Development of Low-Cost Laboratory Experiments for Southern Arkansas University's Engineering Program

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Abstract

The purpose of this paper is to present the preliminary work and plans related to the development of several low cost laboratory experiments in the newly established engineering program at Southern Arkansas University (SAU). SAU was recently approved to initiate a new engineering program, and the university officially started it in fall, 2014. An immediate requirement of the new engineering program is to develop two teaching labs – Solid Mechanics Lab and Thermal-fluid Science Lab. Considering the available resources and the time, the faculty decided to develop several low cost lab setups to meet teaching requirements. In the current work the proposed labs will be mainly used in the Thermal-fluid Science Lab course. Those setups include the following: a conduction heat transfer experiment setup to demonstrate the Fourier's law of heat conduction; a transient heat transfer setup that uses lumped capacitance method; a hydrostatic force on a submerged surface experiment setup; and a mini gas turbine setup. The possibility of using the gas turbine setup using an alternative fuel is also discussed. The expected cost (approximate) for each experimental setup is discussed as well.

Keywords

Lab development, lab experiment, low cost, thermal-fluid

Introduction

The creation of the new engineering program at Southern Arkansas University is one of the best things happening for the people of southern Arkansas. The program officially started in the fall of 2014. As a new engineering program, it faces many challenges, and the development of new labs is one of them. Limited resources and budgetary constraints make lab development not easy. A well-equipped lab in mechanical engineering can easily reach several hundred thousand dollars. In 1999, Rochester Institute of Technology developed[1] a mechanical engineering lab with an approximate cost of $200,000. It is true that some equipment costs more than others. A sizable amount of money needs to be spent on acquiring a Universal Testing Machine where as a simple hardness testing equipment can be bought for under $5000. Today's trend in lab development is to acquire bench top or cart mounted equipment to save space, reduce the development cost, and the maximize the number of experiments that can be incorporated. On such attempt was undertaken by David Torick et al[2], who designed and developed an entire fluid mechanics lab under $6000 to provide an intensive learning experience for their engineering students. Details about the development of inexpensive hands on laboratory experiments in mechanics of materials for distance education have been reported by Jamie Douglas et al.[3]. Charlene Yauch et al.[4] have developed a sand casting lab for eight students under $1040.

Teodora Rutar et al.[5] have developed a low cost Thermodynamics lab to fulfill one of the ABET criteria.

The purpose of the current research is to describe the ideas of developing low cost experimental setups in the area of thermal-fluid science and share it with engineering community in academia. In this paper we mostly focus on the planning and cost estimation of the proposed experimental setups.

Proposed setups

The proposed experiments will be used in Thermal-fluid Science Lab mainly. These are mostly in the planned phase. They will be ready before the lab class starting in the spring of 2016. Solid modeling for illustration purpose was done using SolidWorks. Each experimental setup is described as follows:

Conduction Heat Transfer Experiment Setup

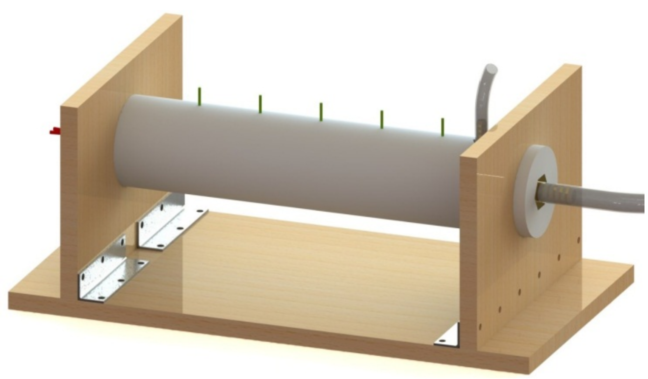

Figure 1a: Heat conduction experimental setup

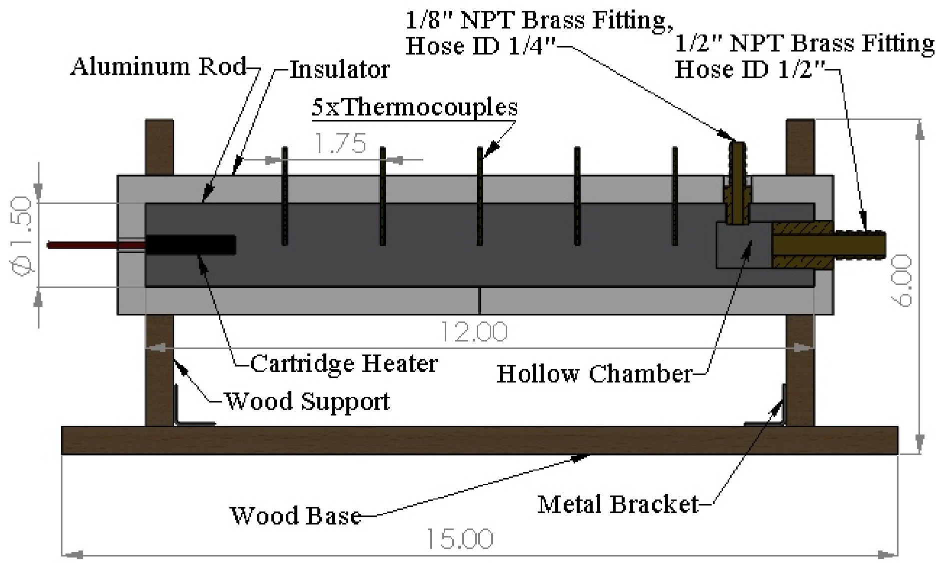

Figure 1b: Section view of the above setup

The purpose of the proposed setup is to demonstrate linear one dimensional heat conduction and the demonstration of Fourier's Law. In the proposed setup heat will be generated in a cylindrical metal rod at one end and on the other end heat will be dissipated by a flow of cold water attached to it that will cause a thermal gradient along the axis of it. The conduction heat transfer test set up is shown in the figure 1a and 1b. The test set up that is being built consists of a cylindrical metallic cylinder, cartridge heater, five thermocouples, and the cooling line. The cylinder will be well insulated and mounted on a wooden base using wooden support. Due to the insulation on the outer surface heat will transfer linearly. The rod will have small drilled holes to insert the thermocouples. Thermal grease may need to be applied to have good thermal contact between a thermocouple and the aluminum rod. Thermocouples can be connected to the digital thermometers or to a data logger to record the centerline temperature of the cylinder. Access to a machine shop with a lathe and a drilling machine may be required. The estimated cost of the setup is shown below:

Table 1: Estimated cost for heat conduction experiment setup

Equipment/Materials	Estimated cost	Source
12" long 1.5" dia aluminum rod	$15	Amazon, eBay
Cartridge heater	$12	Amazon, eBay
5 thermocouples	Under $15	Amazon, eBay
3 Thermocouple reader	$30	Amazon, eBay
Thermal insulation	$15 to $30	
Metal tubes, hoses, and threaded fitting	$15 to $20	Local hardware store
Wooden structure, metal brackets, nuts and bolts,	$20	Local hardware store
Thermal grease	$5 to $10	Amazon, eBay

The entire setup could be built for less than $200. It could be done as a student project, that way student(s) will enjoy doing the hands-on work. On the other hand, if a similar setup is purchased from the market, that could easily cost between $10,000 to 20,000.

Hydrostatic Force on a Submerged Surface Experiment Setup

The setup is widely used to find the total hydrostatic force and center of pressure of a submerged surface. The proposed experimental setup is shown in Figure 2. A cylindrical quadrant is hinged at the axis of it. It has two concentric cylindrical surfaces such that the pressure forces on these surfaces pass through the center of the quadrant that causes zero moment. The entire quadrant is proposed to be made using a 3D printer. The quadrant will be placed in a fish tank. Rod and hinge mounting supports will be also 3D printed and will be attached to the fish tank using glue.

The balanced rod, hinged rod, etc. will be bought from a local hardware store. The entire setup can be easily built under $200 including the cost of the plastic filaments. On the other hand an experimental setup would cost between $3000 and $4000 in the market.

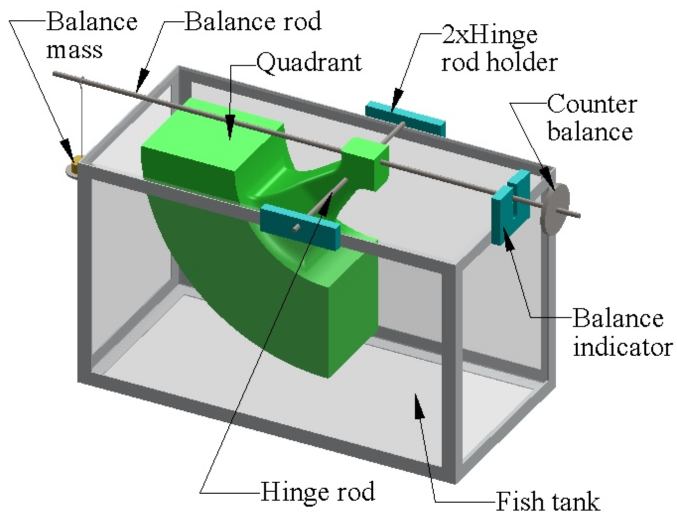

Figure 2: Hydrostatic force on a submerged surface

Table 2: Estimated cost for hydrostatic force on a submerged Surface setup

Equipment/Materials	Estimated cost	Source
3D printed quadrant	$50 (filament cost)	Would be 3D printed
5 gallon fish tank	$40	Amazon
Other parts/materials	$100	Will be 3D printed or purchased

Transient Heat Conduction (Lumped system) setup

This setup can be mainly used for performing the lumped system analysis. However, natural convection experiments and forced convection experiments can also be demonstrated. The setup is shown in Figure 3. This experimental setup has already been made and tested, and will be used in the teaching lab in spring 2016. It consists of a hair dryer, a small metal ball, embedded thermocouples, and a digital temperature read out. The spherical ball used in the experiment should have high thermal conductivity to produce a very low Biot number. The hair dryer has different settings (low, medium, and high) for heat generation. The hair dryer is attached to a clear plastic acrylic tube and the spherical ball is hung in front of it. A rotary vane type anemometer can be used to measure the air velocity. One thermocouple is used to read the ball temperature and the other one is to read the air temperature. The entire setup is placed on a rigid plastic board.

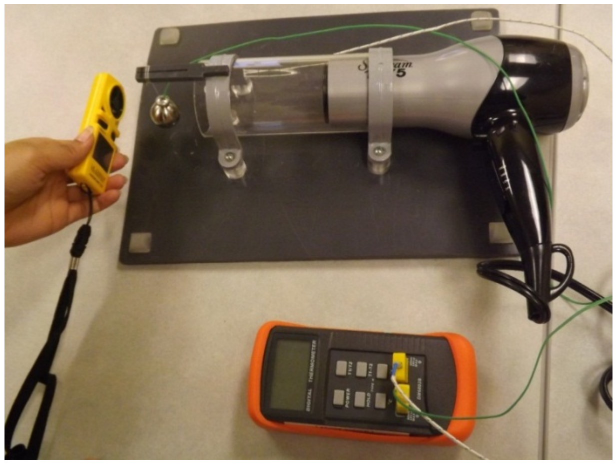

Figure 3: Transient heat conduction (lumped system) setup

Table 3: Estimated cost for transient heat conduction (lumped) setup

Equipment/Materials	Estimated cost	Source
Hair dryer	$25	Walmart
Anemometer	$30	Amazon
Thermocouples (two)	$6	Amazon
Clear acrylic tube	$15	Amazon
Digital thermometer	$18	Amazon
Others (plastic board, support, screws, nuts, etc.)	$30-$40	Any hardware store

For the lumped experiment the ball is heated by flowing hot air through the tube and then letting it cool down in the ambient air. The cooling process can be timed and can be compared with the theoretical results considering it as a lumped system.

Gas turbine experiment setup

A low cost gas turbine setup was built that will allow students to use it in the Thermal-fluid Science Lab to demonstrate how a gas turbine actually works. Students will use this setup to conduct experiments using a regular fuel as well as using a biofuel blended with a regular fuel to measure thrust, exhaust temperature, fuel burning efficiency, etc. The small gas turbine for this setup was purchased as part of an internal research grant. The initial research purpose was to investigate the performance of different biofuels and compare it with regular jet fuel. The turbine was purchased for $2700 at the beginning of the research. A digital force gauge was purchased for $618 to measure the thrust force. To analyze the exhaust gas, a gas analyzer for $450 was purchased. The turbine was placed on a linear rail system and attached against the force gauge that will allow it to move linearly during operation and display the thrust reading on the gauge at different throttle settings. The linear rail system was purchased for less than $100 from eBay. The total cost including everything was almost $4000. The entire setup is mounted on a mobile cart so that it can be taken outside of the building for proper ventilation.

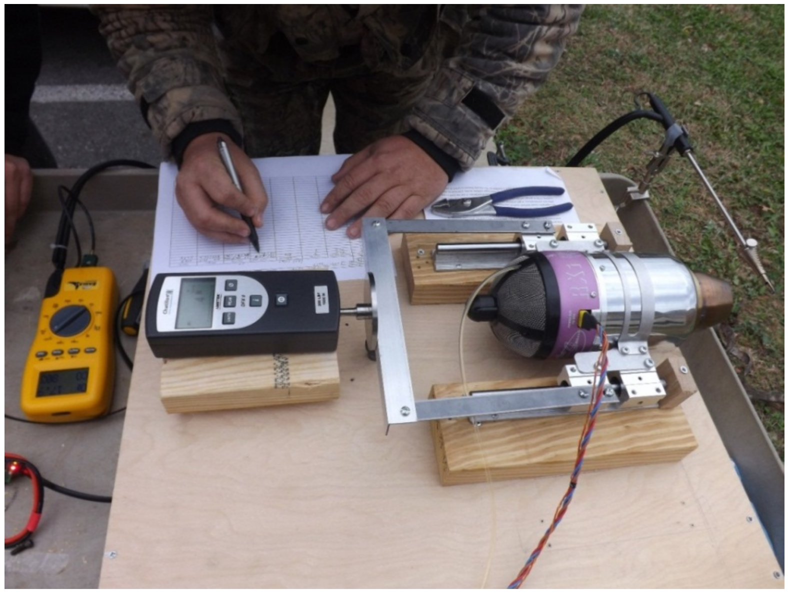

Figure 4: Gas turbine setup

Table 4: Estimated cost for gas turbine experiment setup

Equipment/Materials	Estimated cost	Source
Mini Gas turbine (P90 Rxi turbine) and accessories	$2700	Jetcat-USA, 4250 Aerotech Center Way Suite G, CA 93446
Digital force gauge (DFXII model) 100 N force capacity with accuracy of ±0.3%	$618	Nicoscales.com
Gas analyzer	$450	Amazon/eBay
Linear bearing set	$100 or less	eBay
Movable cart	$120	Amazon
Others (wooden board, support, screws, nuts, etc.)	$50-$60	Any hardware store

Concluding Remarks

This paper presented the preliminary work undertaken by the engineering faculty at SAU to develop low-cost labs in the engineering program. The proposed labs will be offered in the Thermal-Science Lab course in spring 2016 with an approximate class size of twenty students. The evaluation of the low cost labs that are being developed will be evaluated using experimental data, students' critiques, and how well each lab enhances the learning experience. The SAU engineering faculty intends to publish the findings in a future paper.

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Mahbub Ahmed

Dr. Mahbub Ahmed is an assistant professor of engineering at Southern Arkansas University. He completed his PhD in Materials Science and Engineering with an emphasis in Mechanical Engineering at the University of Texas (El Paso) in 2008. He earned his Bachelor of Science in Mechanical Engineering degree from Bangladesh University of Engineering and Technology in July 1997. He completed his masters in Industrial engineering from Lamar University, Beaumont, Texas in 2001. He spent two years working fulltime at a light fixture design and manufacturing company in El Paso as a design engineer. He has worked part-time as a visiting Assistant Professor at the University of Texas at El Paso as well. Prior to joining the Southern Arkansas faculty as a fulltime Assistant Professor in 2012, Dr. Ahmed was a Lecturer at Georgia Southern University for one year and visiting Assistant Professor for three years. His research interests include combustion, computational fluid dynamics, and engineering education.

Lionel Hewavitharana

Dr. Lionel Hewavitharana obtained his BS degree from the University of Peradeniya, Sri Lanka and his MS and PhD from Louisiana Tech University. He has taught at the University of Wisconsin, Platte Ville, Louisiana Tech University, and the University of Central Florida (UCF). At UCF, he was the lead instructor of the Mechanical and Aerospace Engineering Department's Capstone Design course. In January 2015, Dr. Hewavitharana joined Southern Arkansas University as an Associate Professor of Engineering.

Scott McKay

Dr. Scott McKay is the Dean of Science & Engineering and Professor of Chemistry at SAU. He joined the faculty in 2011. Prior to SAU, he was the chair and professor of chemistry at UCM and Director/Founder of the Center for Alternative Fuels and Environmental Science. Before that he was an assistant professor of chemistry at LMU and postdoctoral associate at The University of Alabama studying in the area of crystal engineering. Previous to UA he was a visiting scientist at Lehigh University researching industrial processes of dyes. He has bachelor's degrees in chemistry and geology EKU 1987, a master in analytical chemistry EKU 1989 and a Ph.D. in organic chemistry from The Florida Institute of Technology in Melbourne, Florida 1995. Dr. McKay's research interests are in the areas of alternative energy and fuels, petroleum products, sustainability, crystal engineering, and proton exchange membranes for hydrogen fuel cells.

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Kendra Ahmed is an adjunct professor of computer science at Southern Arkansas University where she teaches video game development and programming. She completed her MSc in Computer Science from Southern Arkansas University in 2015. She previously completed her BBA in Economics from the University of Texas – El Paso in 2007. Her research interests include women in science, online teaching methods, and class development.

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Dr. Mamunur Rashid currently is a lecturer at University of Massachusetts Lowell. He received his BS and MS from Idaho State University, and obtained his Ph. D degree from the University of Utah. Dr. Rashid is a licensed professional engineer and has held several engineering positions throughout his career.