Hovercraft - A Project Based Approach To Introduction to Engineering

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Abstract - **A new model has been designed and implemented for the Introduction to Engineering course ENRG-1101 at Temple University. In the past, the course was run as a large lecture style with all students attending a large lecture and various topics that were covered such as time management, career options, on campus tutoring and resource centers to name a few. Based upon student feedback and low retention rates it was obvious a new model was needed. The focus was to be much more hands-on and use a project orientated approach. In addition, multiple instructors were employed from several departments and it was decided that each instructor would teach topics very specific to the instructors' field of expertise. The large lecture mode was removed in favor of splitting the freshman class into groups and rotating them among instructors. The entire course is centered around the design and construction of a remote controlled hovercraft, entirely designed and prototyped by freshmen.**

Index Terms–Freshmen design, hovercraft.

MOTIVATION AND BACKGROUND

In a study conducted during 2009-2010 academic yearthe we analyzed the student intra-university freshmen transfers out of the College of Engineering to non-STEM disciplines. A snapshot of the transfer statistic is presented in Figure 1.
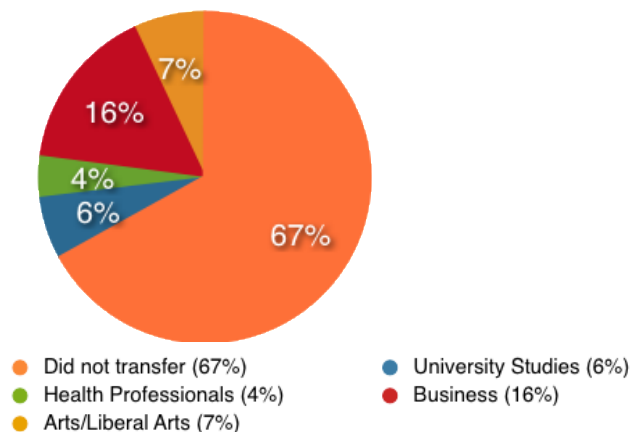

FIGURE 1
TEMPLE UNIVERSITY, INTRA UNIVERSITY TRANSFER DATA
(2009-10)

With an average annual enrollment of 250 students, the number of transfers to non-STEM disciplines represents a 33% drop out rate.

To improve retention rate we sought to improve student learning experience in freshmen engineering design which has increasingly become a gateway course for freshmen exploring a career in engineering. Teaching this course as a purely lecture intensive course has not yielded satisfying student experience or retention rate. We sought to incorporate some new methods explored by researchers in the field of engineering education. We explored possibilities like studio based learning [Foulds et al. 2003 and Little and Carderas, 2001], participatory design [Sanders, 2006] [York 2006], case studies [Conwell et al. 2002] and reverse engineering [Wood et al. 2001]. To incorporate some of the ideas in freshmen design was a challenge, given the lack of mathematical foundation necessary to understand basic design concepts.

In addition to introducing students to the process of engineering design early in the curriculum, the course was also designed to help two specific groups of students:

(1) *Students with undeclared major:* A course in design is typically the culmination of the engineering curriculum. However, by presenting the fundamental concepts at freshman level, this course is designed to give such students a good understanding of the major.
(2) *Engineering majors with undeclared discipline:* The curriculum includes modules from several engineering disciplines, thereby providing a preview of each major.

The course uses a design based, cross-disciplinary syllabus with emphasis on team based design. The course utilizes digital and analog circuit design, computer aided modeling and rapid prototyping tools to introduce students to the process of engineering design. Using this knowledge, the students design and build a prototype of a remote controlled hovercraft and compete among each other. The course also serves to integrate the use of basic math and science skills into design.

The project chosen to incorporate all of the stated goals was a remote controlled hovercraft, designed and fabricated entirely by the students (see Figure2).

TABLE I
MECHANICAL ENGINEERING WEEKLY SCHEDULE

	Lecture	Student Activity
Week 1	Materials Selection 3-D Modeling and assembly	Model & assemble tentative design
Week 2	Prototyping	Print brackets, CNC machine deck & skirt.
Week 3	Newton's 3 laws of motion Balance and stability Rotational degrees of freedom	Determine CG Layout of prop fan to counter adverse yaw.
Week 4	Pressure & flow rate Lift force CFD	Generate impeller performance curve, estimate lift force.

MECHANICAL DESIGN

Solid Modeling and Prototyping:
The students begin their 4-week rotation in mechanical engineering with an introduction to solid modeling using SolidWorks. Working in groups they model a first iteration of their hovercraft. An exploded view of a hovercraft is shown in Figure 4.
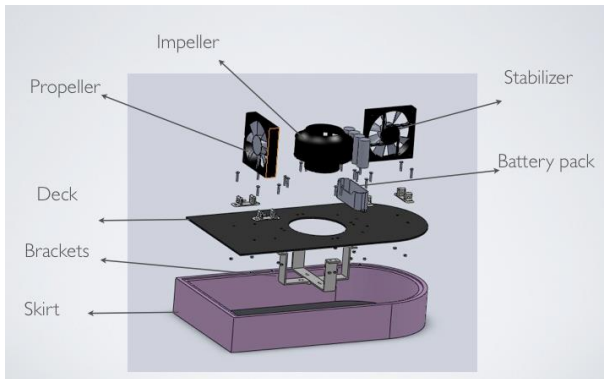

FIGURE 2
EXPLODED VIEW - MECHANICAL COMPONENTS OF THE HOVERCRAFT.

During the second week, the students model the mounting brackets for the impeller and propeller fans and print them using the Dimension BST 768 rapid prototyping machine. The skirt and then deck of the hovercraft are machined using a CNC router. (Figure 3).

FIGURE 3

Newton's three laws and adverse yaw:
During week three, the students are introduced to Newton's three laws of motion and its implications in the design of the hovercraft. The first law is applied when the hovercraft is at rest or moving at a constant velocity. The second law states that the acceleration is proportional to the net force acting on the body, and is inversely proportional to its mass. The hovercraft can accelerate, decelerate, or change its direction by controlling the propeller speed and direction. The third law is used to explain the thrust generated by the propeller fan (action-reaction), similar to the rocket propulsion. The reaction moment on the clockwise spinning impeller blades of a hovercraft imparts a left turning tendency of the hovercraft, which causes the hovercraft to yaw to the left. This left turning tendency of the hovercraft needs to be corrected by placing the propeller fans appropriately to produce an unbalanced thrust that counters the yaw.

At the conclusion of week three, the students are asked to calculate the net force and net moment if (i) both propeller fans are turned 30º in the CCW, (ii) both propeller fans are turned 20º in the CW, (iii) the right fan is turned 30º in the CCW and the left fan is fixed, (iv) one rear fan is turned 20º in the CW, and (v) one front fan is turned 20º in the CW. Thrust per fan = 0.4 N, x = 0.12 m (lateral distance), z = 0.25 m (longitudinal distance), x and z are measured relative to the center of mass located near the center of the impeller as shown in Figure 4.
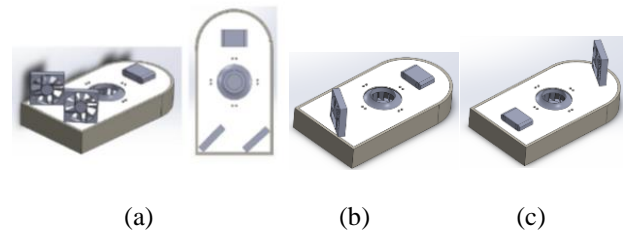

(a)　　　　(b)　　　　(c)
FIGURE 4
POSSIBLE ORIENTATIONS OF PROPELLER FANS TO STEER AND COUNTER THE LEFT TURNING TENDENCY OF THE HOVERCRAFT.

Steering Options:
The students are introduced to several possible options to control the motion of the hovercraft.
(A) Rudder – rotation by a servo mounted behind the propeller; resulting motion of CCW rotation: move forward, slide to the left, and yaw to the right.
(B) Thrust Vectoring - rotating propeller(s) with servo(s); resulting motion of Fig. 4(a): move forward, slide to the left, and yaw to the right; resulting motion of Fig. 4(b): move forward, slide to the right, and yaw to the left; resulting motion of Fig. 4(c): move forward, slide to the right, and yaw to the right. Students are encouraged to explore various options of locating the propeller(s). Locating fans farther

away from the center of mass will result in larger moments for turning. It is demonstrated by power point slides and experiments that the cross (vector) product of distance and force is equal to the moment.

(C) Asymmetric Thrust - differential thrust by speed control of two propellers or braking one side; motion: move forward, no sliding to either side, and yaw to the right. Because of time delay during speed control, this option is the least used by the students.

Pressure vs. Flow rate:

In their last week in Mechanical Engineering, the students learn the relationship between airflow of the impeller and pressure under the skirt. Using ANSYS-FLUENT, the students compute the performance characteristic curves for the impeller, which they then use to determine the area of the deck necessary to generate the necessary lift force. An illustration of the fluid flow calculations is shown in Figure 5 and the impeller performance curve is shown in Figure 6. Figure 7 shows several hovercrafts being tested on the obstacle course.
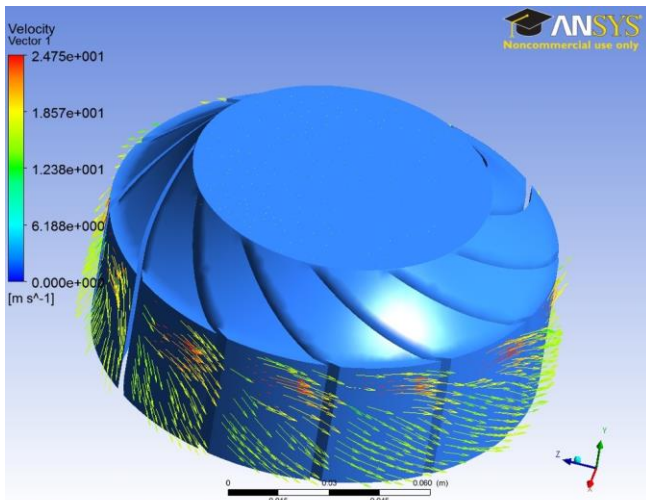

FIGURE 7
HOVERCRAFT IN ACTION

FIGURE 5
COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF FLOW
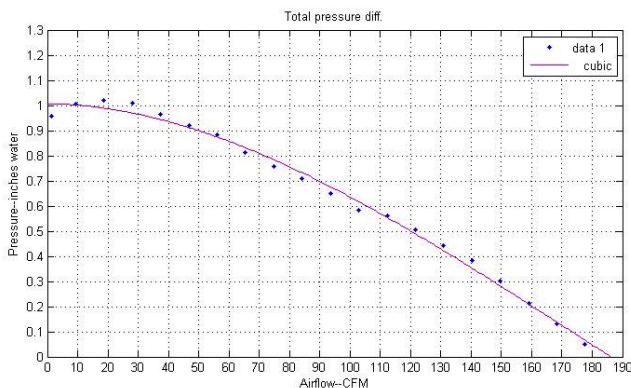

FIGURE 6
IMPELLER PERFORMANCE CURVE

ELECTRICAL AND COMPUTER ENGINEERING

The ECE component mainly focuses on employing the Arduino microcontroller board in a variety of experiments. The Ardiono was chosen for its easy to use Integrated Development Environment (IDE), inexpensive, large community of construction, programming, electronics, and many enthusiast that have posted many projects on the Internet. The very first day of class a poll is taken as to how many students have actually programmed in a language such as: C, C++, Java, Virtual Basic, HTML, etc. Typical responses indicate that less than 5% of 240 students have had no programming experience. Rather than devodt the ECE section of the course to just programming we decided to provide "bare-bones shell programs" found on the Internet and in the examples section of the Ardiono IDE. Useful projects and code found in text [6, 7]. Table II shows a list of the ECE Experiments performed over a four week period. It should be noted that since the students were given example code at the outset of each activity the real challenge comes at the end of each activity where the students are then challenged to take what they have learned and extend it. For example, take the ultrasonic activity. In this activity the students use Parallax ultrasonic sensors to measure distances, in both inches and centimeters, to an object using code from the Arduino examples. The extended part of the activity is as follows: Connect a servo motor to a PWM port and an LED into an I/O port. Place your hand in front of the sensor. If your hand is over 30cm away from the sensor then leave the LED and motor off. If your hand is between 30 cm and 5 cm then make the blinking/timing rate of the LED as a function of the distance the hand is away from the sensor. If the hand is within 5 cm then turn on both the LED and the motor.

TABLE II
ELECTRICAL ENGINEERING WEEKLY SCHEDULE

	Lecture	Student Activity
Week 1	Introduction to Arduino IDE and digital I/O ports	C-Programming Flashing LED's
Week 2	Actuators: DC Motor Control and Continuous and Standard Servos	Interfacing Arduino board to external analog circuitry and breadboarding techniques
Week 3	Sensors: Ultrasonics, Infrared and Photoresistors	Distance measurements, Analog to digital conversion
Week 4	Introduction to Circuit Analysis	Ohm's Law, Power, series and parallel connections

Once the students have cycled through the four weeks of the ECE experiments the next set of tasks is for preparation to integrate the electronics for the hovercraft as shown in Figure 8. This involves learning basics to soldering, Printed Circuit Board (PCB) layout, relays, WiFi shield, H-bridge, Impeller fan, batteries and headers.
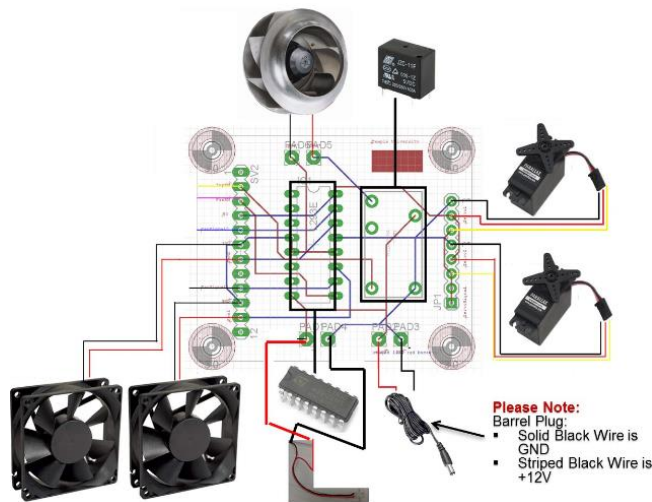

FIGURE 8
SOLDERING AND WIRING THE PCB

Once the PCB is wired the next task is to interface the PCB with the Arduino as shown in Figure 9.
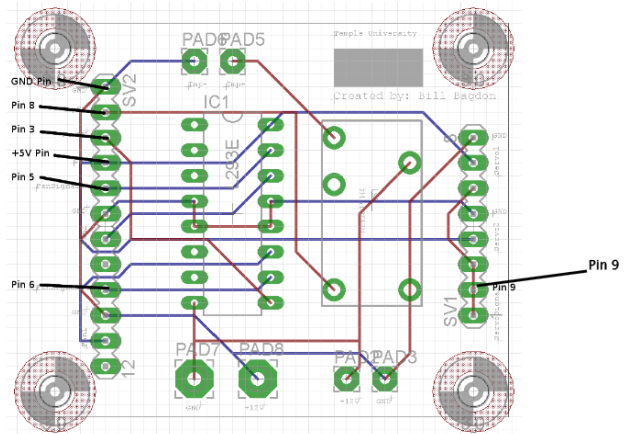

FIGURE 9
ARDUINO PIN CONNECTIONS

The final task is to connect the Arduino/electronics to a WiFi network comprised of the Arduino shield and the iPad. First, the students have to go to the libraries:Libraries\RCKit\RCRx.ccp
Figure 10 shows the code that needs to be modified so that each hovercraft has its own unique identification. The "RCArduino" is modified to a name chosen by the students.

```
22   unsigned char local_ip[] = {169,254,1,100};
23   unsigned char gateway_ip[] = {169,254,1,1};
24   unsigned char subnet_mask[] = {255,255,0,0};
25   const prog_char ssid[] PROGMEM = {"RCArduino"};    // max 32 bytes
26   unsigned char security_type = ZG_SECURITY_TYPE_NONE;    // _NONE, _WEP, _WPA, _WPA2
27   unsigned char wireless_mode = WIRELESS_MODE_ADHOC;
```

FIGURE 10
ARDUINO CODE TO BE MODIFIED

A number of remote control (RC) applications are available on the iPad to serve as a virtual RC interface over the WiFi network such as RCTx. The iPad screen for this app is shown in Figure 11.
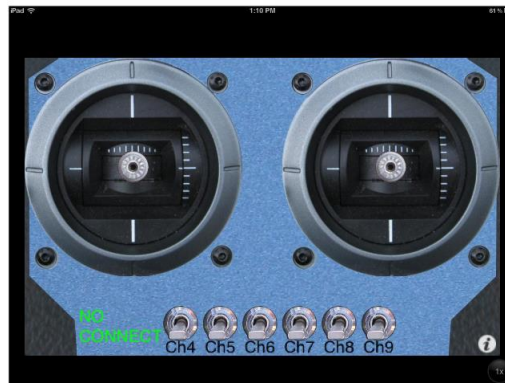

FIGURE 11
RC iPad INTERFACE

This interface allows for the control of multiple servos using the virtual joystick and the impeller fan is turned on and off using the channel 7 switch.

INTEGRATING ELECTRICAL AND MECHANICAL SYSTEMS

The last two weeks of class are reserved for students to put together their hovercrafts by integrating and interfacing the electrical components with the mechanical parts. They learn teamwork and design by assembling, testing and fine-tuning their hovercrafts. Each hovercraft is allowed to install one impeller fan, two servos, and up to three propeller fans for thrust and steering. The design options include the position and orientation of the fans that produce thrusts and generate turning moments. The land based hovercraft has only three degrees of freedom: two translations (longitudinal and transverse) and one rotation (yaw). The roll motion is negligible due to the small centripetal acceleration. Some teams experimented design options with nozzles, diffusers, and ducts attached to the end of the propeller fans.

POWER, SPEED AND ENERGY CONVERSION

The concepts of energy and power (rate of energy) are introduced throughout the semester when teams begin to assemble the electronics, the impeller, and the propeller fans together. Various forms of energy including electrical, mechanical, thermal (e.g., combustion and solar), potential (e.g, hydraulic dam) and kinetic (wind, ocean current, vehicle in motion) energy are demonstrated in the laboratory. Energy conversion is illustrated using the propeller fan: first, the motor converts the electrical battery power (= current times voltage = 6-7 Watts per fan) into mechanical power (= torque times angular velocity), which is then converted into the fluid flow kinetic energy (= air density times volumetric flow rate times air velocity squared divided by two) by the rotating blades. Finally, the fluid flow power is converted into the vehicle thrust power (= thrust times vehicle velocity) when the hovercraft moves at a constant velocity. The thrust is used to overcome friction due to air resistance plus resistance between the skirt and the ground. The final competition is based on the time required to complete the obstacle course. If each hovercraft consumes the same power, the total energy consumption is linearly proportional to the time it takes to complete the course.

ASSESSMENT

In Spring 2013, a total of 237 students registered for the course. At the end of the semester, 7 students withdrew, 13 students (5.5%) received grades below C-, and 217 students (91.5%) passed the course with grades C- or better. The student feedback was very positive, much better than the feedback received before the course adopted the project-based approach. Several seniors working as lab assistants expressed their envy toward the new course where freshmen are exposed to state-of-the art equipment and have fun learning in the course. More data will be collected to compare the retention rates.

CONCLUSION

We were motivated by the high intra university transfer rate out of College of Engineering among freshmen and sought to significantly improve the freshmen Introduction to Engineering course. The goal of this work was to change this course from a lecture based course to a hands on cross-disciplinary experience. Using a Hovercraft as a design project, we were able to communicate several aspects of engineering design to the freshmen, relying on computer modeling to overcome the lack of mathematical background among freshmen.

Initial feedback from the students has been very positive and the course in its new format has been exceptionally well received. However, a systematic evaluation of goals and outcomes is still in progress and will be reported in the near future.

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