computations. The procedure presented in the textbook[2] for the evaluation of the overall heat transfer coefficient was used in the course. Students performed all necessary measurements of the heat exchanger.

Analysis and design of heat exchangers is a critical part of the training in applied thermodynamics. Students in the course were able to obtain a deep understanding of the structural intricacies of the exchanger which is extremely complicated as illustrated in Figure 6. This structure is substantially different in vehicles of different brands and to obtain the operational characteristics requires extensive measurements but at the same time it provides students with valuable experience in this aspect of the design of heat exchangers.

Turbines and Superchargers

Turbines and superchargers are an important part of the curriculum in a thermodynamics course. One of the cars participating in the study, the car of the instructor, was a Mercedes Benz C230 Kompressor shown in Figure 7. This is a supercharged charged car that has a compressor for the air coming into the intake manifold. The significant advantages of the supercharger are very quick acceleration and no loss of power with ground elevation.

Engine cycle analysis such as the one presented in Figures 3, 4 and 5 indicates that power generation is a function of the air pressure in the intake manifold. At higher elevations the power of common cars is reduced significantly while the supercharged ones are not affected by the elevation. This is an interesting fact deserving practical testing. The instructor agreed with students to test the acceleration of the car in Houston, Texas and then drive the car to Colorado over his summer vacation. The test was repeated in the Colorado Mountains at an elevation of

10,000 feet without significant difference in acceleration. The 0 to 60 mph acceleration in Houston was 7.2 sec and 7.3 sec in the Colorado Mountains.

Figure 7. The supercharger, Kompressor in German of the Mercedesc230 Kompressor analyzed in the Thermodynamics course.

Conclusions

During presentation of the Otto or Diesel cycles, students are required to relate the concepts to their vehicles and perform the computations required to evaluate the efficiency of their vehicle engines. Competition develops among students which enhances learning and at the same time creates understanding of energy efficiency and concern for the environment. Each student presents a full thermodynamic analysis of his vehicle engine including test results at the conclusion of the one semester course.

This approach produces a challenging course that provides students with a solid background in thermodynamics supported in practice by knowledge of the characteristics of their own vehicle engine and heat exchanger. It should be noted that the student computations are performed in an Excel environment which provides fast computation and simulation of engine performance. The course was judged successful, student interest was maintained throughout, and student satisfaction with the course was very high.

The view that students have of their cars changed substantially. A student said that he now sees cars as huge heat exchangers with wheels and another observed that greater knowledge of car thermodynamics enhanced his concern for the environment.

The course developed a methodology that can be used for future courses and furthermore, technological advances in future vehicles will allow students to keep up with technological progress at no additional cost to the university.

Bibliography

1. Black, W. Z. and Hartley J. G., “Thermodynamics”, Prentice Hall, 1996.
2. Cengel, Y. A. and Turner R. H., “Thermal Fluid Sciences”, McGraw Hill, 2005.
3. Kakac, S. and Liu H., “Heat Exchangers”, CRC Press, 2002.
4. Kreith, F. and Bohn M.S., “Principles of Heat Transfer”, Thomson Learning, 2001.