Senior Engineering Capstone Project: Modular Advanced River Barge System (M.A.R.S)

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Abstract

To celebrate the 300th anniversary of the founding of the city of San Antonio, the San Antonio River Authority (SARA) and the American Institute of Architects (AIA) sponsored an open competition for a redesigned river barge. The Spring 2016 Senior Capstone engineering students at the University of the Incarnate Word submitted a design for the competition. This paper outlines their design process using the given constraints and criteria. The student team used many of their engineering classes for the design, including MatLab programming, AutoCAD, Electronics, Fluid Mechanics, and Mechanics of Materials. They created a modular design that allowed for easy configuration of multiple uses for the barge, the Modular Advanced River Barge System (M.A.R.S.). While the design was not ultimately chosen by the city, this project was an invaluable experience that provided real-world applications to a practical engineering problem.

Keywords

River Barge, San Antonio, Capstone

Introduction

The City of San Antonio is the seventh largest city in the United States, and its River Walk is one of its distinguishing features. Designed by architect Robert H. H. Hugman in the late 1930s and ‘40s, the River Walk is one of the highest rated tourist attractions in Texas. Since its earliest beginnings, the River Walk has been navigated by small watercraft. Hugman’s bridge designs were tall enough to allow Venetian gondolas to float underneath. When San Antonio celebrated its 250th Birthday during HemisFair ’68, flat-bottomed barges offered visitors rides up and down the length of the river extension. These river barges continue to be used today for tourist cruises, river taxis and dinner barge excursions and have a combined annual ridership of 1.5 million.[1]

In 2018, San Antonio will celebrate its 300th Anniversary. This occasion prompted the city’s elected leaders to re-imagine the “river barge experience”, with a newly designed, sustainable, modular fleet, using innovative technology that could respond to the needs of both tourists and residents. This new river barge experience would provide residents a transportation option for daily commutes, while also serving the needs of the millions who visit the city every year. [1]

The design challenge was underwritten by the San Antonio River Authority and the Convention & Visitors Bureau, and the following requirements and evaluation criteria[1] were presented:

Requirements

- All-electric, battery-powered, 50 barge fleet (hybrid propulsion was not allowed)
- Twelve hours minimum use on one battery charge
- Motor propulsion choice of inboard, inboard/outboard, or outboard
- A 15 – 20 year barge lifespan, at a cost of $40,000 to $65,000 per barge
- Innovative materials in the construction of the barges
- Accommodation for disabled riders, including companion seating for riders in wheelchairs
- Accommodation for commuters
- Accommodation for up to 40 passengers per barge tour
- Accommodation for dining, musicians, and other events
- Traverse through a lock with a barge size no larger than 9 feet by 27 feet
- Provide a safe, level ride with minimal wake
- Complement City of San Antonio branding

Evaluation Criteria:

- Constructability, including the economic feasibility of manufacturing the barge. The goal was to have a majority of the fleet in operation by January 2017.
- Functionality, including durability and longevity of the barge and batteries
- Originality of design
- Innovation

System Design

The modularity of the barge revolves around a designed grid system of recessed steel sleeves in the deck of the boat, as shown in Figure 1. The sleeves, Figure 2, are used to place a steel pole to support the seats and dining table options that are affixed to the pole. [2] A brass cover can be closed when the sleeve is empty. One advantage of the grid system is the simplicity of its design. The seats and tables can be quickly arranged into multiple configurations by simply picking up the seat or table and placing it in another sleeve found within the grid system. Figures 3a and 3b illustrate designs for some of the configurations in the proposed grid system. The tour layout, Figure 3a, is in a forward facing arrangement. This optimizes the passengers' comfort and safety. The grid system also provides multiple dining options. A booth layout could be utilized as shown in Figure 3b. The booth layout seats 24 people and can be adjusted to allow seating for passengers in wheelchairs. A plan view and elevation view of the tour layout are shown in Figure 4.

The proposed system design placed an emphasis on practicality and versatility. The grid system delivers both of these attributes and also provides the city with the ability to continue to build upon its user-friendly design.

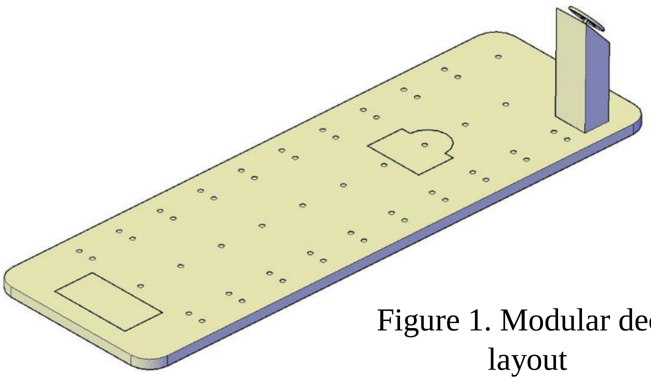

Figure 1. Modular deck layout

Figure 2. Recessed deck sleeve with cap

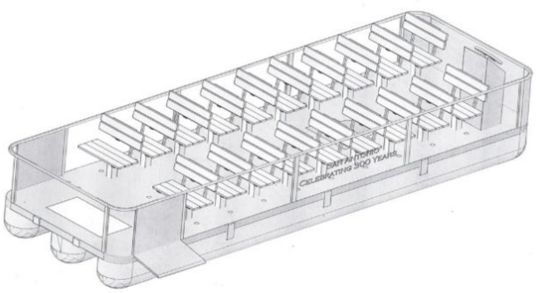

Figure 3a. Forward facing benches for tours

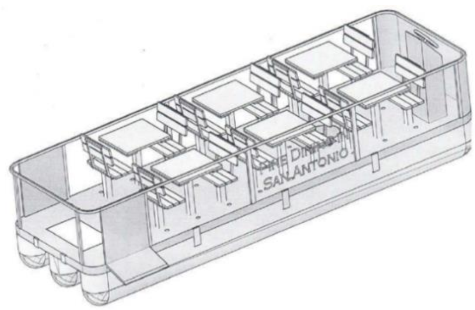

Figure 3b. Booth arrangement for dining

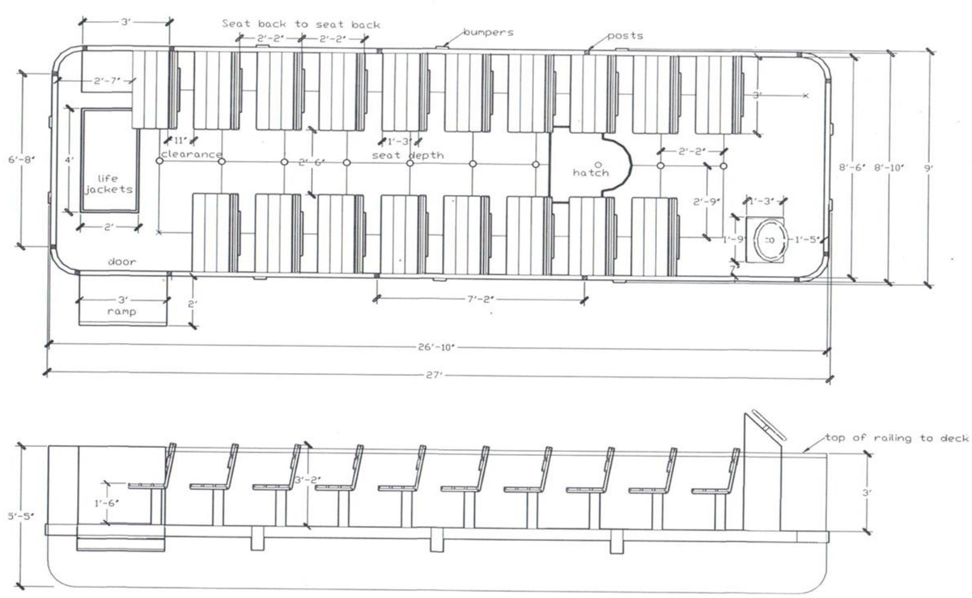

Figure 4. Plan and elevation views of tour layout

System Design Analysis

Buoyancy

In this section, we present the MARS design analysis based on the two critical factors – the buoyancy and the electric propulsion system. In order to achieve an entirely electrically powered barge with a minimum number of batteries, it was imperative to minimize the power consumption of the motor. In the initial design phase, capstone team determined that triple pontoon[3] layout optimized buoyancy force in relation to the force of drag exerted by the water. The two outer pontoons span the length of the barge at 27' with a diameter of 13". The inner pontoon had a length of 18' with a diameter of 13". The front of the inner pontoon was aligned with the front of the outer pontoons. The shorter length of the inner pontoon allows for installation of the inboard engine.

The buoyant force was calculated by using Archimedes Principle, $\rho g v = mg$, where ρ = density of fluid, g = gravitational force, v = fluid volume displaced, m = mass of fluid volume displaced.[4] An important design requirement of the barge was the Americans with Disabilities Act (ADA) compliance. When loading and unloading, some passengers require the aid of a ramp. It was important to ensure that the ramp had a shallow slope to allow for ease in transfer. In order to find the depth levels of the boat in multiple seating configurations, a MATLAB code was developed to easily calculate the depth at which the boat sat in the water. The volume of water displaced was calculated for each design layout. With a given width and length, the height of volume displaced could be calculated using the volume of a box. Figure 5 shows the graph with a linear representation plotting the height of the barge deck above the water at varying weights based on the barge design layouts. The weight of passengers is averaged at 200 pounds.

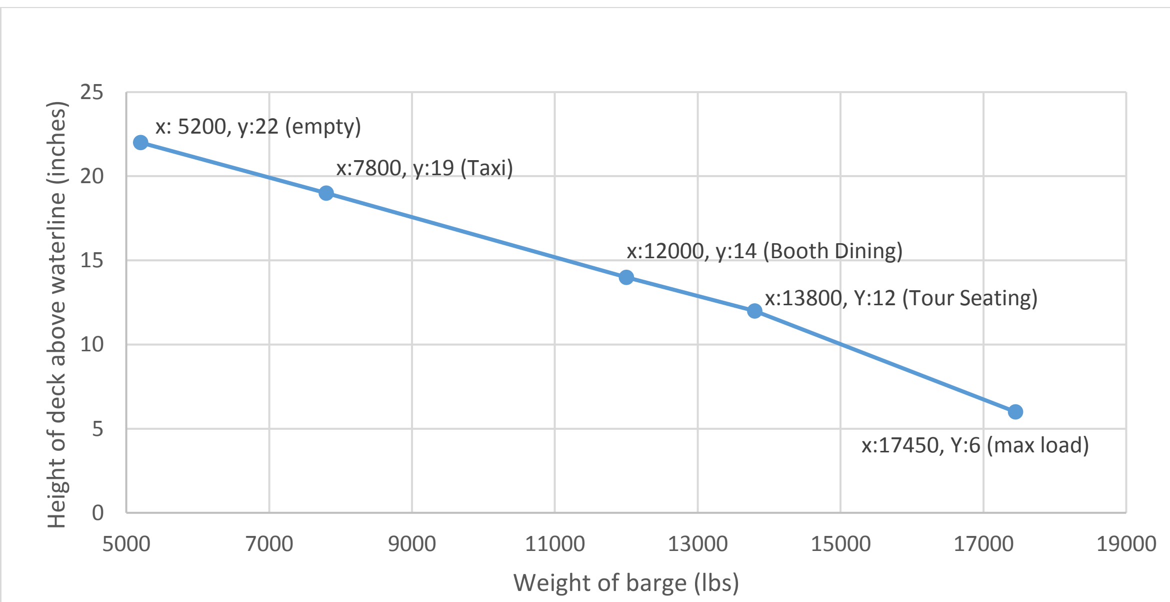

Figure 5. Buoyancy of barge

Motor design

As required in the design requirements, the proposed propulsion system had to be completely electric. The capstone students chose the EP-12 by Elco Motors[5] due to its reliability, cost and the reputation of the company based on customer service. Since 1893, Elco has a long history of producing some of the first electric powered boats. Table 1 lists the full specifications for the EP-12 electric motor. The EP-12 motor provided the MARS design with enough torque to navigate 12 hours on the San Antonio River Walk.

EP-1200	
MOTOR SPECIFICATIONS	
Suggested horsepower replacement range	8 – 18 h.p.
Peak kW	8.8 kW
Continuous kW	5.1 kW
PURE ELECTRIC PERFORMANCE	
Cruising speed	5 – 6.5 knots
Recharging time standard charger	3 – 4 hours
Number of 12 volt batteries (245 Ah)	4 batteries
Battery bank voltage in total	48 vdc
Amps (maximum)	106 amps
Kilowatts (peak output kW rating)	8.8 kW
Kilowatts (continuous output kW rating)	5.1 kW
Nominal Module Voltage	12.8 Volts
Nominal Capacity	138 Ah
Specific Energy	91 Wh/kg
Energy Density	148 Wh/I
Max Continuous Load Current	150 A
Peak Load (30 seconds)	300 A
Max Charge Voltage	14.6 Volts

Table 1: Elco EP-12 Motor Specifications[6]

Batteries

For power, the team selected the U27-12XP 12-volt Lithium-ion battery made by Valence Technology Inc.[7] This specific battery brand was chosen by the team due to its superior efficiency as compared to typical lead-acid based batteries. In addition, these batteries are more environmentally friendly, hold their charge longer, are not affected by charge memory, and superior energy density.[7] Once the team decided to use lithium-ion batteries, they began to investigate how many batteries were needed to supply the barge with sufficient power. The amount of energy required to move the boat was then calculated. The first step was to calculate the drag force of water on the barge. The force of drag was calculated using $F_{Drag} = C_D * .5 * A * \rho * v^2$, where C_D= Coefficient of Drag, A = Area, ρ = density of fluid, v = velocity.[4] This was done at a range of three to ten miles per hour. Once the drag forces were calculated, it was possible to determine the wattage in watt hours, using $Watt\ Hours = Voltage * Amp\ Hours$, needed to overcome these forces. The next task was finding the number of batteries that would be required to supply the energy and the length of time they could supply the energy to the motor. The target goal for this barge was to operate for twelve hours without recharging. With the cruising speed of barges ranging from three to ten miles per hour, it was determined that the optimal speed was seven miles per hour to ensure twelve hours of continuous use. This speed could be achieved with a pack of eight batteries. These batteries would provide 14.13 kW-hours of use time. Multiplying the hours available at each wattage times the speed gave the distance the barge could cover while travelling at that constant speed.

Figure 6 shows the power curve of the battery pack. Figure 7 displays the power curve versus the distances travelled in the three to ten mph range and the optimal speed. The optimal speed for this barge is 7.5 mph which is well above the normal cruising speeds for this barge. Two more additional batteries were added to supply charge for the onboard electronics. MATLAB was used to analyze and plot the results.

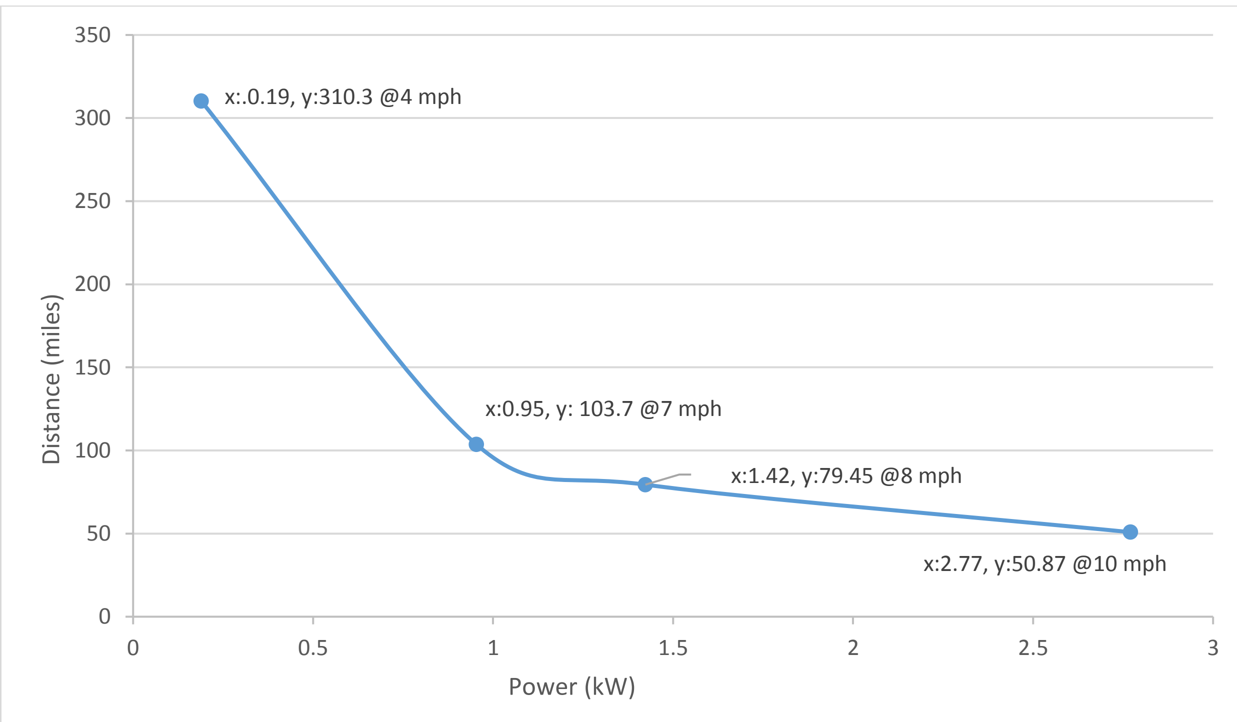

Figure 6. Power vs Distance Curve, based on eight batteries

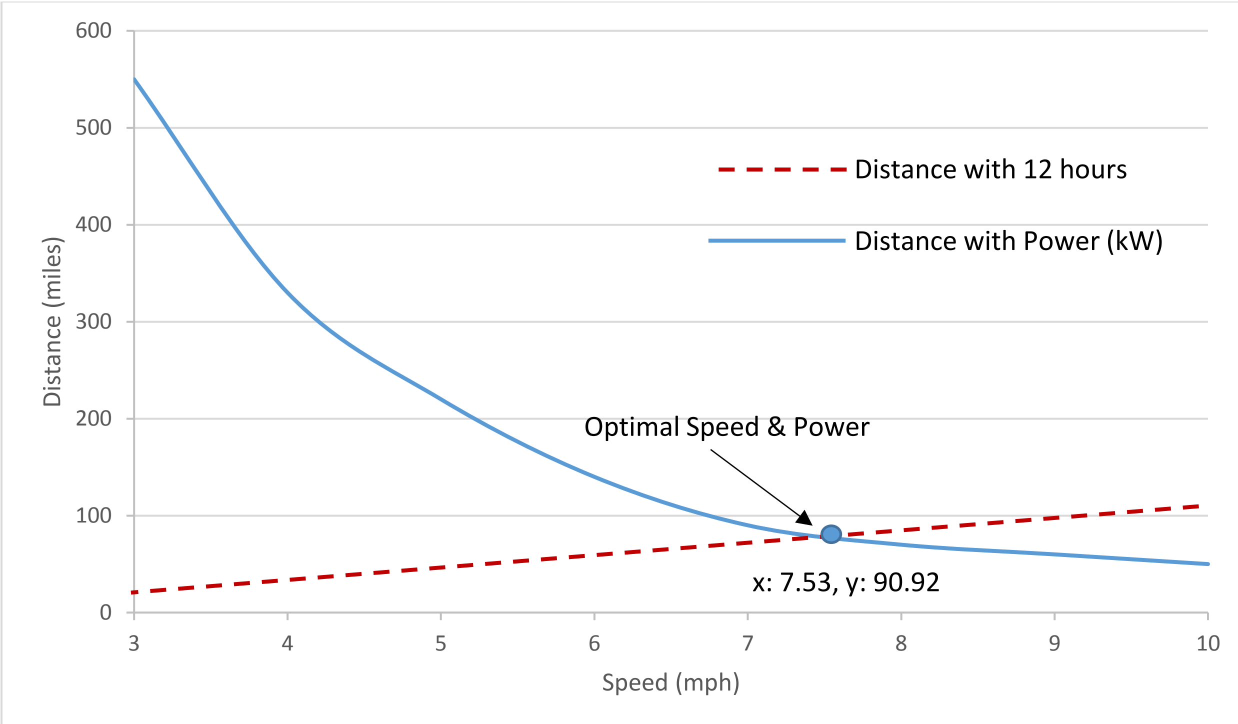

Figure 7. Optimal speed, based on eight batteries

Materials

The students selected each material in the MARS design in order to provide ease of maintenance and longevity. All the materials utilized in the design are readily available in the United States. An integral aspect of the barge is the grid system of steel sleeves[2] within the deck that support our seating options. Steel's strength and ability to resist twist will provide a solid structure to ensure the integrity of the passenger benches. Polished brass caps would cover the open ends of the sleeves in the deck when they were not in use. The brass caps brought an aesthetic appeal to the deck of the boat and required very little maintenance due to the naturally anti-corrosive properties of brass. The benches, shown in Figure 8, were designed using aluminum[8] and composite wood[9] that come together to final product that was both lightweight and durable.

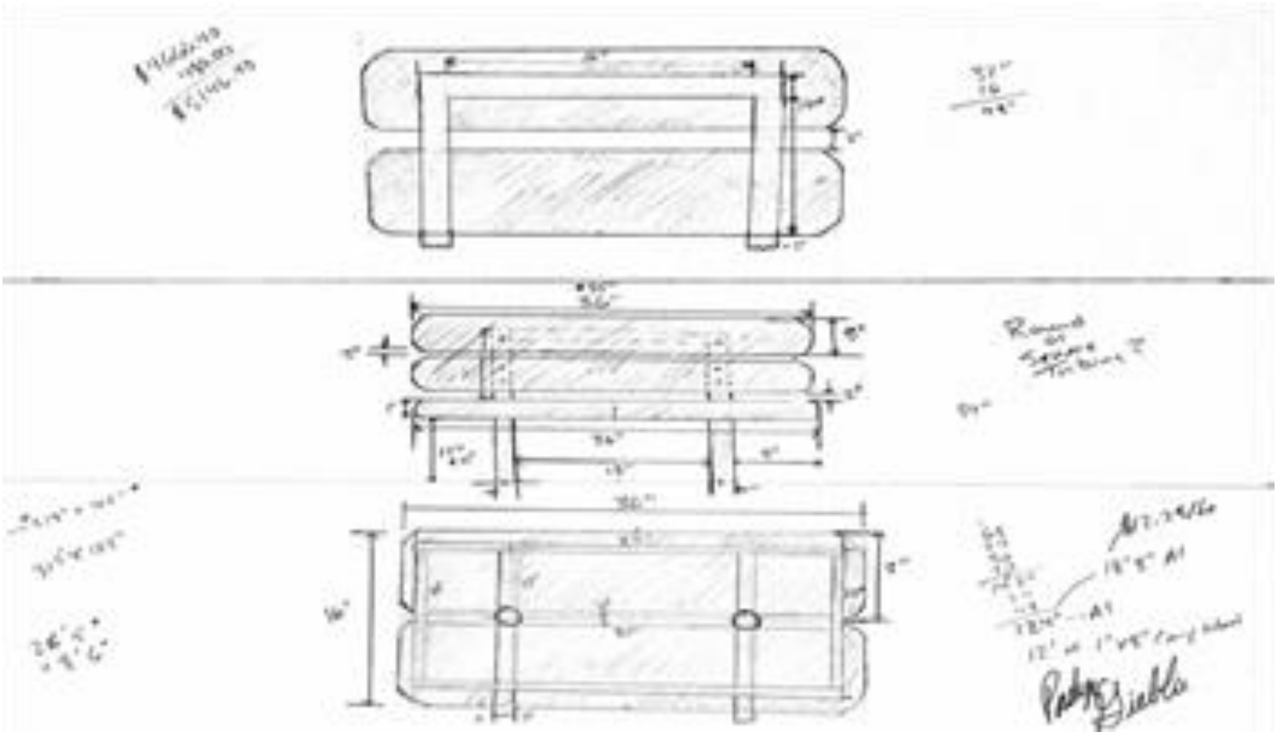

Figure 8. Student bench design

Composite wood uses a combination of recycled materials to create an extremely durable product that resists rot and can last for up to 20 years[9]. Aluminum's ability to resist corrosion provided durability to fit the needs of the barge[8]. These attributes helped to make the movement and rearrangement of the seats very manageable.

Cost Estimates

The construction of barge would emphasize cost effectiveness as well as maintainability. Table 2 shows the estimated total cost of the construction of the barge, which was calculated to be under $50,000. Labor costs were not included in this analysis.

ITEM	QTY	COST	TOTAL
Power Generation			**$ 23,225.00**
Elco 1200	1	$ 8,520.00	$ 8,520.00
Valence U27-12XP	10	$ 1,289.00	$ 12,890.00
Battery Charger	1	$ 140.00	$ 140.00
Drive Shaft	1	$ 600.00	$ 600.00
Prop	1	$ 175.00	$ 175.00
Steering	1	$ 900.00	$ 900.00
Benches and Tables			**$ 4,852.00**
NyloBoard (linear feet)	310	$ 4.00	$ 1,240.00
NyloDeck (36"x36"x1/2")	10	$ 76.00	$ 760.00
Al Tubing (1"x3"x0.125")	28	$ 35.00	$ 980.00
Steel Tubing (4"x4"x3/16")	3	$ 199.00	$ 597.00
Machined Steel Sleeves	51	$ 25.00	$ 1,275.00
Hole Covers			**$ 2,550.00**
Polished Brass Caps	51	$ 50.00	$ 2,550.00
Safety			**$ 1,461.00**
Type III PFD	41	$ 13.00	$ 533.00
HDPE Bumpers, Black	6	$ 14.00	$ 84.00
Speaker, Waterproof, Bluetooth	6	$ 70.00	$ 420.00
Type IV Life Ring	1	$ 50.00	$ 50.00
Fire Extinguisher	1	$ 88.00	$ 88.00
Kill Switch	1	$ 17.00	$ 17.00
Head Set with Microphone	1	$ 10.00	$ 10.00
Horn	1	$ 60.00	$ 60.00
Two-Way Radio	1	$ 199.00	$ 199.00
Hull			**$ 17,098.00**
Aluminum (27'x9')	1	$ 10,000.00	$ 10,000.00
Pontoon Tube (26'x26"x1/8")	2	$ 2,606.00	$ 5,212.00
Aluminum (21'x26"x1/8")	1	$ 1,886.00	$ 1,886.00
		TOTAL	***$ 49,186.00***

Table 2. Itemized List of Materials and Cost

Education Pedagogy

A total of 128 hours is required for a BS in Engineering degree. In addition to the general core courses required by the university and STEM core courses, each engineering student chooses a track of study. These tracks are from 12-14 hours in the areas of electrical, mechanical, mechatronics, or management. A one-semester, 4-hour capstone project is the final requirement for the degree. Capstone projects have covered a wide range of topics, which have included sustainability, campus parking, rooftop gardens, autonomous vehicles, and wind turbines.

In Spring 2016, 3 senior students enrolled in a capstone section with their mentor, Dr. Okan Caglayan. Each capstone group meets late in the previous semester to choose a topic. Dr. Alison Whittemore had received an email from the city of San Antonio announcing this barge competition. After a discussion among colleagues and the student team, they decided to submit a proposal for the new, all-electric barge. The project would cover many of the courses that the students had taken throughout their 4 years of study—Fluid Mechanics, Physics, Electronics, Economics, Mathematics, Mechanics of Materials, Statics, and Dynamics, among others. A capstone class is meant to be just that; the final culmination of studies. This project was ideal for a capstone, with students doing hands-on work with many of the topics they had studied. A fourth student, a sophomore who was not eligible to take a senior capstone class, was so enthusiastic about the project that he was allowed to join the team, even without any course credit.

The students met once per week with their mentor. All members of the team participated in several meetings and tours sponsored by the city for the many competitors, including a two-hour trip on a current city barge along the entire length of the navigable river channel. The students had many questions for the barge driver and city officials. Within the first month, each student had carved out an area of responsibility for the project. They worked to combine the requirements of all-electric power, long battery life, multiple seating arrangements, and safety of the ride. They oversaw the materials and created a budget. In addition, they spent a great deal of time focusing on the aesthetics of the design, and the brand of the city of San Antonio.

The students were competing with large established architectural and engineering companies. Those companies had a great advantage with staffing and graphic designers. However, after sitting through the city meetings, it became clear that our students had a strong command of the complicated engineering design that an all-electric, 12-hour tour vehicle would require. They did extensive modeling with MatLab to come up with a design that would have the power to carry the heavy, all-day loads. The team came up with a highly original modular design to facilitate the rapid layout switch for tours, dining, entertainment, and commuters.

The design process was often very stressful on the students. It was difficult to balance this design project with their other classes, varsity sports, employment, and family obligations. For the first few weeks, there was tension in the process of deciding who would cover which research area, and who would be the spokesperson for the team. There were many late nights and vociferous conversations, but the project was completed and submitted by the deadline. It would have been a great accomplishment if our barge design had been selected, but in the end, the city chose to go with a design that that provided a strong visual impact.

Even though this capstone design did not win the competition, the professors involved with the project considered it a great success. Student used much of the course material from their degree plan to design the barge. They researched multiple areas of technology. They came up with innovative design processes. They went through the tough process of creating a cohesive team. They created schematic drawings, graphs, and tables, and submitted a strong, professional application. These are all invaluable skills for their engineering careers, where they will apply for grants, write reports and papers, and present their findings. The M.A.R.S project gave them these skills and more.

Conclusion

This project was a very successful capstone experience for our students. The project was both exciting and challenging, and students rose to the task. They did not have access to advanced technical or design software, and still were able to create a workable, attractive barge for the competition. The modular design they created can be used in projects beyond a simple barge. This project provided invaluable experience in real-world applications to a technical and aesthetic challenge.

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Alison Whittemore, Ph.D.

Dr. Whittemore founded the Department of Engineering at UIW in 2003. She earned a BS and MS in Civil Engineering from Rice University, a BFA in printmaking from the University of Texas at San Antonio, and a PhD in Organizational Leadership from UIW. She currently teaches and serves as chair of the department. She is also the co-director of the UIW Sustainability Office. Her research focuses on sustainability and green building.

Okan Caglayan, Ph.D.

Dr. Caglayan currently serves as an Assistant Professor of Engineering in the Department of Engineering at the University of the Incarnate Word (UIW). He earned a Ph.D. degree in Electrical Engineering from the University of Texas at San Antonio. The scope of his research ranges from developing new techniques in the areas of digital signal processing and image processing with pattern recognition applications.

Yura Galvez, Padyn Giebler, and Andrew Grossman

These three students were Senior Capstone members of the MARS project and earned their BSE in May 2016.

Max Martinez

Sophomore in engineering and design enthusiast