Project Proposal
Team WET Design
The Levitating Sphere Project

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Project Web Site- http://wetdesign.ece.utah.edu/

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Introduction

WET Design is generously sponsoring a senior clinic in cooperation with the Computer, Electrical and Mechanical Engineering departments. The idea WET Design put forward is to have a group of students work on an interactive fountain design. The stated goal was to have a fountain that could interact with the environment and observers more than is currently done. Initial suggestions from WET Design were purposely vague so as not to pollute any ideas that might come forward from the student team. After discussing several ideas we settled on the one we thought was very interesting as well as challenging.

Our goal for this project is to design and construct a fountain that will keep a sphere levitated through the use of laminar flow jets. A graphic of this is shown in Figure 1 below. The fountain will be approximately 8 feet in diameter with six to eight laminar flow jets positioned around the perimeter. The direction of each of these jets will be controlled with two motors. One will control the side to side motion of the water stream and the other will control the vertical trajectory. All of these jets will work together to keep the sphere aloft. By coordinating the direction and pressure of these jets the sphere will be moved around to different positions and varying heights.

The fountain will interact with observers by detecting their position and movement. As an observer approaches the fountain the system will detect this movement and translate the position of the observer into a change of position of the levitating sphere. For example, if an observer approached the fountain from one particular side the sphere would move towards the opposite side of the fountain. Or if many observers approached from all sides the height of the sphere could be increased.

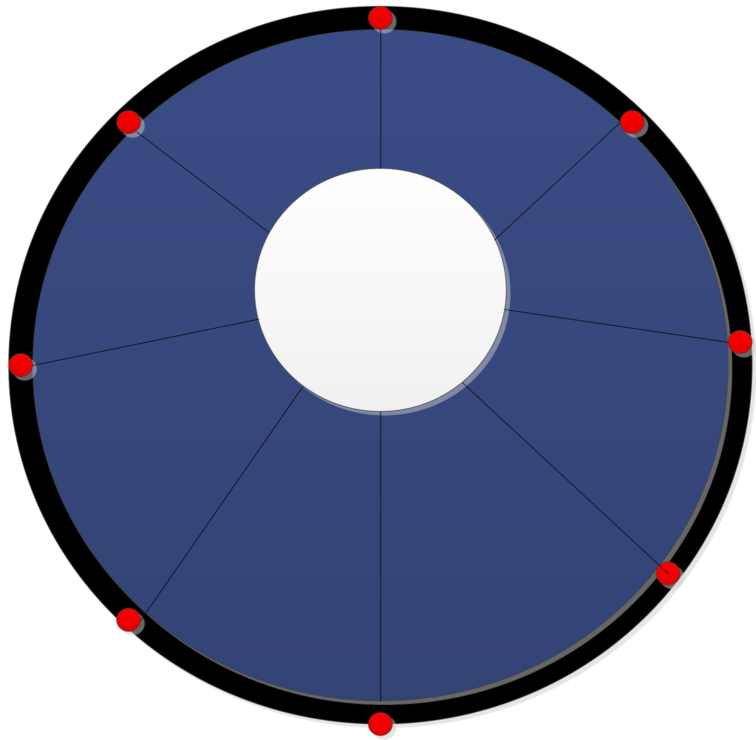

Figure 1 Sphere held aloft by laminar flow jets

The detection of position and movement of observers will be handled through the use of sonar range finders. These sonar range finders will be positioned around the circumference of the fountain with the sensors directed outward. From the signals generated by the range finders we will determine where people are and where they are moving. This will be translated into specific predetermined reactions on the part of the water jets.

We will need to be certain the sphere is never dropped from its suspended position. One safeguard to help assure this is to keep people back from the jets a certain distance. To this end, the pool will need to be surrounded by a guard rail. Although this will mandate keeping people back from the edge of the pool, they will still be able to get quite close.

Hardware details

Sonar range finders

Sonar range finders work by sending out signals that echo off of objects that they encounter. When this echo returns to and is detected by the sonar range finder unit, the time between broadcast and subsequent detection of the echo is measured. The time period is then translated into a discrete distance. The frequencies that are broadcast by these units are above 20KHz, which is about the high limit of human hearing, and thus are inaudible to humans. The range finders we will be using broadcast a 40KHz frequency signal.

The model of range finder selected for this project is the SRF02 manufactured by Devontech, LTD. This unit has a maximum range of approximately 20 feet and minimum range of 6 inches. The SRF02 has the capability to communicate either through a serial interface or by using the I2C communication protocol. For this project we intend to use the I2C communication protocol. This is the default communication protocol mode for the SRF02 and no setting will need to be changed to implement this. Because this project will require 14 sonar range finder units, every individual SRF02 will need to have a unique address. When the SRF02 units are shipped, they have the default address of 0xE0. This address easily configured by the user, and up to 16 separate addresses are available for use.

We plan to mount 14 range finders along the edge of the fountain, directed outward towards any approaching spectators. Our decision to use 14 range finders was reached by using the following logic.

It seems reasonable to have a particular distance at which we can be sure that no person will go undetected. The greater this distance becomes the higher the number of required range finders becomes. This is because the width of the detectable area changes with the distance from the placement of the SRF02. See Figure 2 for the example from the datasheet [1] for the SRF02.

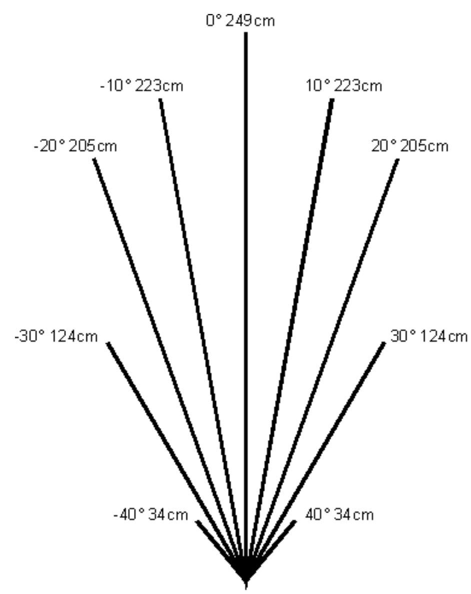

Figure 2 SRF02 beam pattern

The beam set at 20 degrees has a length of 205 centimeters. To convert to feet we just divide the 205 centimeters by 2.54 to get 80.7 inches, we then divide by 12 to get 6.7 feet. To calculate the lateral distance covered we use trigonometry and geometry as follows.

$$(1)\ 6.7\ feet * \sin(20) = \text{ 2.3 feet}$$

The equation (1) gives half of the lateral coverage so we just multiply this by 2. This gives 4.6 feet of lateral coverage for each SRF02 unit. However, we need to get a more accurate distance. To determine the center point of this 4.6 foot lateral spread we just use an equation similar to (1).

$$(2)\ 6.7\ feet * cosine(20) = \ 6.29\ feet$$

Equation (2) gives the distance from the center of the SRF02 to the center point of our 4.6 foot wide lateral signal spread. Now we need to calculate the circumference at that point. With our 8 foot diameter, or 4 foot radius, plus the 6.29 foot distance to the lateral spread we are measuring we have a total radius of 10.29 feet. To calculate the circumference we just use

$$(3)\ \ circumference = 2 * \pi * 10.29 = 64.65\ feet$$

Each individual SRF02 unit gives 4.6 feet of lateral coverage and we need to cover 64.65 feet. This translates into 14 SRF02 units. To determine the distance between mountings of the SRF02 units along the edge of the fountain we just proceed as above in equation 3 to find the circumference and divide this by 14. This gives a distance of ~21.5 inches between each sonar range finder. If we determine we want to expand our range we can mount more range finders. But it is important to remember that what we just calculated is the minimum distance someone could approach the fountain without being detected. This would mean walking perfectly between two of the range finders signal paths, an event that is not very likely.

Configuration of the sonar range finders will include setting the address, and the ranging mode. Commands for configuration are sent to register 0 on the SRF02 units. To set the address, a group of three command values need to be written to register 0, followed by the desired address. The command tuple is 0xA0, 0xAA, and 0xA5. This is then followed by one of the following addresses: 0xE0, 0xE2, 0xE4, 0xE6, 0xE8, 0xEA, 0xEC, 0xEE, 0xF0, 0xF2, 0xF4, 0xF6, 0xF8, 0xFA, 0xFc, or 0xFE. The programmed address can then be verified by observing the LED flashes on the SRF02. The pattern is one long flash followed by a number of short flashes that indicate the unique address as values between 0 and 15. Once all 14 SRF02s have been configured with the proper address we will then set the ranging mode.

The ranging mode is configured by writing a value to the command register. The SRF02 has three modes to select from, inches, centimeters, or milliseconds. Because this project does not require high accuracy in distance measured, the selected mode will be inches. Therefore, writing a hex value of 0x50 to the command register will be all that is required.

Communicating with the SRF02 range finders will require some experimentation. One issue that may come up is interference between adjacent range finders. It is possible, if we fire all of the range finders at the same instant, that they may detect pings that originated from a neighboring SRF02. Information from the manufacturer as to whether they can all be fired at the same instant is ambiguous at best. [2] If the project requires the SRF02s to be fired in sequence, this will result in a time of 0.91 seconds for all 14 range finders to be fired and read. This is because we need 65ms to ensure an individual range finder has transmitted and received its signal. With 14 range finders required to give the coverage needed, this total delay becomes significant.

Motors /Motor Drivers
We will need to control the direction of up to eight laminar flow jets. These jets will need to be able to rotate in a 3 dimensions. To accomplish this we will need at least two motors per jet, one to rotate horizontally and another to rotate vertically. Because of this we will need somewhere between 8 & 16 motors to accommodate 4-8 jets.

We plan on using stepper motors powerful enough to rotate the laminar flow jets and powerful enough to hold the jets at a certain angle when the water is flowing. Stepper motors have two benefits that fit our system. They provide the most torque at zero RPMs and they can rotate to relatively precise known angles. This will allow us to hold the jets when the water is flowing and aim the jet in the direction we need.

To control and power the stepper motors we plan on using motor drivers that have two different voltage levels, one for the motor and one for the control logic level. The motor drivers we plan on using are the "A4988 Stepper Motor Driver Carrier with Voltage Regulators" from pololu.com. These expose multiple control lines two of which we plan on using. These two control lines are called direction and step. Direction is used to tell the motor which direction to rotate and step is used to tell the motor to take a step in the direction of rotation. Because two lines are required to control each stepper motor and we will need 8 – 16 motors we will need 16 – 32 control lines going to our centralized control system.

SmartFusion Board
To read the sonar range finders and control the motors we will need a centralized computing system that can make all of the control decisions. It will need to have an I2C interface as well as at least 16 GPIO lines for the motors. We would also like to be able to send commands in real time from a PC and possibly configure things on the fly. To do this the centralized interface will need to have a UART connection so it can talk over USB through a UART to USB chip from FTDI.

The system that we have chosen that satisfies all of these constraints is the SmartFusion evaluation board. As seen on the next page in Figure 4 which is a graphic taken from the SmartFusion user guide[4] the SmartFusion has hardware support for I2C and UART and has 32 configurable GPIO lines. This will allow us to control up to eight motors using the hardware GPIO. In addition to this it has an on board FPGA in case we need any glue logic to support any external devices that we may need and have not planned for.

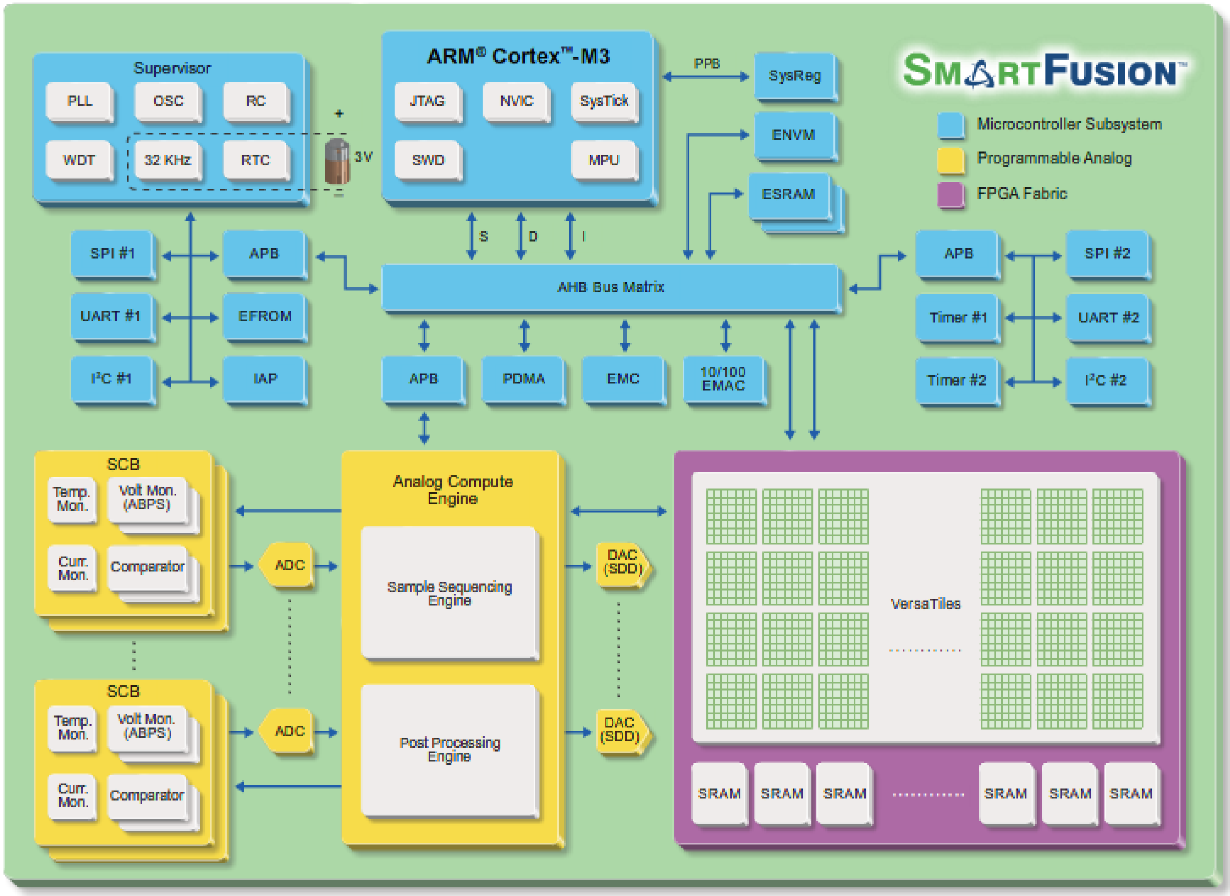

Figure 4 SmartFusion Hardware Diagram

Besides just meeting the physical constraints there are many benefits that the development environment provides. The development environment comes with software drivers for the I2C, UART and GPIO hardware which will save us time from reading datasheets and figuring out what registers to access to control these devices. It also contains a UART to USB chip on the evaluation board so connecting to a PC over USB as a COM port will be easy and quick to set up. The entire C standard library is provided as part of the development environment and the printf can easily be configured to print over serial to the PC.

Because of all of these benefits and because of the familiarity we have with the device we have decided to use the SmartFusion evaluation board as our central control for our system.

Bill of Materials

Presented on the next page is our bill of materials. The costs listed are the costs per device. There is a high probability that more materials will be needed than what is shown in this list. For example materials for the pool and construction of the laminar flow jets will likely need to be added to this list.

Device	Cost	Where to purchase
13 Range Finders	24.50	http://www.acroname.com/robotics/parts/R287-SRF02.html
16 Motor Drivers	19.95	http://www.pololu.com/catalog/product/1183
16 Stepper Motors	19.95	http://www.pololu.com/catalog/product/1200
SmartFusion Eval	99.00	http://www.actel.com/products/hardware/devkits_boards/smartfusion_eval.aspx
Total	1056	

Tasking

The WET Design team consists of more than just the two computer engineers that authored this proposal. Along with the two computer engineers, the team will include two mechanical engineers, Samuel Noertker, and Ed Grant as well as two electrical engineers, Matthew Prince, and Blaine Plastow. To take advantage of the skill set available, the tasking for this project will be broken up into the three main pieces as detailed below.

Design and construction of fountain

This phase will include finding a suitable structure to make up the pool portion of the project. It will need to include a sturdy platform around the perimeter upon which the laminar flow jets can be mounted. The sonar range finders will need to be mounted along the outer edge of this platform. The fountain will also need to have a pump that can draw water from the bottom of the pool to fill and pressurize a holding tank from which the laminar flow jets will be driven.

Each of the laminar flow jets will need to be mounted on plates that can swivel from side to side. These plates will be driven by stepper motors. The lateral range will most likely be less than 30 degrees.

Each of these jets will also need to have the ability to change the trajectory of the jet of water. This will require another stepper motor for every jet.

Construction of the 8 laminar flow jets with control valves will be time consuming but fairly straightforward.

A suitable pump for the project is the Bell and Gossett series 100 1/6 HP circulator pump. [3] This pump is capable of a maximum working pressure of 125 PSI. The series 100 can supply 32 gallons per minute at 1 foot of head pressure. This works out to 8 gallons per minute per laminar flow jet for a fountain with four jets. If the project requires more jets we can connect another circulator pump in parallel to double our gallons per minute capability.

A suitable pressurized holding tank for this project is the 44 gallon Dayton holding tank. It is capable of a maximum working pressure of 125 PSI. It can therefore handle the maximum PSI that the Bell and Gossett pumps will generate.

This fountain pump-holding tank system will need to include pressure monitoring equipment to allow for control of the pump. If the pressure exceeds a maximum threshold value, the pump will be shut off. If the system pressure drops below a certain threshold the pump can be turned on. The water level in the holding tank will also need to be monitored. It may well be the case that the system includes two pumps, and the second one can be turned on when pressure needs to be increased or when the water level needs to be increased in the holding tank.

This phase seems best suited to the skills of the mechanical engineers on the team with assistance from the electrical engineers.

Design and construction of motor, and pump circuits

This part of the project will be need to take as input, the low voltage signals that are output by the logic circuits, and convert them into signals of the appropriate amplitude to drive the stepper motors and water pumps. This will entail designing and building the analog circuitry, and constructing it in such a way as to be completely resistant to the water that will be present in this project.

This portion of the project is clearly in the domain of the team's electrical engineers.

Interfacing with sensors and creating a simulation of the fountain

The project will have 14 sonar range finders as the primary input to the system. The signals from all 14 of these will be present on the I2C bus. Each of the SRF02 devices will have a unique address that will allow us to identify it, and map its location. These signals will then be interpreted and parsed to give us the coordinates of observers in the vicinity of the fountain. We can then manipulate the output signals based upon what we would like to have the levitating sphere do in reaction the observer's position.

Creating a simulation will be necessary if the WET Design team is unable to secure an adequate lab space where we can set up the fountain. In this case we will need to have enough space to set up all of the sonar range finders to experiment with the signals presented by these units. These input signals will then need to be fed into the logic controls of our software and converted into appropriate output signals. These output signals will need to be monitored by testing software to assure they are exactly what is required.

This simulation step may be done even if we have a setting where we can set up the actual fountain. The thoroughness of the testing we can do in a simulation is much greater than what we could achieve through directly interacting with a fountain.

Interfacing with the sensors and the simulation portion of the project clearly falls under the domain of the computer engineers.

Scheduling and project milestones

Figure 3 below shows the Gantt chart scheduling for summer 2012. Sean Walton and Tyler Nichols will order and take delivery of the 14 range finders and the Smart Fusion microcontroller. The order will be placed in early May, pending approval from Professor Schmid. Upon receipt of the sonar range finders their addresses will be set, then connected to the I2C bus to enable testing of the SRF02 units.

The milestone for this phase will be to have configuration of SRF02 units completed, and to have successfully implemented ranging operations. This milestone is expected to be achieved by June 1st.

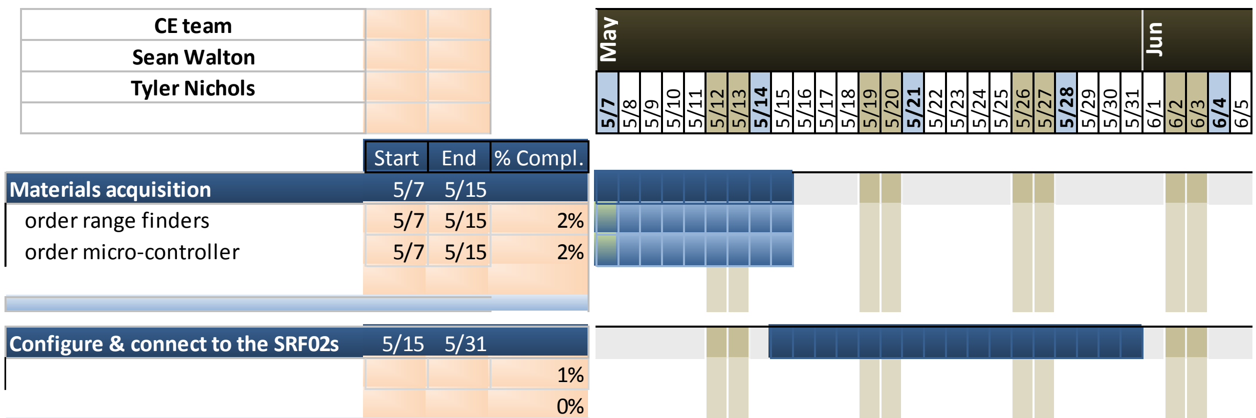

Figure 3 Gantt chart for materials acquisition

Figure 4 and 5 below show the proposed flow of the project beginning next fall semester. The major milestones for this phase will be to have the pool completed and in place, having working laminar flow jets, mounting the laminar flow jets on turrets, and having the circulation pump and pressure tank connected. The stages of this project will need to happen in the order they are listed here, although there can be some overlap in places. Specifically, the stepper motor controls can be implemented while construction of the laminar flow jets is happening. Ideally, the stepper motor controls for the laminar slow jets will be ready when the laminar flow jets are completed so the team can proceed to mount them along the circumference of the pool.

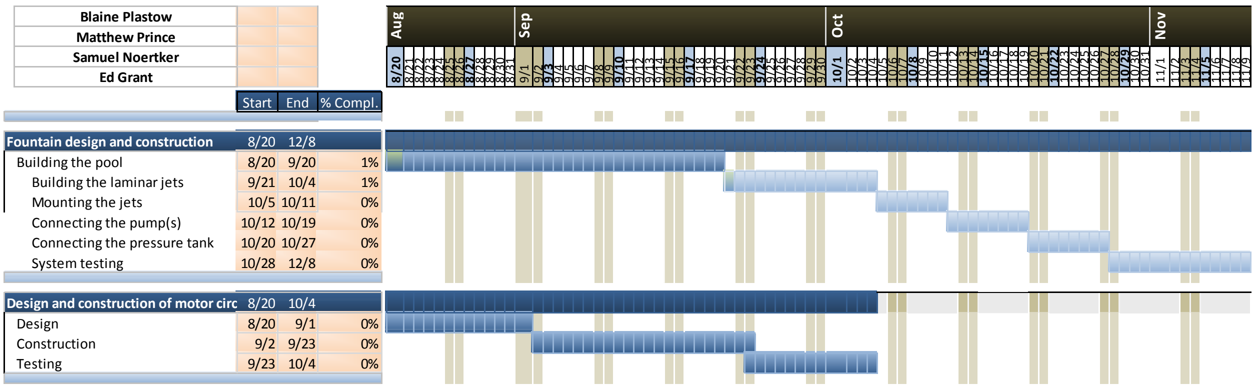

Figure 4 work schedule for fall semester 2012 part 1

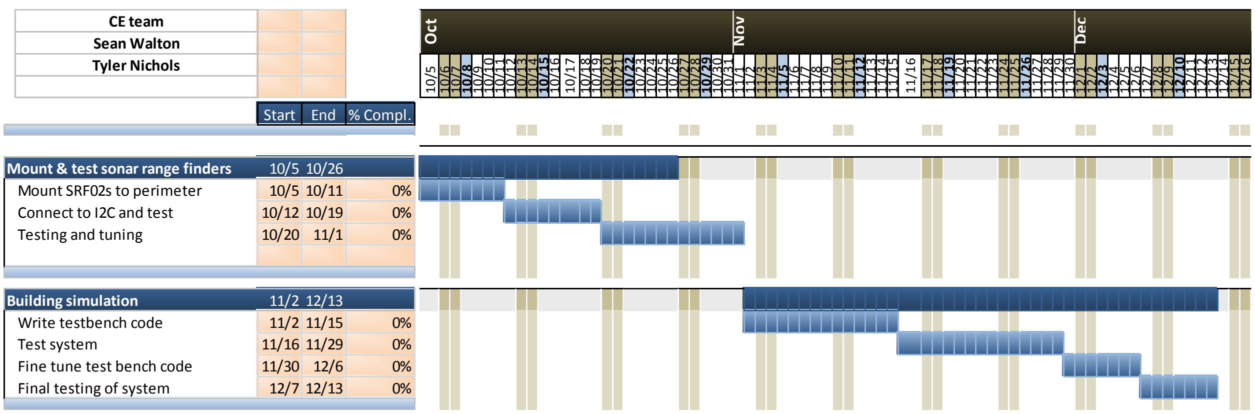

Figure 5 work schedule for fall semester 2012 part 2

Risks

There are many risks associated with our current plan. These include developing an accurate mathematical model that reflects the control of the sphere; Design and implementation of this model so that it satisfies the real world constraints; Devising a way to track the sphere if it turns out to be needed; Construction of laminar flow jets that are capable of sustaining and controlling pressure; Finding an appropriate location to prototype and demo the system.

The largest risk in all of this is the design of an accurate mathematical model. We plan to spend much of the summer working on this. If an accurate mathematical model cannot be derived by the end of summer we will likely need to decide on a different route to take hence it is our largest risk.

If we can derive such a model the next largest challenge will be designing an actual physical system that can implement the model. Hopefully in deriving the model we will gain further insight into whether we can build the system with our current knowledge and time constraints.

Also it may turn out that wind and other non-controllable environmental factors will have enough force to move the sphere. This will create a problem because our model currently relies on the sphere not moving anywhere except where we dictate through the control. If it can move independently of the control we will need to adjust the control to compensate in order to keep the sphere where we tell it to be. But in order to do any of this we will first need to know that the sphere is moving on its own so we will need to track its position. Hence developing a system to track the sphere is one of our potential risks. Ideally after the mathematical system has been derived we will know whether we need to track the sphere or not.

One plan that may allow the team to avoid tracking the sphere, is to compensate for wind in real time. By measuring the wind we can get a close estimate of the force the sphere is experiencing due to wind. The formula for the force on a sphere due to wind is given by the equation below.

(1) $$R = \frac{1}{2} * D * \rho * A * V^2$$

In equation 1, D is the drag coefficient. For spherical object this value is approximately 0.5. Rho is the density of air. This value is roughly 1.29. A is the cross-sectional surface area. For a sphere with a 14 inch radius this value is 0.397 M^2. V is the wind velocity. This equation reduces down to

(2) $$R = 0.128 * V^2.$$

The graph shown in Figure 6 was derived from equation 2. This figure shows the force on the sphere in Newtons with respect to wind speed as measured in miles per hour. It should be noted that the equation uses meters per second for velocity, and the graph relates wind speed in miles per hour. The force becomes somewhat significant by the time the wind speed reaches 25 miles per hour.

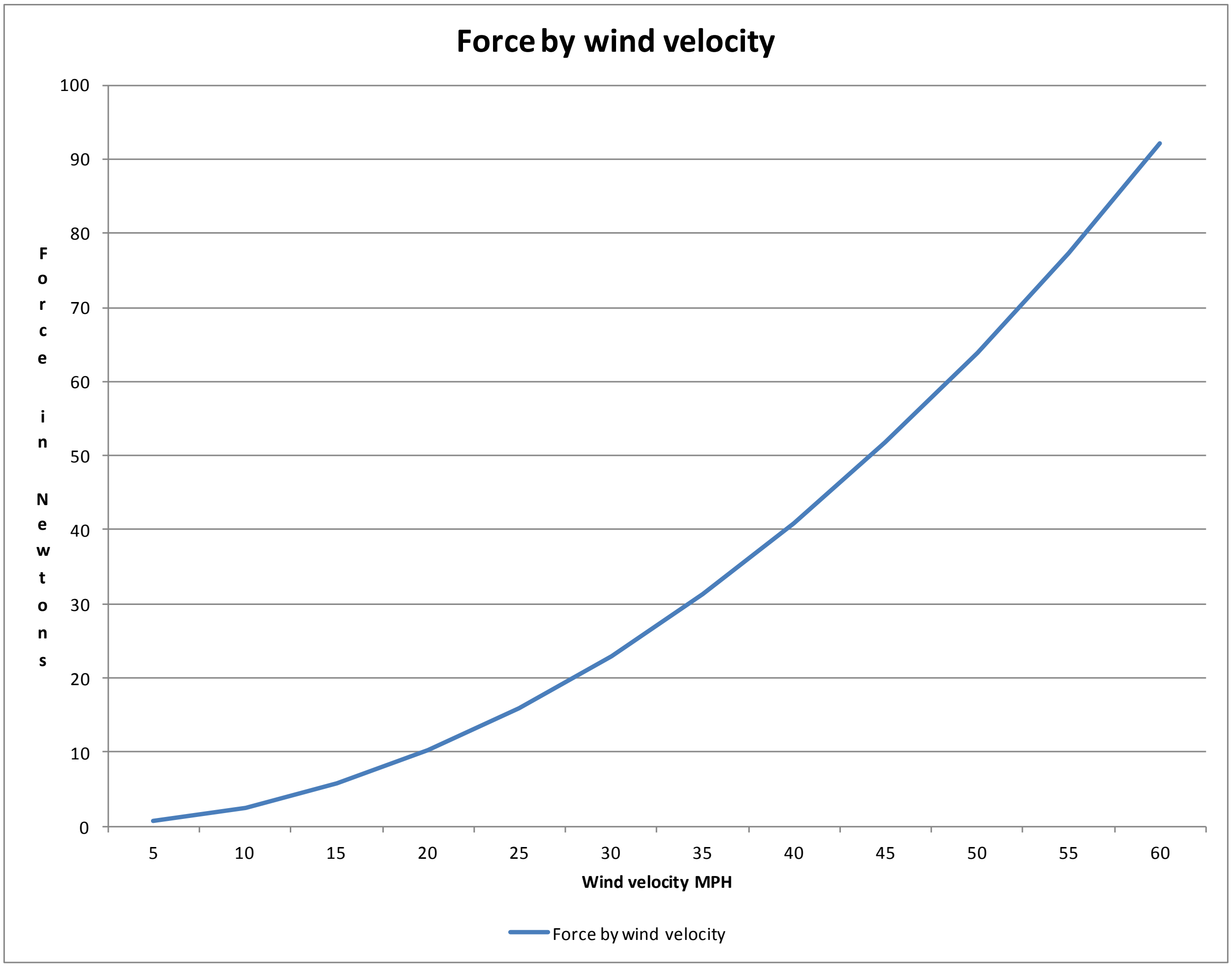

Figure 6 force in Newtons with respect to wind speed

Another potential risk is that we may not be able to use the laminar flow jets and pumps provided by WET Design. This is because of the size of these devices. They are meant for large systems and we may not be able to find and build a pool that is suitable for such a large system. Because of this we may need to build our own laminar flow jets and acquire pumps capable of driving these jets. Since our experience and expertise is not in mechanics we hope to be able to rely on the Mechanical Engineers on our team to help us solve this problem if we need to.

Conclusion

In conclusion, we are satisfied with the direction that our plans our moving and in the progress we have made so far. We have reason to believe that the risks mentioned above can be resolved with careful planning, coordinating and calculation. Because of this we plan to move ahead with our current plan and work first on mitigating our largest risks.

Bibliography

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