

Internal Combustion Engine Demonstrator for First Year Introduction to Engineering Laboratory Course

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Abstract

We describe a small, inexpensive four-stroke engine setup for an introductory engineering laboratory course. The setup includes instrumentation for atmospheric temperature, absolute atmospheric pressure, exhaust temperature, and exhaust differential pressure. Data collection is PC-based utilizing National Instrument's LabVIEW[®] software. With minor modifications and simple upgrades, the setup could be used in more advanced undergraduate engineering courses.

Introduction

The objective of this paper is to describe a small, inexpensive four-stroke engine setup. Inexpensive purchased parts and simple tools available in most machine shop facilities allow for fabrication of the setup. The original setup was for an "Introduction to Engineering Laboratory" course for first-year engineering undergraduate students at The Catholic University of America. Note that the overwhelming majority of these students did not have any prior knowledge or experience with engineering. With minor modifications and simple upgrades the device can be used throughout a typical undergraduate engineering curriculum.

First, we present material to motivate students to the importance of the study of internal combustion engines. This material is not complete or exhaustive. Its purpose is to give a sketchy overview of why the study of internal combustion engines is anything but a dead, unneeded undertaking. In addition, the material helps to address ABET Outcomes (h) and (j)¹ by placing the study of internal combustion engines within a societal context and by addressing the major issues associated with this technology. We then describe the engine itself and some upgrades that allow its use in more advanced undergraduate engineering courses. A discussion on the safe operation of the engine follows. Finally, we present some sample results and draw some conclusions.

Motivation

Energy is one of the main drivers of the modern global economy. For example, United States consumers spent approximately \$700 billion dollars on energy in 2000², which is approximately 7% of the United States' Gross Domestic Product. In 2001, there were 403 Quadrillion Btu of primary energy consumed in the world, this value having increased at an average annual rate of approximately 1.4% between 1992 and 2001². Fossil fuels account for over 85% of this total. In particular during the year 2002, petroleum accounted for 36.1 %, coal for 23.7 %, natural gas for 25.7 %, hydroelectric for 6.7 %, nuclear for 6.6 %, and biomass, geothermal, solar, and wind for 1.3 % of the total primary energy consumed². This extreme dependency on fossil fuels will need to lessen in the future since the known worldwide easily-recoverable fossil fuel reserves are limited. In fact, at the current rate of worldwide consumption there is enough oil to last 45 years, enough natural gas to last 65 years, and enough coal to last 224 years³. One sector that is almost completely dependent on petroleum is the transportation sector, which accounts for 27.2 % of the total primary energy consumed in the United States¹. The numbers of vehicles in use, and the numbers of kilometers driven continues to rise each year. However, the news is not all bad. There has been a steady increase in average fleet efficiency (as measured by the number of kilometers driven per liter of gasoline) for motor vehicles by over 40 % from 1973 to 2002². There have also been significant steps taken to bring electric, hybrid-electric, and fuel cell vehicles to market, although their widespread introduction probably lies many years into the future. Thus, one major motivating factor for introducing beginning undergraduate engineering students to the study of internal combustion engines is to ensure that there are a sufficient number of qualified and interested engineers to solve tomorrow's daunting tasks brought on by an ever decreasing supply of fossil fuels.

A second global problem that has surfaced, or at least become increasingly more urgent to the world community, during the last half of the 20th century and at the beginning of the 21st century is global warming, where greenhouse gases, for example, carbon dioxide, water vapor, hydrofluorocarbons, etc., trap the earth's infrared radiation leading to an increase in the mean temperature of the earth's surface. These greenhouse gases can be either naturally occurring or man-made. The concern about potential global climate change was, and is, so great that the United Nations established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC issued its first assessment report in 1990. This led to an environmental summit in Rio de Janeiro in 1992, and finally to another environmental summit in Kyoto in 1997. The Kyoto Protocol⁴ is an international agreement intended to lower greenhouse gas emissions. In particular, the agreement calls for the signing nations to commit to greenhouse gas emissions for the period 2008 to 2012 relative to the particular nation's 1990 emissions. For example, reductions of 7%, 6%, 8%, and 6% were agreed to by the United States of America, Canada, the European Union, and Japan, respectively; the Russian Federation, New Zealand, and Ukraine all agreed to maintain their 1990 emissions levels; and Norway, Australia, and Iceland agreed to increases of 1%, 8%, and 10%, respectively³. Thus, a second major motivating factor for introducing beginning undergraduate engineering students to the study of internal combustion engines is to ensure that there are a sufficient number of qualified and interested engineers to

solve tomorrow's problems brought on by the need to reduce global-warming gas emissions through more efficient and cleaner engine designs.

Engine Design

The engine is a 5 HP, overhead valve, four-cycle, recoil start, reciprocating engine with a horizontal shaft. The stock engine includes a float carburetor. The prototype setup demonstrates the feasibility of this approach for incorporating small engines into an undergraduate engineering curriculum. The project execution will occur in several phases in order to provide experience with the equipment at progressive stages of additional instrumentation and power absorbing attachments and to minimize initial cash outlay. The current intention is to replicate the developed prototype in order to provide enough units for three or four students per apparatus. Phase I (for use in an "Introduction to Engineering Laboratory" course) is described, in detail, and the additional phases (if the setup is upgraded so that it can be used in more advanced undergraduate engineering courses) are described, in general. The instrumentation allows students to gain experience with data collection and synthesis. The data acquisition system is PC-based, using National Instrument's LabVIEW[®] software. Direct reading instrumentation is also possible for additional cost savings. Table 1 lists the equipment used for the Phase I engine setup.

The overall configuration consists of the engine mounted on a small (22 x 40 inch bed), yet heavy-duty wagon with 10 inch, pneumatic tires and a pull-type steering handle. The bed of the wagon is a composite of 12-gauge steel and ¾ inch plywood. The wagon arrangement allows for easy removal and storage of the equipment when reconfiguring the laboratory space for other uses during the semester. The engine is mounted on the handle-end of the wagon with enough space on the other end of the bed to install various power absorbing equipment. An insulated, aluminum, sound attenuation box covers the engine and power absorbing equipment. The sound attenuation box is open at the ends for air intake and to allow the exhaust pipe to project beyond the box. The wagon's pneumatic tires also serve to reduce the noise transmission into the operating space.

Phase I includes instrumentation of the engine for atmospheric temperature, absolute atmospheric pressure, exhaust temperature, and exhaust differential pressure. We modified the exhaust by welding an approximately 12 inch length of steel tubing to flanges which were compatible in size and bolting pattern with both the engine exhaust port and the stock muffler. The steel tubing re-directs the engine exhaust toward a flex duct connection in the rear of the sound attenuation box. In addition, the exhaust instrumentation connects to this tubing. A compression fitting connects the exhaust thermocouple, whose tip is in the mid-stream of the exhaust gases. We had to bend the thermocouple's stainless steel sheath due to its excessive length. Straps support the thermocouple tubing to small aluminum brackets attached elsewhere to the engine. Flexible plastic tubing and a short length of stainless steel tubing attaches the exhaust pressure transducer to the pressure snubber. The stainless steel tubing serves to insulate the transducer's plastic tubing from the hot exhaust gases. Note that the pressure in the exhaust section is low and we do not attempt to capture the in-cylinder pressure cycle with the apparatus described herein. To accurately capture the in-cylinder pressures would require a several kilohertz sampling frequency

and a high-temperature capable (and therefore more expensive) pressure transducer. The snubber dampens the pulsations of the engine exhaust. A gate valve with open dimensions exceeding the tubing size connects to the exhaust tubing downstream of the instrumentation and upstream of the muffler. The purpose of the gate valve is to allow changing the engine back-pressure for comparison of thermodynamic performance. To prevent the students from shutting the gate valve completely (which could over-pressurize the exhaust tubing), a small clamp placed on the valve's stem mechanically prevents complete closure. The exhaust tubing attaches to the wagon bed by means of an aluminum bracket and bolts to the tubing at the muffler flange. The atmospheric temperature and pressure instruments mount to the wagon bed in front of the engine.

Phase II upgrades include an instrumented hydraulic pump on the shaft for measuring torque and a tachometer for rotational speed. In this way, we will know the engine's output power. Phase III includes instrumentation for measuring fuel, air, and exhaust volumetric flow rates for engine efficiency measurements. Phase IV includes an exhaust gas composition analyzer for combustion and emissions analyses. Alternate power absorption equipment could include, among others, a mechanical disc braking system, an electrical generator and resistor bank, a positive displacement hydraulic oil pump, or a centrifugal water pump.

Safety Considerations

The interior laboratory space must include a suitable exhaust fan. The sound attenuation box should incorporate an HVAC collar to facilitate connection of a flexible trunk (which, in turn, should connect to an exhaust fan). Otherwise, one must use ductwork that has sufficient flow to vent the exhaust gases produced by the engine. The space should include at least one (or more depending upon the number of units, layout and air circulation) carbon monoxide sensor with an effective alarm. One must control the presence of flammable items, including extra fuel, in the laboratory space and in proximity to the running engines. Fueling procedures are necessary to minimize and deal with fueling prohibitions, fuel storage, and spillage. Fire extinguishers and smoke detectors within the laboratory space are necessary.

Table 1. Equipment used for Phase I engine setup.

Component	Supplier	Supplier Contact Information	Model Number	Cost (\$ US)	Description of Component	Use of Component
5 hp Tecumseh Engine	Northern Tool & Equipment	www.northern-online.com	60514-B398	230	Four stroke gasoline engine	Component of study
Flatbed Wagon	Northern Tool & Equipment	www.northern-online.com	143102-B398	120	Cart	Easily movable test stand
Thermocouple	Omega Engineering	www.omega.com	TJ36-CAIN-316U-12	31	Type K transition joint probe; ungrounded junction; 304 stainless steel sheath; 3/16 inch diameter; 12 inches length	Measure exhaust gas temperature
Compression Fitting	Omega Engineering	www.omega.com	SSLK-316-14	10	1/8 inch male NPT	Secure and seal exhaust thermocouple to exhaust tube
Thermocouple	Omega Engineering	www.omega.com	TC-PVC-K-24-180	16	Type K PVC coated tip thermocouple; 15 feet length	Measure atmospheric (ambient) temperature
Thermocouple -to-Analog Connector/ Converter (2 needed)	Omega Engineering	www.omega.com	SMCJ-K	97/each	Converts thermocouple input to a cold junction compensated, amplified analog output	For ambient and exhaust temperatures
Absolute Pressure Transducer	Omega Engineering	www.omega.com	PX139-015A4V	85	Range 0 to 15 psia	Measure atmospheric (ambient) pressure
Differential Pressure Transducer	Omega Engineering	www.omega.com	PX139-015D4V	85	Range 0 to 15 psig	Measure differential exhaust pressure
Pressure Snubber	Omega Engineering	www.omega.com	PS-8G	10	1/8 inch x 1/8 inch NPT	Dampen exhaust pulsations for the pressure transducer

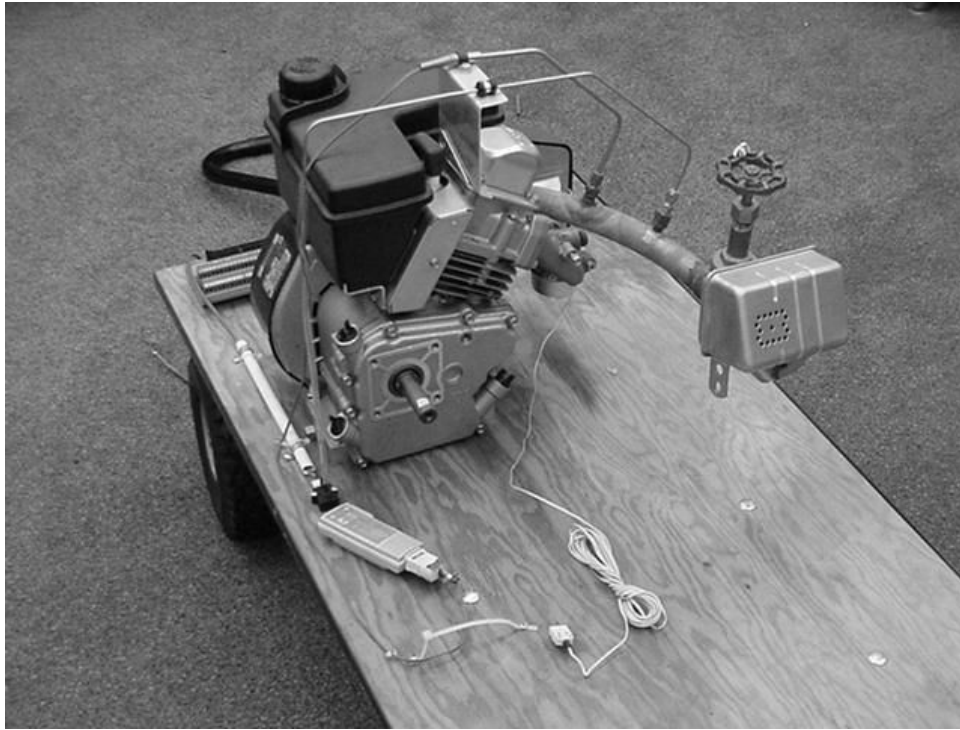


Figure 1. A view of the engine setup.



Figure 2. Students working with engine setup.

Sample Results

The types of experiments that can be performed using the engine as it exists in Phase I are certainly limited; however, we believe students can still be exposed early in their undergraduate academic careers to a rewarding laboratory experience for minimal monetary outlays. Students can be exposed to data acquisition, LabVIEW[®], uncertainties in measurement, manipulation of data, report writing, simple instrumentation, and can make qualitative statements about the engine's performance. For example, Figure 3 shows sample exhaust temperature data for a transient warm-up and Figure 4 shows sample steady-state exhaust temperature data for several engine speed/back pressure combinations. For example, from Figure 3, students can qualitatively understand thermal mass and transient heat transfer, and from Figure 4, students can qualitatively understand how the engine's performance decreases with increasing engine back pressure. Also, from Figure 4, they could estimate the engine's volumetric efficiency by making an exhaust volumetric flow rate measurement using, for example, a vane anemometer, and comparing this with the volumetric flow rate estimated from knowledge of the engine speed and displacement volume. They could also, from Figure 4, estimate the thermal energy input to the exhaust stream by using the previously estimated volumetric flow rate, a density estimate (calculated using, for example, the Ideal Gas Law, with the measured temperature and pressure data), and the temperature difference between the inlet air and the exhaust gas. They could then compare this estimated thermal energy input to the exhaust stream with the estimated energy input (they would need to measure the amount of fuel consumed over a period of time and have knowledge of the heating value of the gasoline) to have a sense of how much of the available energy is "wasted" in the exhaust stream.

While much could be done with the Phase I engine, upgrades proposed in Phases II-IV would allow not only first-year students to have a rewarding laboratory experience, but undergraduate students throughout the undergraduate program would be able to have a rewarding laboratory experience appropriate to their level and exposure to appropriate theoretical material in other coursework. As mentioned previously, Phase II upgrades include an instrumented hydraulic pump on the shaft for measuring torque, and a tachometer for rotational speed. In this way, we will know the engine's output power. Phase III includes instrumentation for measuring fuel, air, and exhaust volumetric flow rates for engine efficiency measurements. Phase IV includes an exhaust gas composition analyzer for combustion and emissions analyses.

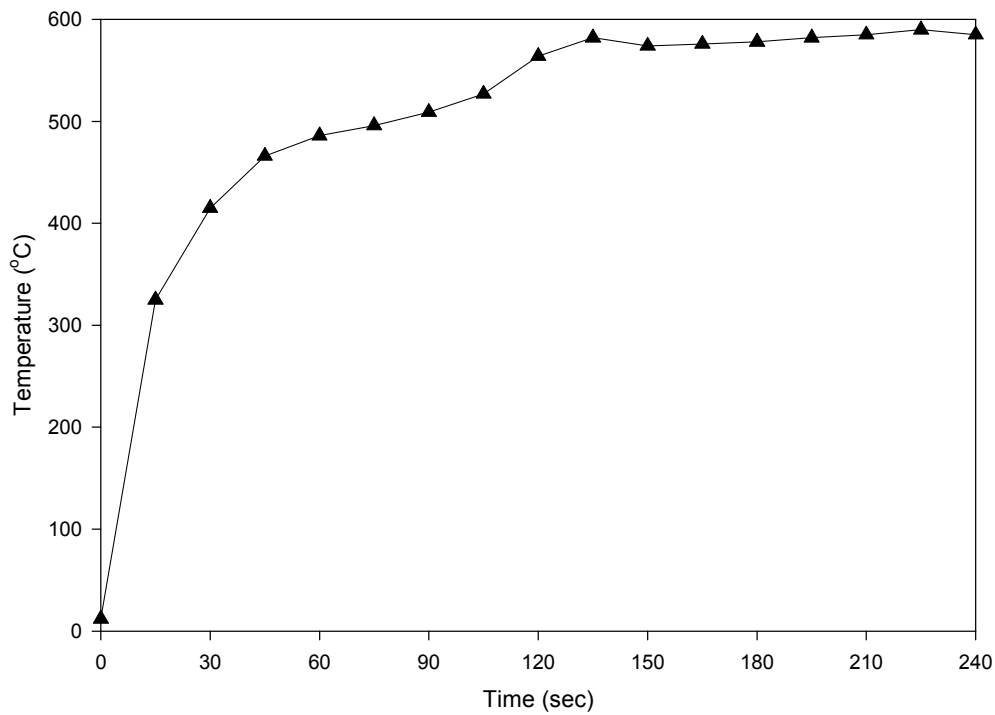


Figure 3. Sample exhaust temperature data for a transient warm-up.

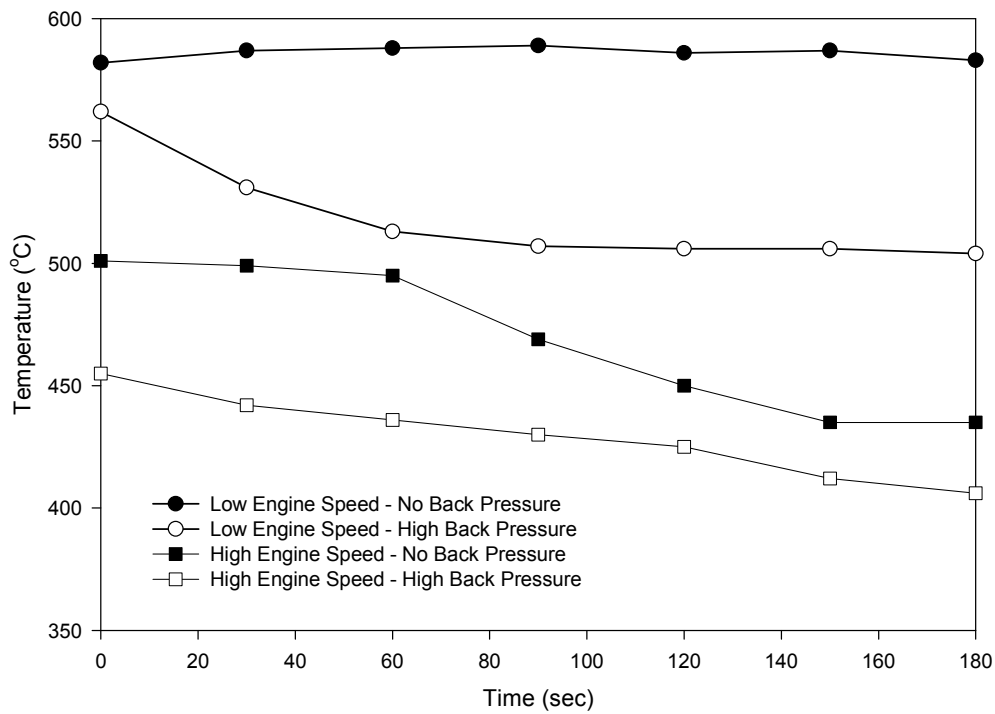


Figure 4. Sample exhaust temperature data for different engine speed/back pressure combinations.

Conclusions

For the modest expense of approximately \$800 in hardware and using existing analog-to-digital converters and software, entry-level engineering students can have a useful thermodynamic experience that also introduces them to data collection and analysis. Using a phased approach for upgrades to this equipment, one could use the same simple equipment to provide more advanced laboratory experiences in the areas of thermodynamics, power generation, combustion, and environmental impacts of technology.

References

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