THE DETAIL DESIGN OF A WOODEN, SOLAR-ELECTRIC LAUNCH FOR THE CARMANS RIVER MARITIME CENTER

by

Hampton K. Dixon, Andrew J. Lachtman, and Lidia Mouravieff

A thesis submitted in partial fulfillment of
the requirements for the Bachelor of Science Degree in
Naval Architecture and Marine Engineering

Hampton K. Dixon

Andrew J. Lachtman

Lidia Mouravieff

Certification of Approval

Roger H. Compton, Dean

Date

Professor Matthew R. Werner, Principal Advisor

Date

Webb Institute
Glen Cove, New York

ACKNOWLEDGMENTS

We have a few colossal acknowledgments to make,
Before we celebrate our thesis with a bodacious cake.
Without the Carmans River Maritime Center,
We would not have embarked on this educational venture.
From our first true clients, we learned a lot,
And gained valuable experience we could not have bought.
A huge thanks to our advisor, Professor Werner.
From the start, he had us composing our page turner.
His nonstop motivation and constructive criticism
Kept us ahead of the game, which is altruism.
Prof. Hennings was onboard the project from day one,
And constantly supported us until we were done.
Mr. Steve Corkery helped introduce wooden boats.
His love for traditional crafts made us take good notes.
Our powering predictions are more reliable
With Prof. Hadler's help — that's undeniable.
Our written report is sure to wow,
Thanks to the edits by Professor GOW.
Lastly, we are grateful for each of us in HAL,
Throughout the past year, we have become grander pals.
Webb is the source of many memories and much knowledge,
And for that, we thoroughly cherish our favorite college.

ABSTRACT

In an age of advanced composite construction, America's rich tradition of wooden boatbuilding is slowly fading into the past. During the winter of 2010, the Carmans River Maritime Center (CRMC), a non-profit museum and workshop for wooden boatbuilding located in Brookhaven, New York, partnered with Webb Institute to design a solar-electric wooden launch for ecological tours of the Carmans River and surrounding environments. This project aims to meet the CRMC's design needs. Given the mission of the vessel, emphasis was placed on utilizing eco-friendly technologies including photovoltaic panels and all-electric propulsion. Through research and a strong client-designer relationship, the team recommended solutions for synthesizing modern technology with traditional aesthetics. The design package includes a lines plan, construction drawings, and bill of materials for the 24-ft, six-passenger launch powered by a 4.0-kW electric outboard motor with a design speed of 5 knots.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

VARIABLES

A_T	Frontal area to wind
B	Beam
BHP	Brake horsepower
B/T	Beam to draft ratio
C_{AA}	Air resistance coefficient
C_B	Block coefficient
C_D	Drag coefficient
C_F	Frictional resistance coefficient
C_P	Prismatic coefficient
D	Depth of hull at amidships
EHP	Effective horsepower
i_E	Half-entrance angle
F_n	Froude number
K	Wind directionality factor
L/B	Length, waterline, to beam ratio
LOA	Length, overall
LWL	Length, waterline
R_{AA}	Air resistance
R_F	Frictional resistance
R_n	Reynolds number
R_R	Residuary resistance

R_T	Total resistance
S	Wetted surface area
Sn	Scantling number
T	Draft
V_s	Vessel speed
$\forall$	Underwater volume
V_R	Relative wind speed
ρ_{air}	Density of air
ρ_{sw}	Density of saltwater

ABBREVIATIONS

ABS	American Bureau of Shipping
ABYC	American Boat and Yacht Council
AC	Alternating current
AGM	Absorbed glass mat
CFR	Code of Federal Regulations
CRMC	Carmans River Maritime Center
DC	Direct current
DOD	Depth of discharge
ICE	Internal combustion engine
ITTC	International Towing Tank Conference
NPL	National Physics Laboratory

SYMBOLS

A	Amps
Ah	Amp-hours
ft	Feet
gpm	Gallons per minute
hp	Horsepower
in	Inches
kg	Kilograms
kt	Knots
kW	Kilowatts
kWh	Kilowatt-hours
kW_p	Kilowatts, peak output
lb_f	Pounds (force)
lb_m	Pounds (mass)
nm	Nautical miles
V	Volts
W	Watts
Wh	Watt-hours
W_p	Watts, peak output

INTRODUCTION

In an age of advanced composite material construction, America's long tradition of wooden boatbuilding is slowly fading into the past. Fortunately, maritime museums across the United States have been established to preserve the skills of shipwrights for future generations to learn and to appreciate. The Carmans River Maritime Center (CRMC) of Brookhaven, New York was founded in 2002. The Center's goal is "to sustain the maritime skills and traditions associated with Brookhaven Hamlet and the Great South Bay" (Carmans River Maritime Center).

During the 2010 Webb Institute winter intercessional period, CRMC President Steve Gould approached Webb Institute faculty members Professor Matthew R. Werner and Professor John F. Hennings about the prospect of involving Webb students in the design of a wooden tour boat for the CRMC to build and operate. The CRMC's location near the mouth of the Carmans River and its proximity to the Wertheim National Wildlife Refuge position the facility as a prime origin for river tours to the national refuge (Figure 1).

The Center determined that an electric launch would be the most environmentally benign vessel, allowing visitors, particularly elementary school groups, to enjoy the natural beauty and wildlife of the river without the noise and exhaust of an internal combustion engine. Although electric launches are commercially available, the CRMC wanted a wooden launch that could be built onsite, thereby serving as both a showpiece of the center's wooden boatbuilding capabilities and as a gateway to the Carmans River.

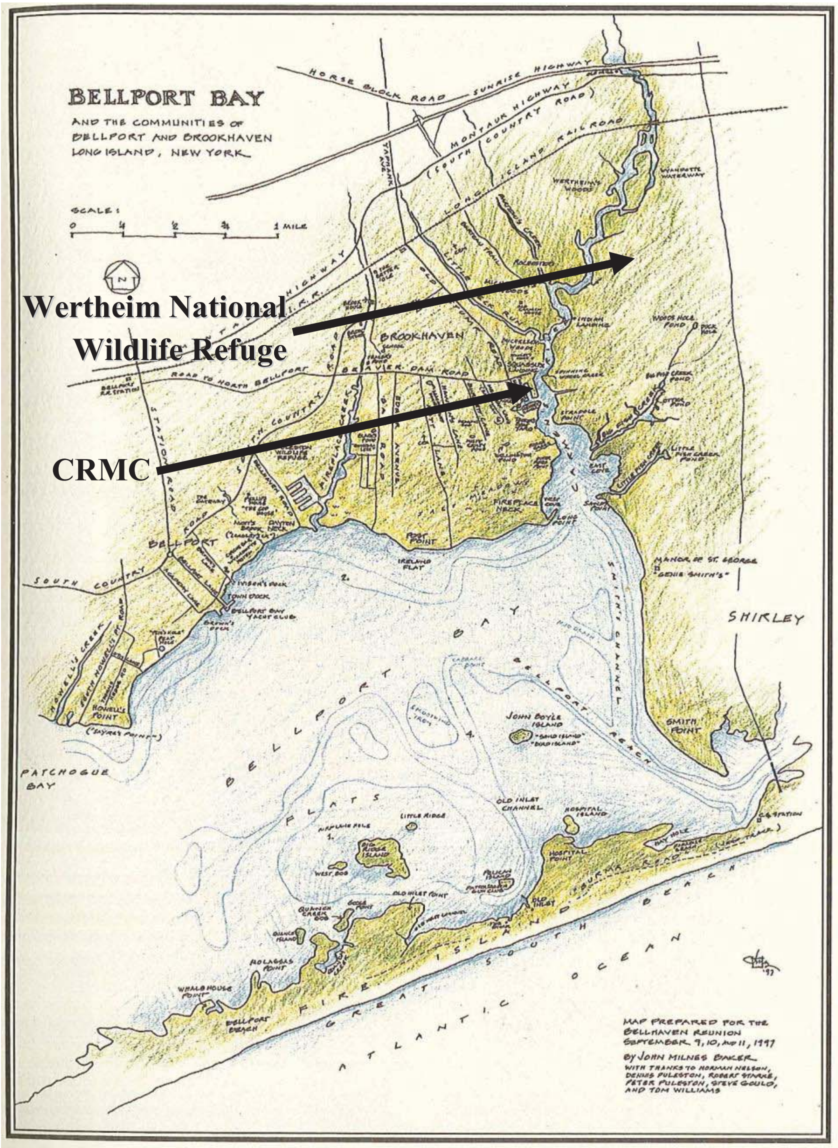

Figure 1: Map of the Carmans River
Source: Borg and Shreeve

This thesis project aims to satisfy the design needs of the CRMC while providing the thesis team with an understanding of wooden boat design and construction. In addition, the project exposed the team to new developments in photovoltaic and small-scale electric propulsion technology. The design process began with the compilation of a database of similar vessels, the selection of a parent hull form, and the completion of a conceptual design. Design options were considered, weighed, and rationally selected based on input from research, the adviser, industry mentors, the client, and prior experience. The CRMC had the final authority on all design considerations, and formal design presentation meetings with the client were held at the conclusion of the conceptual and preliminary design stages.

BACKGROUND

CARMANS RIVER

Boatbuilding along the Carmans River began with the first settlement by the Unkechaug Indians over 500 years ago. The river provided them with access to whaling and fishing on the Great South Bay and in the Atlantic Ocean. The Unkechaugs built boats of varying sizes from tree trunks, including 80-man dugout canoes (Borg and Shreeve). Although Native Americans no longer inhabit the area, wooden boatbuilding continues along the river to this day.

At the beginning of the twentieth century, Captain Samuel Newey owned and operated a successful shipyard on the site of the CRMC. Newey's yard built boats ranging from rowboats and yachts to tankers. The site changed ownership several times before 1999, when the Post-Morrow Foundation purchased the site to house a facility that would emphasize the traditional boatbuilding skills of the region. In 2002, the site became known as the Carmans River Maritime Center. The following mission statement was developed:

> *"The Mission of the Carmans River Maritime Center is to operate an educational facility for the building, restoration and repair of wooden*

> *boats while sustaining the maritime skills and traditions associated with Brookhaven Hamlet and the Great South Bay."*

In support of the organization's mission, the CRMC is planning to expand its fleet of boats to allow visitors to explore the local environment and wildlife. The Carmans River is home to more than 40 species of fish and more than 240 species of birds, some of which are shown in Figure 2 (Borg and Shreeve). A large number of mammals and amphibians inhabit the Carmans River's shorelines.

Figure 2: Wildlife in the Carmans River

The Wertheim National Wildlife Refuge, located along the Carmans River, is one of the last undeveloped estuary systems that still exist on Long Island and is a major habitat for migratory birds. Salt water marshes are unique ecosystems that rapidly are being lost on Long Island and across the United States. The refuge spans 2,550 acres with roughly half of that area being aquatic habitats (Long). In addition to preserving the art of wooden boatbuilding, the CRMC is now looking to provide ecological tours of the river as well as trips to the Wertheim National Wildlife Refuge so that visitors may experience the wildlife's natural habitats. To achieve this, the vessel will utilize electric propulsion. In addition, electricity will be generated onboard using photovoltaic cells.

ELECTRIC MARINE PROPULSION

Large- and small-scale applications of marine electric propulsion are not novel ideas. On the large-scale, electric propulsion was first used in a diesel-electric system on the Russian tanker *Vandal* in 1903 to allow for reversing (Koehler and Oehlers). Since the 1980s, diesel-electric propulsion has been widespread throughout the cruise ship industry. Today, diesel-electric propulsion has been used to power a variety of vessel types, ranging from roll-on/roll-off cargo ships to oil tankers.

Elco Motor Yachts and Duffy Electric Boat Company have been producing electric-powered pleasure boats since 1893 and 1970, respectively. Both companies now specialize in electric-powered production boats with fiberglass hulls and wood trim work. The Classic Elco Launch (Figure 3) has a more traditional look, with a plumb bow and a cockpit coaming that provides for a comfortable height to the passenger seats. The coaming allows the freeboard to be reduced to 24 in, thus lightening the look and improving the aesthetics of the hull. The Duffy 22 Bay Island (Figure 4) has a more modern feel with its flared bow and aft steering console. The Duffy boat is constructed from fiberglass, and its faux-planked hull accentuates its contemporary design.

Figure 3: 24’ Classic Elco Launch
Source: www.rexboatingclub.com

Figure 4: Duffy 22 Bay Island
Source: Duffy Boats

Advantages of Electric Boats

Electric motors for small boats have many advantages over internal combustion engines (ICEs). Compared with an ICE of similar power output, electric motors have greater energy efficiency, greater power density, less noise, no exhaust, and fewer maintenance requirements. Torqeedo, a marine electric motor manufacturer, claims that "Electric motors are superior over internal combustion motors in every power class: they are smaller, lighter, cheaper to produce, and easier to maintain" (Torqeedo). Electric motors do not need to idle when stopped, thereby eliminating the energy waste that occurs there is no load on an ICE.

Electric motors are simpler machines than ICEs. Electric motors have, in essence, only two parts: a stationary part (stator) and a rotating part (rotor). Many essential components in an ICE, such as air filters, lubricating oil, cooling water, timing belts and gears, valves, exhaust systems, and fuel injectors, are unnecessary with an electric motor. Gasoline powered vehicles have on the order of ten times as many moving parts as an electric vehicle (Plug In America). With fewer support systems and moving parts, electric motors are more reliable and require less maintenance than similarly-sized ICEs.

Disadvantages of Electric Boats

The current limit in battery technology, not motor technology, is the primary disadvantage of electric propulsion. Electric propulsion has flourished in the rail industry where many trains are powered by overhead electric cables or electrified third rails. This eliminates the need for large energy storage onboard. However, boats do not have the option of being powered remotely and must carry their energy source with them.

Batteries have a significantly lower energy density than do carbon-based fuels. Gasoline has 600 times the energy density of standard lead batteries and still 100 times the energy density of advanced lithium-based batteries (Torqeedo). Batteries come in fixed shapes and sizes, which can be more challenging for arrangements than a fuel tank.

The inherent weight and cost of batteries is also a disadvantage when selecting electric propulsion. Batteries also have a finite lifespan and require replacement after as few as 500 cycles.

However, with the current effort by governments and automotive manufacturers to increase the production of electric cars, battery technology is improving rapidly to meet society's automotive power and range requirements.

Photovoltaic Technology

Sunlight is the most abundant energy source available to man. It provides us with heat to keep us warm, light by which to see, and energy for plants to grow. Dr. David Goodstein, a professor of physics at the California Institute of Technology said, "The total amount of sunlight that falls on the planet is 20,000 times the amount of fossil fuel power we are using now. There's plenty of energy from sunlight. We just haven't begun to learn how to use it properly" (Gelpke).

One of the most common methods currently available for turning sunlight into useful energy is by the use of photovoltaic, or solar, cells. "Photovoltaic" comes from the Greek word "photo" meaning light, and "volt" referring to electricity (Photowatt). Solar cells convert light to direct current (DC) electricity by means of the photoelectric effect. The electricity produced by solar cells may directly power DC machines, be converted by an inverter to AC power for use by AC machines or devices, or be used to charge batteries. Solar cells have no moving parts and require minimal maintenance beyond periodic cleaning of the light-absorbing surface.

The phenomenon of the conversion of light energy to electrical energy was first discovered by the French physicist Alexandre Edmond Becquerel in 1839 (Lenardic). In

1905, Albert Einstein made comprehensive theoretical studies about photovoltaic technology. He won the Nobel Prize in physics in 1921 “for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect.”

Up through the mid-twentieth century, photovoltaic technology was limited primarily to scientific research. Bell Laboratories developed the first practical silicon-based solar module in 1954 (Chodos). This silicon solar cell, developed by Chapin, Fuller, and Pearson, had an energy conversion efficiency of 6% (Chapin). In 1963, Sharp Corporation successfully began to mass-produce the first solar cells (Sharp). Early solar cell use was constrained primarily to remote applications where no other source of reliable and practical electricity was available. These early applications included buildings far from the electrical grid, call boxes on distant highways, and space stations and satellites in earth-orbit.

The market’s interest in early solar cell technology was dampened by its low electrical conversion efficiency. Over the last 50 years, solar cell efficiency has increased while the production costs have decreased (Figures 5 and 6). Today, solar cells are gaining momentum as a method of large-scale electricity production for the nation’s electrical distribution grid (Figure 7).

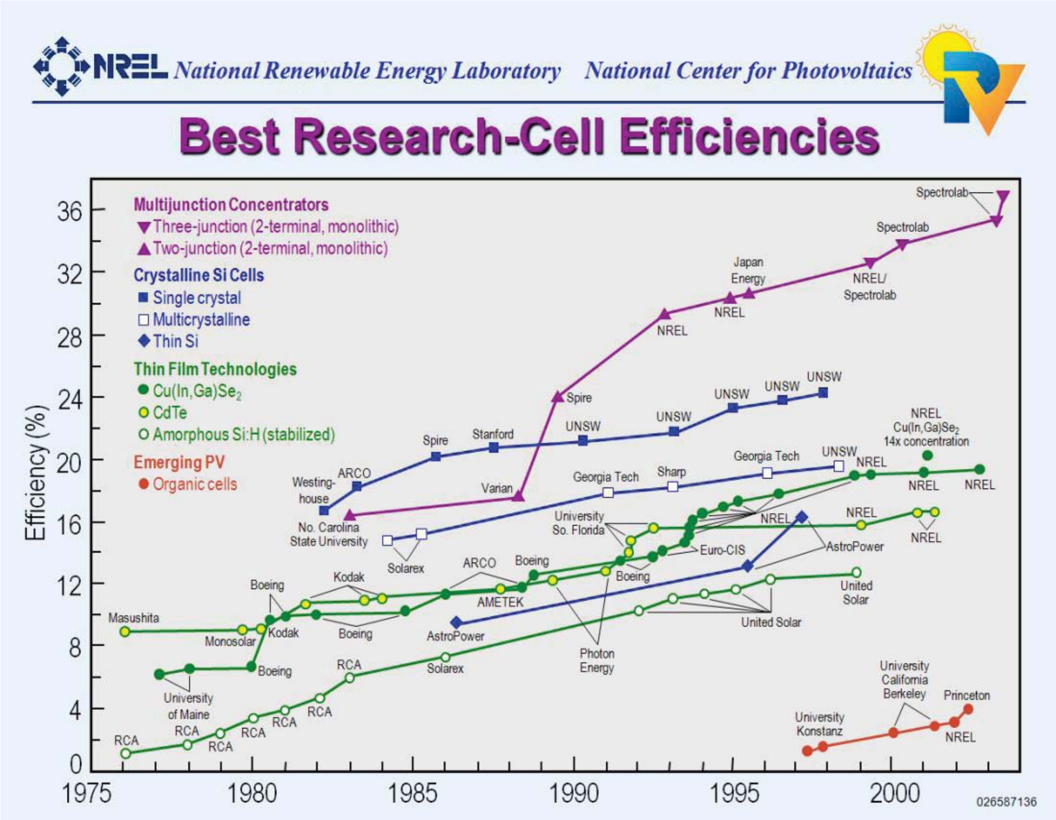

Figure 5: Improvements in Photovoltaic Cell Efficiencies
Source: NREL

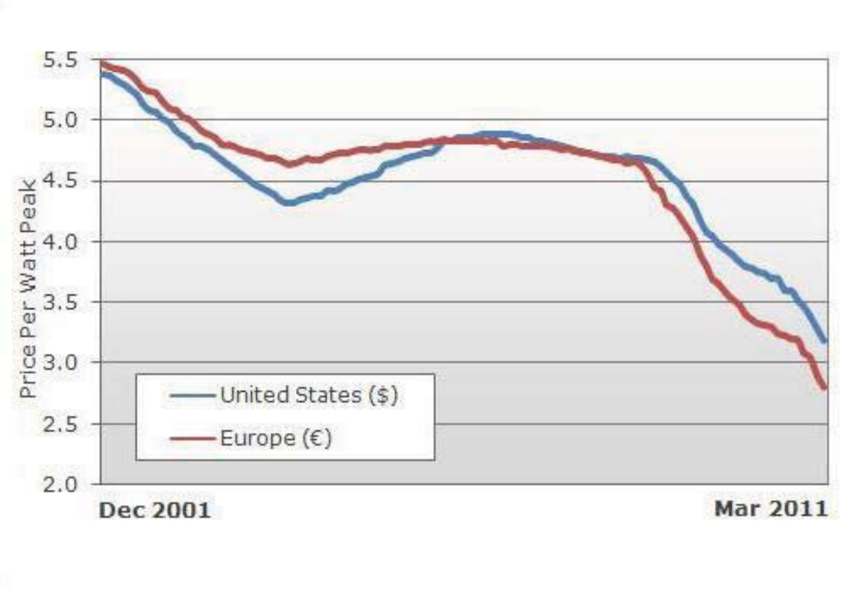

Figure 6: Price of Solar Modules Over the Past Ten Years
Source: Adapted from http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices

Figure 7: 14-MW Solar Array at Nellis Air Force Base
Source: http://www.nellis.af.mil/nellissolararray.asp

The voltage of a solar cell is determined by the molecular composition of the silicon junctions in the cell. Although fluctuations can occur depending on the temperature and the power output of the cell, the cell's output voltage remains relatively constant. The voltage of a solar cell is typically about 0.5 V. Many solar modules are 12 V, consisting of 24 cells in series. The electric current output of the solar cell is dependent on the area of the cell and the intensity of the solar radiation. (GLREA)

PREVIOUS WORK

Although solar energy and electric propulsion are not novel ideas, there is limited applicable Webb Institute thesis work that pertains to these fields. Past theses have focused on large-scale applications of hybrid electric propulsion, such as diesel electric ships. While the fundamental electrical concepts from these theses are similar to this project, overall the theses were not considered to be applicable.

Narrowing the scope to small-craft applications, the Guzik, Kaiser, and Webster (2003) thesis was of greater value to this project. This thesis developed the preliminary design of a boat intended as an entry in the Solar Splash design competition. While the overall mission of the Solar Splash boat is quite different from the CRMC tour boat, the electrical system and propulsion design is similar. The Solar Splash competition involves an endurance run wherein competitors must operate their vessels for two hours with the objective of going as far as possible on a single battery charge, with the only permissible additional energy source being onboard solar panels. The endurance run requires the vessel to be optimized for extended range and battery life, a critical need for the CRMC's launch.

OBJECTIVES

The objectives for this thesis include:

- To learn about the construction of wooden boats,
- To learn about photovoltaic cells and electric propulsion for small vessels,
- To develop a design with the feedback of a client,
- To develop detailed construction documentation for use by CRMC, and
- To specify components and materials for use in the construction of the vessel.

DESIGN CONSIDERATIONS

The CRMC wooden launch was developed using an iterative design process that began with a conceptual design and concluded with a construction-ready design package and bill of materials. At the end of each design phase, design reviews were held with the CRMC to present the product, solicit feedback, and to discuss the state of the project.

The final design is called *EcoTour 24*, and the rationale for the design is discussed in the following sections.

MISSION AND DESIGN OBJECTIVES

A "Mission Goals and Design Objectives" survey was submitted to the CRMC to determine the priorities that would drive the *EcoTour 24*'s design. The results in rank order are shown in Table 1.

Table 1: Mission Objectives and Design Goals

Rank	Mission
1	Interpretive touring of the Carmans River and surrounding wildlife areas
2	Traditional aesthetics
3	Electric propulsion
3	Solar-powered
5	Wooden construction to demonstrate the boatbuilding skills of CRMC
6	Crossing the Great South Bay to Fire Island
7	Low maintenance cost
8	Low construction cost

DESIGN CONSTRAINTS

The design constraints of the launch were instituted and delineated by the CRMC.

Characteristics

Table 2 below outlines the limitations set for the characteristics of the launch and the reasoning behind each of them.

Table 2: Table of Limitations for Principal Characteristics

Characteristic	Constraint	Reason for Constraint
Length	No greater than 26’	Set by CRMC
Beam	No greater than 8’6”	Trailerable limitation*
Draft	No greater than 2’	River shoal depth
Complement	1 operator, 1 interpreter, 6 passengers	USCG 6-Pack License / Operator of Uninspected Passenger Vessel (OUPV)

*Limit imposed by NY DOT, https://www.nysdot.gov/portal/page/portal/nypermits

The length constraint was established by the CRMC based on their building facilities. The beam is limited to 8’6” so that the vessel may be trailered in compliance with New York state law. Based on experience on the Carmans River, the CRMC set a draft limitation of 2 ft.

The CRMC will use the vessel for paid tours of the Carmans River and surrounding waterways. The United States Coast Guard requires tour service providers to employ licensed operators for boats with paying passengers. The operating capacity was limited to meet the provisions of the United States Coast Guard’s Operator of Uninspected Passenger Vessel (OUPV), or “6-Pack,” license. In contrast to higher-tonnage licenses, the 6-Pack license is much easier to obtain, requiring only a few hours of coursework, a written exam, limited sea time, and a physical exam. As a result, the 6-Pack license is a quick and inexpensive way of satisfying the Coast Guard requirement. Although the vessel’s complement is limited to six passengers by regulations, the CRMC launch can accommodate additional guests up to the design limit when the vessel is not used for paying passengers.

Propulsion

The CRMC required the launch to have an electric propulsion system in order to minimize the local environmental impact and to decrease the disturbance to wildlife.

Based on a desire to embrace trends in "green" technology, the CRMC required solar panels for underway and dockside battery recharging. Embracing green technology also provides additional opportunities for funding the construction with federal and local grants.

Operating Range

The CRMC identified two distinct missions for the launch. The primary mission is to transport guests from the CRMC's Squassux Landing to the Wertheim National Wildlife Refuge's dock. The CRMC envisions making as many as two round-trip nature tours in one day. In addition, the CRMC requested that the launch have sufficient range to be able to transit the Great South Bay to Old Inlet on Fire Island. This secondary mission would be carried out less often. Table 3 lists the distances between Squassux Landing and the two destinations.

Table 3: Distance from CRMC Origin to Expected Destinations

Destination	Distance from Squassux Landing (nm)
National Wildlife Refuge	2.0
Old Inlet on Fire Island	3.7

The one-third rule is an old adage, "one-third to go out, one-third to come back, and one-third for emergencies and dealing with adverse currents, winds, or weather" (Baron). While originally used by the United States Coast Guard to educate boaters on planning for how much fuel to carry, the guideline is useful for adding a safety margin to the range requirement. Using the one-third rule and the maximum round trip distance of 8 nm, the launch required a minimum range of 12 nm.

Construction

Preserving the art of wooden boatbuilding is central to the CRMC's mission. Although wooden construction for the tour boat was a given, the CRMC was open to investigating three different construction methods: cold-molded, strip-planking, and clinker. Cold-molded and strip-planking are two modern, wood-epoxy construction methods, while clinker is a more traditional wooden construction method.

HULL FORM

The hull form may be considered as the consummate intersection between engineering and art. The CRMC placed a strong emphasis on traditional aesthetics and expected the hull form to embody the spirit of classic launches of the late nineteenth century. A similar-vessel database was compiled with input from the CRMC and members of industry in order to draw inspiration from previous designs, both old and modern. The database includes 30 vessels, primarily wooden and electric-powered, that were designed for personal, recreational use. The database is included as Appendix A.

After developing the database, the CRMC trustees were asked to identify vessels from the database that they liked. Common characteristics among the vessels were identified, and new hull form silhouettes were drawn. The hull form silhouettes were submitted to the CRMC, and the trustees voted for the silhouette that best represented the desired aesthetic for the vessel. The silhouette that resonated most with the trustees is shown in Figure 8.

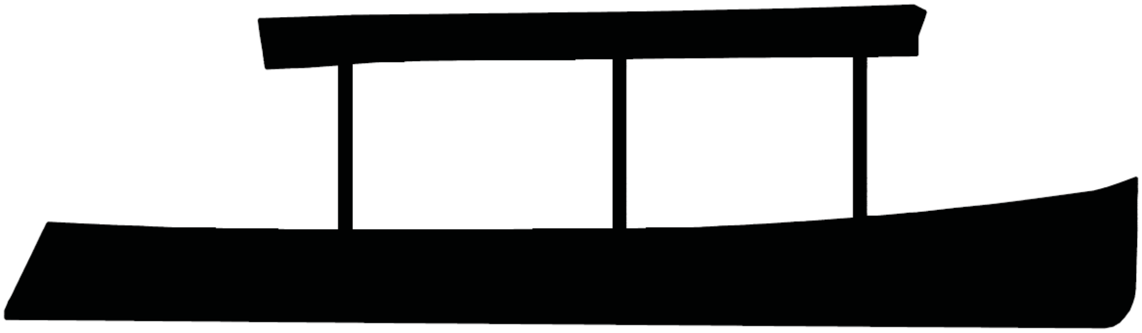

Figure 8: Hull Form Silhouette

Based on the selected silhouette, it was evident that the CRMC considered a plumb bow and reverse-raked transom to be aesthetically pleasing. The low freeboard and gentle sheer curve were also desirable features.

With the desired aesthetics captured, the engineering considerations returned to focus. Minimizing the resistance was a priority in order to increase the vessel's range. To that end, a round-bilge hull form was selected over a hard-chine form, because hard-chine full displacement boats have approximately 18% more resistance than do their round bilge counterparts (Hadler).

The basic parameters of length and beam were established from the parametric database and modified as necessary to meet the arrangement requirements and to fit within the identified dimensional constraints. The CRMC supplied an annotated drawing from an old issue of WoodenBoat magazine that served as the parent hull form and a "point of departure." The vessel shown in Figure 9 originally appeared in WoodenBoat #43 and was designed by Nelson Zimmer. The launch has an overall length of 21 ft.

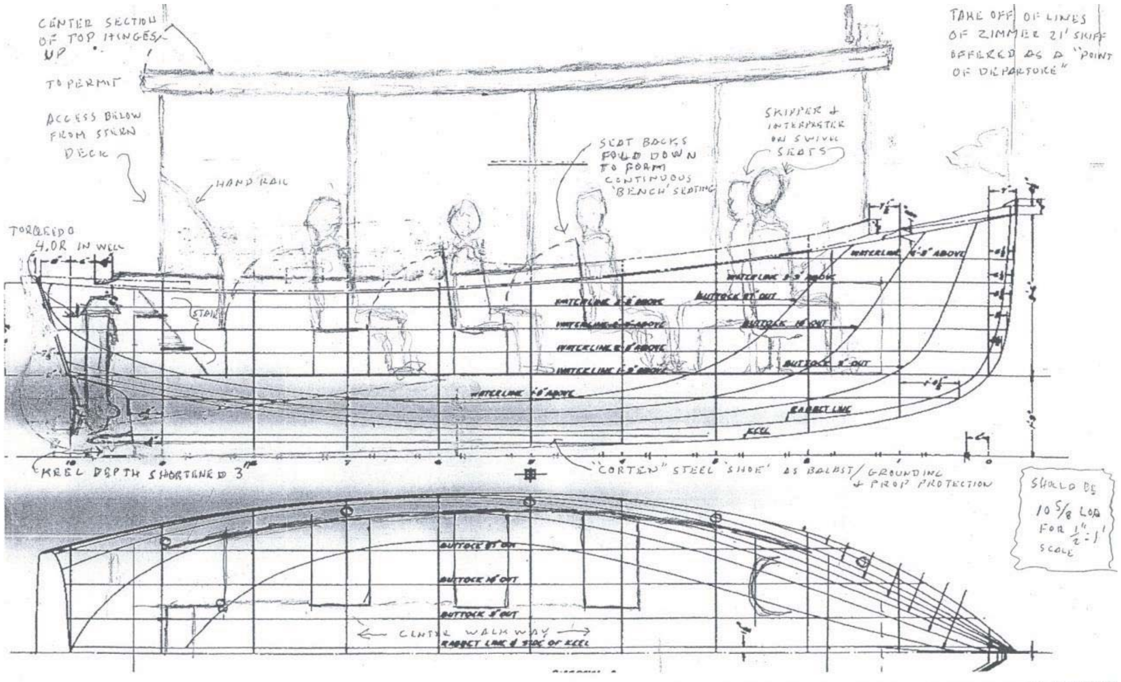

Figure 9: Nelson Zimmer's Launch
Source: Adapted from WoodenBoat #43

The lines from the Zimmer launch were imported into 3D modeling software and then modified to meet the aesthetic characteristics that the CRMC desired. The parent hull was lengthened to 24 ft overall, and the sheer and freeboard were reduced. The transom was modified to have reverse rake, and the size of the foredeck was increased. A motor well was added near the stern to accommodate an outboard electric motor.

Concurrently, a weights and centers workbook was developed to track the weights and positions of items added to the launch. The workbook includes weight groups for structure, machinery, outfitting, and personnel loads. The weight estimate was refined throughout the design process and is provided in Appendix B.

The redesigned 3D model was exported into hydrostatics software. The lightship and deadweight weights and centers estimates were incorporated into the hydrostatics model, which was used to determine the hydrostatic equilibrium condition of the vessel, principally the full-load draft and trim. The hull form was then modified by adjusting the underwater volume until the full-load draft met the design draft.

In addition, the hydrostatics model was used to generate the curves of form and assess the stability of the *EcoTour 24*. The stability assessment is addressed in the Rules and Regulations section. The hydrostatic calculations are shown in Appendix C.

GENERAL ARRANGEMENT

Based on meetings with the CRMC early in the concept design stage, the thesis team developed several concepts for the general arrangement of the *EcoTour 24*. The concepts were compared with historic launches and modern eco-tour boat designs from the similar vessel database. Discussions with the CRMC about the concept designs and overall mission of the launch were integrated into the final arrangement.

Bow Lockers

Storage is important on all small craft. Traditional lockers near the bow provide 47 cubic feet of dry storage for personal flotation devices, a chain locker for the anchor, and space for the personal belongings of the passengers. The CRMC indicated that the launch might be used as a platform for collecting water samples. Racks for scientific equipment can be built into the lockers for secure storage. A cooler for picnic lunches can also be placed in one of the bow lockers. Although the bow lockers contain ample storage, these spaces are not designed as an enclosed space for passengers, and they therefore do not require lighting, ventilation, or a secondary means of egress.

Canopy

Based on the vessel database, it was determined that many classic launches were covered with canopies. Canopies provide protection from rain and sunlight. The covering enhances passenger comfort and shields the cockpit from water and sun damage. In the case of the *EcoTour 24*, the canopy also provided a place to mount the requisite solar panels. The canopy follows the shear line of the hull to improve the canopy's aesthetics. The canopy also has 2 inches of camber to improve drainage of rainwater.

Although a canopy with solar panels was an initial design consideration, some members of the CRMC were uncertain whether a canopy might have a deleterious effect on viewing the Long Island wildlife. Forgoing the canopy would have ensured a clear view of birds, trees, and the sky. An open-air tour boat may have also provided a better experience of immersing passengers in the environment, free from headroom constraints.

However, solar panel power output, and therefore the power available to charge the vessel's batteries while away from the dock, is a function of panel surface area. Eliminating the canopy would have reduced the available surface area for the solar panels. Compared with 70 ft^2 on the canopy, one 17.5 ft^2 panel on the foredeck was impractical because of the decreased energy output. Placing the panels on the foredeck would also create a trip hazard and make the panels more susceptible to damage. It was evident that the solar panels would have to be located remotely at the dock if a canopy was not included. This would preclude solar charging while underway or moored away from Squassux Landing.

In order to mitigate concerns over obstructed views, the sightlines from different seating positions were analyzed. An inboard profile and a midship section were used to illustrate the effect of the canopy on longitudinal (Figure 10) and transverse (Figure 11) sightlines, respectively.

Anthropometrics data from Adler's *Planning and Design Data* were used to determine the dimensions of a 50-percentile man and 50-percentile boy. The man is 6'-2", and the child is 4'-7", the average height of a fifth-grade student. As the figures indicate, the sightline to the sky improves as passenger height decreases. Passengers can also improve their sightlines by leaning out over the gunwale.

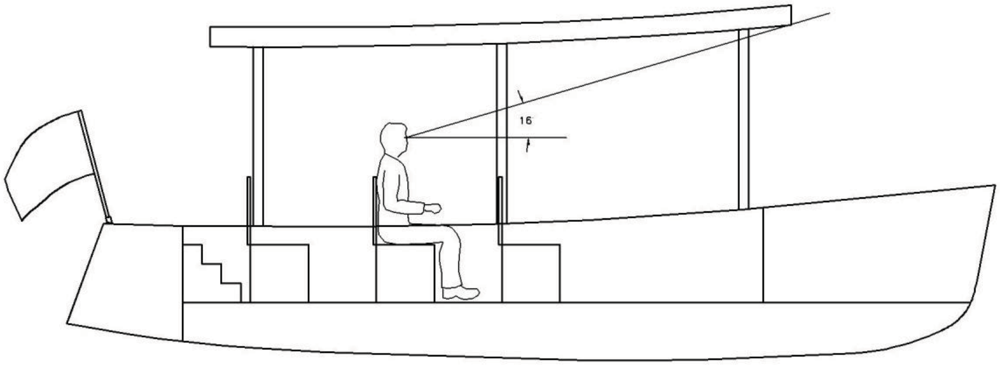

Figure 10: Longitudinal Sightline Under Canopy for an Adult

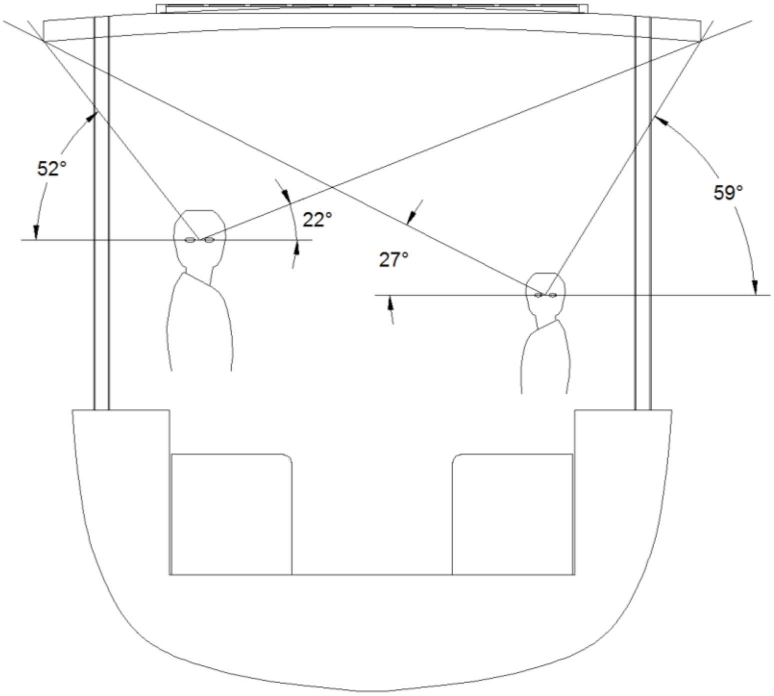

Figure 11: Transverse Sightlines Under Canopy for an Adult and Child

Seating Arrangement

The positions of seats for the interpreter and the captain were discussed with the CRMC. To create some separation from the distractions of the passengers, the seat for the captain is located under the forward end of the canopy on the starboard side, as is traditional practice. This provides for the best field of vision for the captain. Similarly, the interpreter is seated opposite the captain on port side of the boat. This allows for good communication with both the captain and the passengers during the tour.

Three different passenger seating configurations were considered: outward facing benches on centerline, inboard facing benches along the gunwale with a center aisle, and individual forward-facing seats with a center aisle.

In the outboard facing bench configuration, two benches with a common seat back would be built on centerline. The benches would provide under-seat storage and a comfortable seating position away from the gunwale. Moving the passengers inboard reduces their transverse sightlines significantly; however, the outboard facing benches allow the passengers to view the wildlife while remaining within a sociable distance of one another.

However, the major concern with this passenger-seating arrangement is the constricting effect that it has on the aisles on each side of the vessel. Even with the maximum allowable beam of 8’6”, the two aisles to port and starboard are less than the width of a man’s shoulders. With these observations and the realization that a center aisle is a more efficient use of space, this configuration was determined as impractical. The remaining seating arrangements make use of a center aisle.

Benches along the gunwale are a common seating selection among boats in the parametric database and other tour boats. Although this reasoning would make the outboard benches a logical choice, there are additional considerations to take into account. With benches providing longer seating units, flexible storage is available under the seating. Should the CRMC ever decide to use the boat with non-paying passengers, say a private tour for trustees or potential donors, the vessel could easily accommodate more than six passengers on benches. On a tour boat, socializing is part of the experience. Configuring the seating in benches that are across from one another allows passengers to sit next to and face each other. Passengers also may turn easily towards the water or the sky to see the surroundings. Figure 12 illustrates the arrangement of the boat with benches. Dimensions shown are in feet.

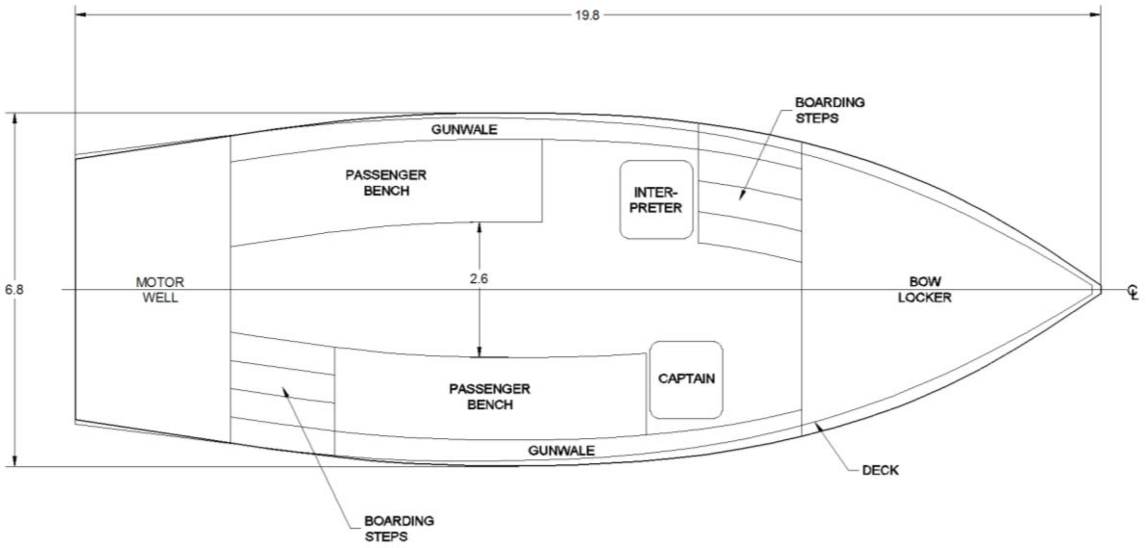

Figure 12: Bench Seats Arrangement

Individual seating offers different advantages to bench seating. Providing a seat for each passenger gives each passenger his own space. Individual seats would allow for some under-seat storage for each passenger. A disadvantage of individual seating is the fact that the number of passengers will be limited to the number of seats available. In order to meet the 2-ft minimum regulatory aisle width, the vessel's beam would have to be increased by approximately 1 ft. Widening the vessel increases the powering requirements. Similarly, the length of the resulting vessel would have to be greater than a boat with the same amount of seating available on benches. An example of the configuration with individual seating is shown in Figure 13. Dimensions shown are in feet.

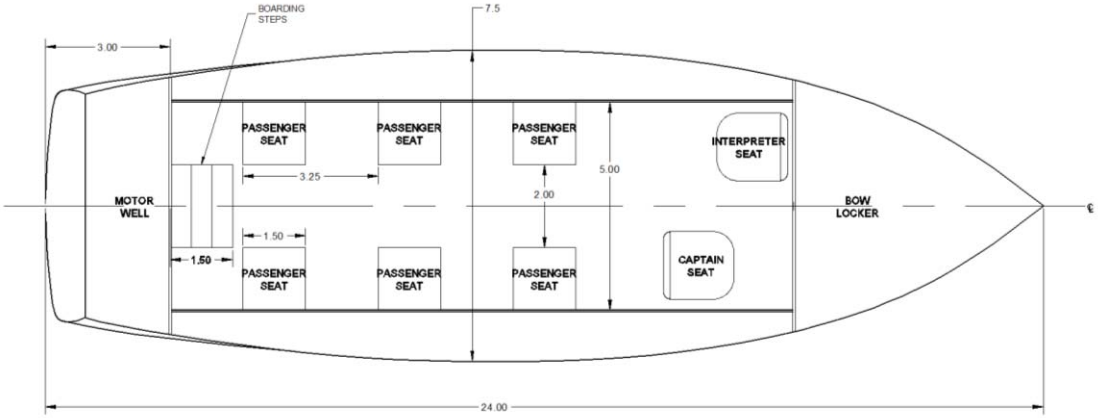

Figure 13: Individual Passenger Seats Arrangement

The CRMC trustees believed that individual passenger seating was the most appropriate for interpretive tours of the Carmans River. As a result, the *EcoTour 24* features six individual passenger seats. However, flexibility was added to the seating arrangements by allowing the individual seat backs to fold down to form a continuous bench. Depending on the operator's choice, the vessel can be transformed easily from individual seating to bench seating. Figure 14 illustrates the *EcoTour 24*'s convertible seating.

Figure 14: Convertible Seating Arrangement

Motor Well

CRMC had reservations against using an aesthetically-displeasing electric outboard motor. These were addressed by the design of an enclosed well for the motor at the stern. The motor well is accessible from above through a hinged section on the top of the aft compartment. The motor is fitted to a manual lifting bracket so that it may be lifted and tilted out of the water when not in use. More discussion on the prime mover selection may be found in the Propulsion System section.

Steps

Steps were located at the stern at the request of the CRMC. There are three steps with an 8-inch riser and 10.5-inch tread. The trustees preferred to have the steps lead down from above the motor well to the cabin sole. This allows for the vessel to be boarded from the stern. On each side of the steps, removable stanchions will be used to provide hand-holds as passengers ascend and descend. The stanchions may be stored when not in use, preserving the overall lines of the vessel from the disruptive appearance of a permanent railing system.

CONSTRUCTION METHODS

Three wooden construction methods were considered for the launch. These methods are cold-molding, clinker, and strip-planking. Consideration was limited to these construction methods as they fell within CRMC's comfort zone.

Cold-Molding

Cold-molded construction refers to the use of multiple layers of diagonal veneers to form the hull shell (Figure 15). Cold-molded boats are typically lighter in weight and stronger than planked boats. According to yacht designer Mark Smaalders, "a properly built cold-molded boat will almost certainly require less regular maintenance [than a planked hull]" (Smaalders). However, the primary disadvantage of cold-molded construction is the significant amount of labor required to build the boat. The members of the CRMC advised that using cold-molded methods to construct the vessel would be difficult owing to its rounded bilge. Cold-molding is more commonly used to construct wooden boats with a hard chine, as opposed to a rounded bilge. Cold-molding is a good choice for high performance boats where a stronger, lighter structure is of utmost importance. While weight plays a key factor in the *EcoTour 24's* overall resistance, it was determined that the construction challenges presented by cold-molded construction overrode the value of the weight savings.

Figure 15: Cold-molded Construction
Source: Nexus Marine

Clinker

Clinker boatbuilding, also called lapstrake, consists of fastening individual longitudinal planks to transverse frames or bulkheads (Figure 16). According to Dave

Gerr, lapstrake construction requires much skill and patience to plank a boat, especially at the stem and the transom (Gerr). The construction is simple to repair because each plank can be replaced individually without disturbing the remainder of the hull structure.

However, the CRMC advised against lapstrake construction because it can be cumbersome to maintain. With lapstrake construction, the planks are able to shrink and expand as the moisture content of the planks changes. In colder climates such as the northeast, the expansion and contraction can become an issue during winterization. Each winter such a vessel must be removed from the water and the planks must be treated and caulked. At the end of the winter, a clinker-built vessel must be inspected for leaks and recaulked if necessary.

Figure 16: Clinker Construction
Source: Woodwork Forums

Strip-Planking

Strip-planking construction is similar to clinker construction, except that the planks are epoxied and nailed to each other. The planks are much narrower than planks used for traditional plank-on-frame construction (Figure 17). The narrower planks and the epoxy help to form a watertight seal that is not prone to leaking caused by changes in moisture content. This significantly reduces the hull maintenance that will be required over a vessel's life. The epoxy and edge nails form a very rigid hull that is strong both longitudinally and torsionally arising from the fact that the planks are fixed in longitudinal position. Strip-planking does require more labor to construct than clinker because of the narrow, more numerous strips, but it requires fewer man-hours than for cold-molded construction.

Figure 17: Strip-planking Construction
Source: John Ashley

Table 4 outlines the advantages and disadvantages for each of the construction methods discussed. Strip-planking was chosen at the recommendation of the CRMC as the construction method for the launch because of its low maintenance and beneficial structural properties.

Table 4: Summary of Construction Methods

Cold-Molding	Clinker	Strip-Planking
Multiple veneers	Planks	Narrow planks
Epoxied	Screwed	Epoxied and nailed
Higher strength/weight	Lower strength/weight	High strength/weight
Least maintenance	More maintenance	Less maintenance
Most laborious	More laborious	Least laborious

STRUCTURE

The launch's initial structural analysis was developed using methods from Dave Gerr's book, *Boat Strength*. Gerr specifies the principal scantlings for a given type of boat based on the scantling number, which is defined as

$$\mathrm{Sn} = \frac{\mathrm{LOA} \times \mathrm{B} \times \mathrm{D}}{1000 \times \mathrm{ft}^3}\,. \tag{1}$$

A graph corresponding to each structural member was used to determine the scantling. Figure 18 is an example of a graph used to determine the plank thickness for a small wooden boat. Gerr also recommends wood species for each type of structural member. The majority of the launch's structural scantlings were determined using Gerr's methods. As a check, scantlings determined using Gerr's methods were compared with examples of similarly-sized vessels found in Ian Nicholson's *Cold-Moulded and Strip-Planked Wood Boatbuilding.*

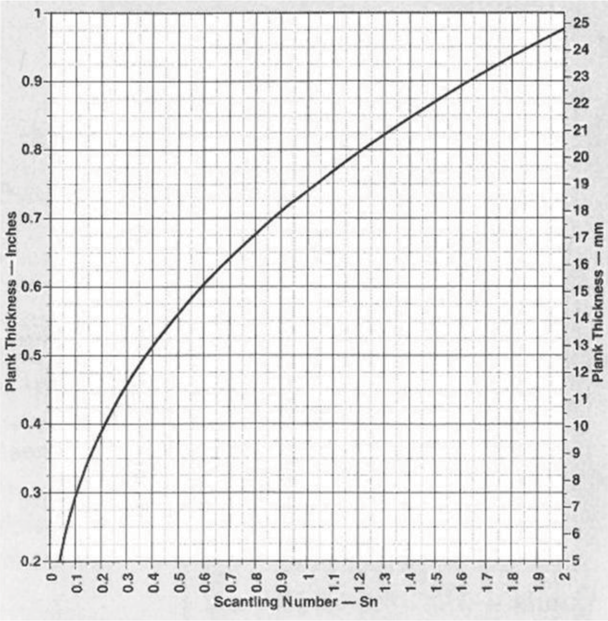

Figure 18: Plank Thickness for Small Boats Based on Scantling Number
Source: Gerr

Table 5 lists the structural scantlings and material chosen for each of the structural members.

Table 5: Structural Scantlings

Structural Member	Scantlings	Recommended Material
Hull strip-planking	¾” × ¾” cross-section	Douglas Fir
Center keel	4” molding, 2” siding	White Oak
Stem	4” molding, 2” siding	White Oak
Clamp stringer	1” molding, 2 ¾” siding	White Oak
Solid bulkheads	¾” thickness	Marine Plywood
Solid floors	¾” thickness	Marine Plywood
Bent frames	½” × ½” cross-section	White Oak
Decking	¾” thickness	Marine Plywood
Topsides decking	½” thickness	Teak
Edge nails	1 ¾” long, 3/32” diameter	Si-Bronze Ring Nails
Plank fasteners	1 ½” long, 7/32” diameter	Si-Bronze Wood Screws
Butt blocks	¾” × 7/8” x 10 ½”	Douglas Fir
Hull Sheathing	36.2 oz/yd^2	Glass Cloth
Deck Sheathing	6.675 oz/yd^2	Glass Cloth

Figure 19 shows a 3D rendering of the internal structure of the launch. Structural members that are shown include the keel and stem, clamp stringer, solid bulkheads, solid floors, and bent frames. Decking and internal longitudinal supports for the decking are not shown. The solid floors were added to the structural design to support the weight of the batteries. The fixed steps leading aft to the transom provide additional rigidity to the motor well bulkhead.

Figure 19: Isometric View of Internal Structure

RESISTANCE AND PROPULSION

Three components of resistance were considered when developing the prediction for the required power for the *EcoTour 24*: frictional, residuary, and air resistance. While it generally is considered good practice to conduct model testing to determine the resistance of a new hull form, the thesis team decided that existing correlation lines, formulas, and systematic series for small craft were sufficient to provide a reasonable approximation of the vessel's resistance.

Frictional Resistance

The frictional resistance was calculated using the International Towing Tank Conference (ITTC) 1957 model-ship correlation line. The ITTC '57 line was developed to standardize the method for scaling frictional resistance from model scale to full scale.

Although originally intended as a temporary solution, the ITTC '57 line has persisted as the standard equation for estimating skin friction for model and ship scales. The correlation line is defined as

$$C_F = 0.075/(\log_{10} R_n - 2)^2, \tag{2}$$

where C_F is the coefficient of frictional resistance, and R_n is the Reynolds number.

Air Resistance

Air resistance, or air drag, is normally a marginal component of a large vessel's overall resistance; however, air resistance becomes a more prominent source of drag for small craft. Still-air resistance is the added resistance encountered as a vessel moves through a mass of air. Still-air resistance predictions typically are included in total resistance predictions.

Still-air resistance predictions are idealized because vessels do not operate often in environments without moving air currents. Head winds can add significant resistance. Based on the *EcoTour 24*'s sensitivity to power consumption, the thesis team used a conservative approach to estimate the air resistance by applying a head wind resistance component. After talking with South Shore boaters, the average wind speed on the Great South Bay was assumed to be 10 knots. Although quartering winds pose a greater augment to resistance (Lewis), the calculations were limited to a head-wind case that has a directionality factor K of 1.00. The air resistance was calculated based on a relative or encounter wind velocity V_R equal to the sum of the true wind speed and the vessel speed. Based on nominal drag coefficients from Munson (2006), drag coefficients were determined for the hull frontal area above the waterline, the canopy supports, and the canopy itself. These drag coefficients were 0.30, 1.50, and 1.90, respectively. The air drag formula is defined as

$$R_{AA} = \frac{1}{2} K C_{AA} A_T \rho_{air} V_R^2, \tag{3}$$

where A_T is the frontal area of the vessel.

Residuary Resistance

The residuary resistance of the vessel consists of all non-frictional components of hydrodynamic drag, including, but not limited to, wave-making, wave-breaking, spray, and appendage drag. The residual resistance of the vessel was determined using results from systematic model series testing. After comparing the parent hulls of various systematic series, the British National Physical Laboratory (NPL) Series and the Series 63 Methodical Test were used to estimate the residuary resistance.

The NPL Series by Marwood, *et al.* (1969) and by Bailey (1976) was developed for high-speed, round-bilge displacement hull forms. The parent form is shown in Figure 20. The series comprises 22 models in which L/B and B/T are varied. The models were tested at speeds with Froude numbers ranging from 0.30 to 1.20.

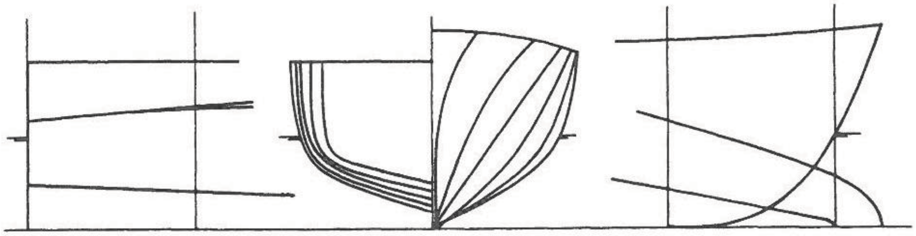

Figure 20: NPL Methodical Series Parent Hull Form
Source: Lewis (1988)

Table 6 compares the characteristics of the closest NPL model with the characteristics of our design.

Table 6: Principal Characteristics of NPL Series Model Compared to the *EcoTour 24*

	NPL Model	*EcoTour 24*
Length/Beam, L/B	3.33	3.55
Beam/Draft, B/T	3.19–10.21	5.21
Block Coefficient, C_B	0.397	0.457
Prismatic Coefficient, C_P	0.693	0.623
LCB (Aft of ⊗)	−6.4%	−6.9%
Entrance Angle, i_E	20.5°	23.0°
S/√(∀L)	2.8–3.9	2.98
Froude Number	0.30–1.20	0.067–0.371

Series 63 was developed by Beys in 1963 based on a round-bilge utility boat with a 15.24-m length. The series has five models that share the parent body plan and are geometrically similar. Beys varied the L/B ratio by multiplying the waterline and buttock spacing of the parent model (Figure 21) by a constant. A list of the model characteristics is shown in Table 7.

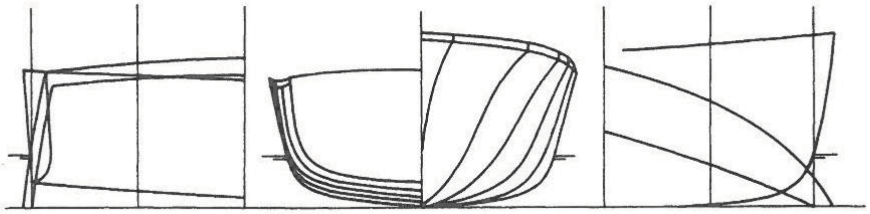

Figure 21: Series 63 Methodical Series Parent Hull Form
Source: Lewis (1988)

Table 7: Principal Characteristics of the Series 63 Model Compared to the *EcoTour 24*

	Series 63 Model	*EcoTour 24*
Length/Beam, L/B	3.0	3.55
Beam/Draft, B/T	6.90	5.21
Block Coefficient, C_B	0.448	0.457
LCB (Aft of ⊗)	−3.34%	−6.9%
Froude Number	0.067–0.545	0.067–0.371

The resulting residuary resistance components from the NPL Series and Series 63 were compared and are shown in Figure 22. The NPL residuary resistance prediction is less than the Series 63 prediction. At the 5-kt design speed, the Series 63 prediction is 32% higher than the NPL Series. The Series 63 parent hull's characteristics more closely match the *EcoTour 24* than the NPL models, and the Series 63 model testing was conducted within the *EcoTour 24's* Froude number range. Series 63 was selected as the basis for the residuary resistance component.

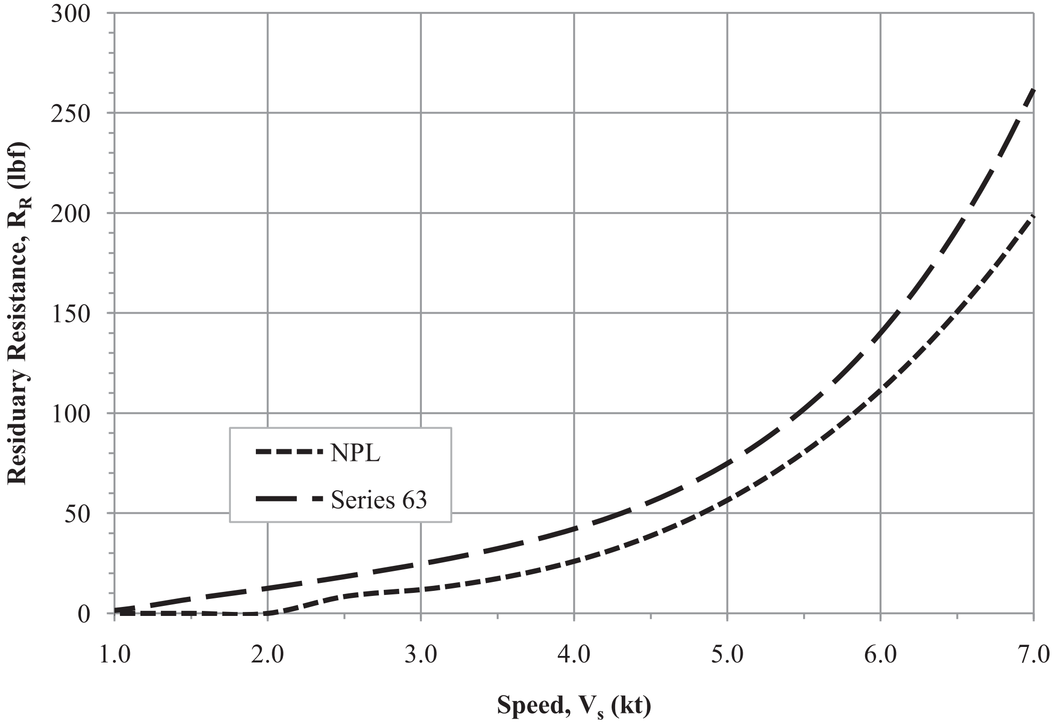

Figure 22: Comparison of Residuary Resistance Components

Total Resistance

The frictional, residuary, and air resistance components were combined at each speed to determine the expected total resistance at that speed. The resistance calculations were made over a range of Froude numbers from 0.031 to 0.433, or 0.5 kt to 7 kt, and can be viewed in Appendix E. The effective horsepower is the amount of power necessary to counteract the resistance and can be considered analogous to the power expended by an invisible hand pushing the boat through the water. The effective horsepower is given as

$$\mathrm{P_E = R_T V_s}. \tag{4}$$

The effective horsepower considers neither losses in the propulsion system between the prime mover and the propeller nor the hydrodynamic losses of the propeller. The propulsive coefficient η_P is a means of accounting for these losses. Ordinarily, model tests would yield propulsive factors that contribute to the calculation of the overall propulsive coefficient. As model tests were not conducted for the *EcoTour 24* and the systematic series consulted for the resistance prediction did not include propulsive factors, a conservative estimate of the propulsive coefficient was required. Within the industry, a 50% propulsive coefficient is considered conservative, and this value was corroborated with the selected prime-mover manufacturer's technical information.

The systematic series consulted in this resistance prediction involved calm water model testing. Calm water studies do not consider the added resistance caused by waves in higher sea states. A sea margin is used to account for this added resistance. Based on advice from Professor Hadler, a 15% sea margin was applied.

Brake horsepower is the input electrical power to the motor. The brake horsepower is calculated as

$$\mathrm{P_B} = \frac{\mathrm{P_E(Sea\ Margin)}}{\eta_\mathrm{P}}. \tag{5}$$

These brake horsepower values were used to size the propulsion motor. Figure 23 shows the vessel's predicted speed-power curve.

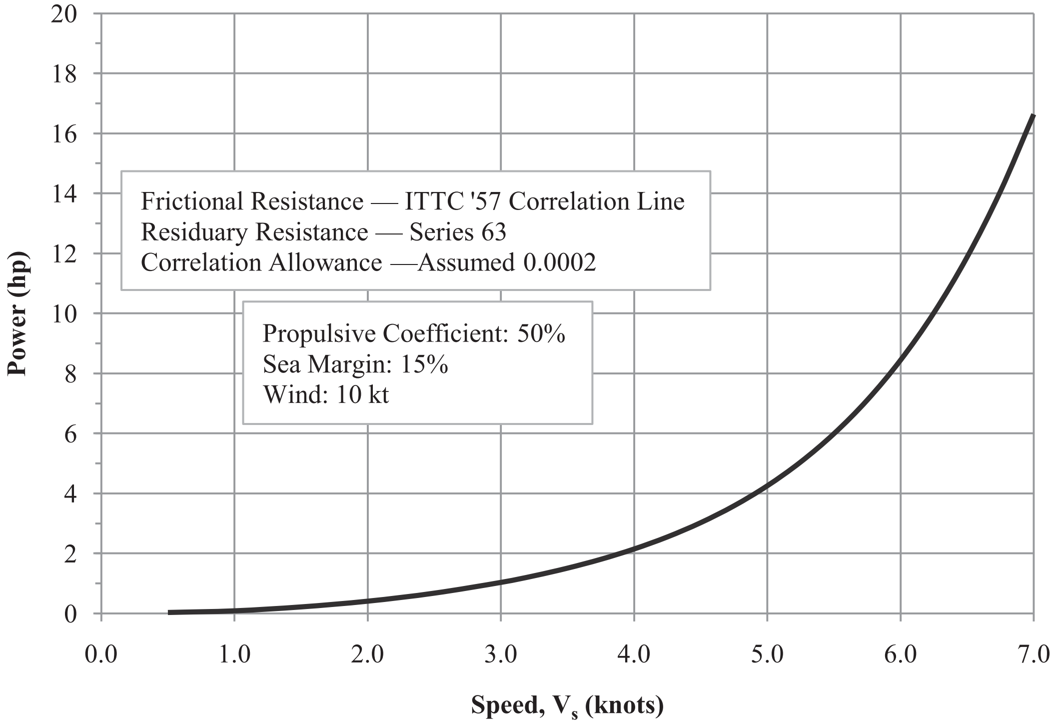

Figure 23: Brake Power Prediction for Bare Hull

In order to achieve the design speed of five knots, the propulsion motor must be rated for at least 5 BHP.

ELECTRICAL SYSTEM

The vessel has two separate electrical systems: a 48-V DC system for the propulsion motor and a 12-V DC system for the house requirements including navigation lights, bilge pumps, and VHF radio. The 48-V and the 12-V systems are both charged from the central inverter/charger.

Propulsion System

The propulsion system consists of the electric motor, propulsion battery bank, and solar panels. An inboard and outboard motor were both considered for powering the vessel. Pros and cons for each motor option were examined.

The primary benefit for using an inboard electric motor is that it is the most-conventionally-used solution for electric boats. There is much existing information for the design of inboard electric motor propulsion systems. Drawbacks of using an inboard motor include: the hull penetration for the propulsion shaft below the waterline; the increased installation and maintenance challenges; the complications of a rudder system required for steering; and the shafting that affects the arrangements.

Benefits of an outboard motor include its simple integration into the design from its being a single component; greater energy efficiency with reduced shafting losses with the motor's rotor located in line with the propeller in the hub of the motor; lack of hull penetrations; easier installation; and improved maneuvering performance arising from the ability to direct thrust. Drawbacks of an outboard motor are that it is slightly more expensive than an inboard electric motor drive system, has non-traditional aesthetics, and requires an average draft increase of 6 inches. The major characteristics of inboard and outboard motors are summarized in Table 8.

Table 8: Summary of Inboard and Outboard Motors

Inboard Motor	Outboard Motor
Lower cost	Higher cost
Traditional	Less proven
More components	Simpler system
Hull penetration	Drop-in installation
Rudder steering	Directional thrust

The outboard electric motor considered for the *EcoTour* 24 is made by the German company Torqeedo (Figure 24). The company is emerging as a leader in small-craft electric propulsion. After speaking to both representatives from Torqeedo and boaters who use their technology, it was determined that the greatest advantages of the

Torqeedo product were efficiency and weight. One Torqeedo owner recently had competed in an all-electric boat race. His 23-ft launch averaged 5.6 knots in 15-knot winds and 3-ft breakers, endured the 24-mile course, and won first place. Other outboard electric motors were investigated, such as the Minn Kota E-Drive, Ray System 300, and AquaWatt Green Power 10, but Torqeedo was clearly the most advanced in terms of technology and industry recognition

Figure 24: Torqeedo Cruise 4.0RS Outboard Electric Motor
Source: Torqeedo Catalog

Range anxiety is an obstacle for some owners with all-electric propulsion. Range anxiety may be defined as the fear that one will be stranded away from the dock without sufficient energy reserves to return. Increasing the range of an ICE-propelled boat generally means increasing the boat's fuel capacity. The solution for an electric boat is not as simple as increasing the fuel tank. Additional batteries come at a high acquisition cost and a significant weight penalty. As a result, the naval architect has to look for other ways to improve range, primarily by increasing performance efficiency. Outboard motors are inherently more efficient because there are fewer losses associated with shafting and the lack of a hull penetration. Additionally, by eliminating the need for a long shaft run and a rudder steering system, the vessel's weight will be decreased. An outboard motor also saves valuable space in the bilge that can be occupied by the batteries necessary to maximize the range.

While streamlining components also simplifies the design and construction, the most attractive benefit of selecting an outboard motor is risk mitigation. Electric outboard motors are sold as a package, complete with the motor, propeller, motor controller, and cabling. In the design and construction of small craft, a frequent, costly problem is the selection of an optimal propeller to match the motor. This can result in the purchase of multiple propellers for testing on the vessel before the optimal propeller is identified. However, choosing a system that has already optimized the propeller to the motor eliminates the risk of selecting an improper propeller. A similar issue applies to the motor controller system. An optimal propulsion system results in gaining the most-controlled performance and greatest operational information to the operator. This can be accomplished by choosing a motor that is paired with a specific controller and information system.

In terms of safety-risk mitigation, the Torqeedo is designed for operation in a marine environment. The motor is sealed and waterproofed, and it does not present a risk for electrocution if submerged. The outboard motor eliminates the need for a hull penetration; therefore, the risk of water ingress around the shaft seal is also eliminated, keeping the battery compartment dry.

The Torqeedo 4.0RS was selected as the propulsion motor for the EcoTour 24. Compared with other Torqeedo electric outboard motors, the 4.0RS provides the most brake horsepower with the shortest shaft length. Table 9 lists the technical characteristics of the propulsion motor.

Table 9: Torqeedo Cruise 4.0RS Technical Data

Brake Power	4000 W
Effective Power	2240 W
Input Voltage	48 V
Static Thrust	189 lb
Propeller Speed	1300 rpm
Weight	37.7 lb

Batteries

Various battery technologies were evaluated based on market research. The three battery technologies considered were flooded lead-acid, absorbed glass mat (AGM), and lithium-ion.

Flooded lead-acid batteries are the oldest type of rechargeable battery. They have a low energy density, resulting in a larger battery volume and higher weight for a given energy storage capacity. Flooded batteries are not sealed, which results in the slow release of hydrogen gas. The space containing the batteries must be vented in order to prevent the buildup of dangerous levels of hydrogen gas. The batteries also require regular inspections to replenish the evaporated electrolyte with distilled water. Also, if the electrolyte comes into contact with seawater, it can release deadly chlorine gas (von Wentzel). From an environmental view, lead-acid batteries require more energy to manufacture than other battery technologies. This manufacturing energy is offset by lead battery recycling, with over 96% of lead-acid batteries being recycled in the United States (Lead Battery Recycling).

AGM batteries are a more advanced type of lead-acid battery with a glass-like material that contains the electrolyte. The glass mat allows AGM batteries to be sealed and does not risk spilling electrolyte. Also, AGM batteries can come into contact with seawater with little risk of damage or injury, and they are the most-shock-resistant lead-acid batteries available. AGM batteries are low maintenance, as long as proper care is taken to ensure that the charging system is matched appropriately to the batteries. Overcharging AGM batteries drastically reduces their service life (von Wentzel). AGM batteries have energy densities that are comparable to flooded lead-acid batteries. AGM batteries have a high cycle life and are able to withstand up to 500 full discharges. Their low self-discharge, or the loss of charge when not in use, also makes them ideal for solar applications (Lifeline Batteries).

Lithium-ion batteries are the most advanced batteries available on the market. They have very high energy densities—up to 150 Wh/kg. Their high cycle life allows them to withstand thousands of discharges. When not in use, lithium-ion batteries lose charge at a slow rate, typically less than 5% per month. However, lithium-ion batteries have many downsides. Their useful service life is about two to three years, after which time the batteries lose their ability to hold their charge. Although the failure rate is minimal, lithium-ion batteries can explode. The cost of lithium-ion batteries is also a major consideration, because they can cost up to ten times as much as AGM batteries with similar energy capacities (Brain).

After considering the various types of batteries available, the CRMC agreed with the recommendation to use AGM batteries. AGM batteries are prevalent in marine applications and are considered to be safe batteries. Although they are heavier and have a lower energy density than lithium-ion batteries, AGM batteries have appropriate performance characteristics for this application. The Lifeline GPL-27T battery was selected for the *EcoTour 24*. Other AGM batteries were considered, but based on our research, the Lifeline batteries appear to provide the highest energy density and lowest cost when compared with other AGM batteries. The group 27 batteries were chosen as the largest of the Lifeline batteries that can be moved easily and do not negatively affect the battery arrangements owing to their size. Each 12-V battery weighs 65 lb and has a rated capacity of 100 Ah, or 1200 Wh. More detailed information on battery comparisons may be found in Appendix F.

The 48-V propulsion battery bank consists of eight 12-V batteries connected in series with two parallel branches, while the 12-V house battery bank consists of two 12-V batteries connected in parallel. The batteries supply 9.6 kWh for propulsion and 2.4 kWh for house loads. The ten batteries have a total weight of approximately 650 lb. Although the batteries are heavy, placing the batteries low in the vessel improves its stability characteristics. The cost for the selected battery banks is approximately $2900.

Solar Panels

Two types of solar panels were investigated as possible options: rigid panels and thin-film flexible panels. The solar panels were compared based on the criteria shown in Table 10. The total power, cost, and weight values were determined for 70 ft^2 of solar collecting area atop the canopy. The efficiency of the solar panels is defined as the electrical power output from the panels divided by the solar energy of the incident light on the panels. The total power is the peak power available from the solar cells in an ideal condition. The cost and weight values are for only the panels themselves and do not include any cabling or other equipment.

Table 10: Comparison of Solar Panels

	Rigid	Flexible
Model	Sharp NU-U240F1	SolMax-Flex-12 V 200 mA-Pretab
Efficiency	15%	3.5%
Durability (Warranty)	25 years	1 year
Total Power	960 W_p	185 W_p
Total Cost	$2700	$4400
Total Weight	176 lbs	12 lbs

In comparing between the two panel types, the rigid panels are seen to far outperform the thin-film flexible panels in every aspect except for weight. Although the weight of the panels is of some concern because they are located on top of the canopy, the rigid panels are still highly recommended because of their favorable performance characteristics and lower cost. Also, because the panels are built into the canopy, there is no need for the panels to be so flexible that they can form around a rounded surface. The Sharp NU-U240F1 rigid solar panel was selected for the *EcoTour 24*. Sharp is one of the most-established manufacturers of solar panels in the world and the chosen panels are their most powerful model available on the open market. Four panels will be connected in series to provide 48 V DC power to the charging system.

Charging System

The charging system of the vessel is controlled by an Outback 3000W FX3048T charger/inverter, which can receive power from either the solar panels or the shore-power supply. A 120-V, 30-A, 50-ft cable is located at the stern for the shore-power connection to the charger/inverter. The output from the solar panels is connected to an Outback Power Systems FLEXmax 60 MPPT charge controller. The charge controller works to regulate the voltage from the solar panels to a uniform level, thereby optimizing the power yield from the solar panels and preventing the batteries from being overcharged. The charge controller is designed to work in conjunction with the chosen charger/inverter. Power from the charger/inverter may supply simultaneously the 48-V propulsion battery bank, the 12-V house battery bank, and an onboard 120-V AC outlet.

House Loads

The house loads are powered from two 12-V house batteries through a fused DC distribution panel located below the steering wheel. House loads served by the DC distribution system include the port, starboard, and all-around navigation lights, port and starboard bilge pumps, two 12-V DC outlets, and one 25-A spare circuit. The 12-V DC outlets can be used for non-permanent electric devices used onboard such as a handheld VHF, GPS, or spotlight.

Safety Features

Several safety features were designed into the electrical system. Appropriately-sized fuses and circuit breakers are used to prevent excessive currents in the system. Both the propulsion battery bank and the house battery bank contain two separate branches that can be isolated or combined using the battery switches depending on the operator’s preference. A galvanic isolator is included to shield the launch’s electrical system from stray galvanic currents when connected to shore power.

AUXILIARY SYSTEMS

The number of auxiliary systems in the vessel’s design is limited in order to minimize electrical consumption and to simplify construction.

Steering

The *EcoTour 24’s* steering is controlled by a classical wooden steering wheel located just forward of the captain’s seat and adjacent to the motor controller. Two options were considered for the steering system: a mechanical cable-steering system and a hydraulic steering system.

Table 11 lists specifications for the two steering systems considered. The primary benefits of the cable steering system are its simplicity, lower weight, and lower cost. Hydraulic steering systems provide better steering precision and comfort. However, given the low weight and small form factor of the motor, a hydraulic steering system has greater capacity than is needed for this application. The increased cost, weight, and complexity of a hydraulic steering system are not justifiable. The Torqeedo Cruise 4.0RS Operating Manual indicates that a light-duty mechanical steering system is sufficient. The Torqeedo motor comes fitted with the required link arm and mechanical connections to integrate seamlessly with a cable steering system.

Table 11: Steering System Technical Specifications

	Cable	Hydraulic
Model	Teleflex No Feedback Safe-T II	Teleflex BayStar Steering Kit
Max outboard size	V-4	150 hp
Price	$239.99	$499.99
Weight	15 lb	23 lb

Navigation

As per ABYC Section T-17, a navigational compass is required and is installed at the helm for use by the captain. No other navigational equipment is required by regulations. CRMC has not indicated that they desire additional electronic navigational equipment such as an onboard GPS or depth sounder. However, these may be added easily during or after construction.

GOVERNING RULES AND REGULATIONS

Regulatory considerations are integral to the design of the *EcoTour 24*. The United States Coast Guard enforces Title 46 Shipping of the Code of Federal Regulations (CFR) for marine design and inspection. The launch's size is not within the boundaries covered by the CFR; therefore, the launch is not legally bound to conform with the CFR. Instead, the CFR served as a set of reference guidelines where appropriate. More appropriately, the American Boat and Yacht Council (ABYC), an industry trade group, has written standards for small craft. The ABYC standards, with minimal input from the CFR, are the basis for auditing the *EcoTour 24*'s safety and design. A compliance matrix with the applicable rules and regulations is included in Appendix G.

Code of Federal Regulations

Within Title 46, Subchapter T outlines the regulations for Small Passenger Vessels (under 100 gross tons). The subchapter is relevant to vessels that carry between six and 150 passengers. While the launch is far less than 100 gross tons, this is the most applicable subchapter because the launch will carry six passengers and two crew members. These regulations describe the operation and safety of the vessel.

The "Construction and Arrangement" section describes hull structure, escape requirements, passenger accommodations, and rails and guards.

"Intact Stability and Seaworthiness" details the conditions that the launch must meet to comply with the simplified stability proof test. The stability requirements influenced the dimensions of the vessel, particularly the vessel's beam. An example of sufficient stability (Appendix C) is that when the vessel is boarded by six passengers and two crew, the metacentric height is 1.74 ft, which is significantly greater than the 0.5 ft minimum required.

"Damage Stability and Flooding Protection" specifies the location and integrity of the collision and watertight bulkheads. This aided in the definition of the structure of the hull and the positioning of machinery and batteries.

Requisite safety equipment is detailed in "Lifesaving Gear," which describes the requirements for the types and storage of emergency communications and ring life buoys.

Many of the guidelines for machinery are not applicable to the launch because of the lack of an internal combustion engine and combustible fuel. For the bilge system, a vessel not longer than 26 ft and carrying fewer than 49 passengers requires only one portable hand pump with a capacity of at least 5 gpm (CFR Title 46, 182.520). However, an electrically powered bilge pump improves the convenience and speed of emptying water from compartments that are difficult to access. Two electric bilge pumps are installed, and a manual bilge pump is also included onboard the launch. Details regarding steering gear, power sources, grounding, lighting, and vessel controls and operations are also described.

Title 33 of the CFR covers Navigation and Navigable Waters and contains some relevant requirements. For a vessel such as the *EcoTour 24*, no fire-extinguishing equipment is necessary. However, a Class A-B-C fire extinguisher is installed at the captain's console. Also, requirements regarding personal flotation devices are provided.

American Boat and Yacht Council

ABYC refers to many regulations in the CFR and includes standards that are more applicable to smaller vessels that have been developed by the industry. For electrical requirements, the CFR references ABYC's sections entitled "AC and DC Electrical Systems on Boats" and "Electric Navigation Lights." Other electrical standards set by ABYC are included for battery-related equipment. ABYC also provides guidance in arrangement considerations such as seating and sightlines. Standards for anchoring, mooring, means of boarding, and hatches also are addressed by ABYC.

COST ESTIMATE

A detailed cost estimate of all materials and equipment necessary for the construction of the *EcoTour 24* was performed to allow the CRMC to plan a budget accordingly. While minimizing cost was an important consideration, the CRMC preferred to satisfy other goals, including utilizing electric propulsion with solar power and wooden construction, over cost reduction.

The cost estimate is incorporated alongside the tables of weights and centers in Appendix B. The scope of the cost estimate was limited to initial purchasing costs associated with construction materials and initial outfitting. Average market prices for materials and manufacturer list prices for components were used. Labor costs were not included because the CRMC has yet to determine the construction timeline, subcontractor wages, and number of volunteers that will work on the project. Lifecycle costs including maintenance and battery replacement costs were not considered in the estimate.

The cost of materials and equipment needed to construct the *EcoTour 24* is estimated at $30,000.

CONCLUSION

DESIGN SUMMARY

The final design of the *EcoTour 24* was presented to the CRMC Trustees on March 19, 2011. The design was accepted with minor aesthetic modifications. The final design is summarized in Table 12. Renderings of the model are shown in Figure 25–27.

Table 12: *EcoTour 24* Principal Characteristics

Length, overall	24'-0"
Length, waterline	23'-1"
Beam, molded	7'-6"
Draft	1'-3"
Freeboard, ⚯	2'-4"
Design Speed	5 kt
Range at Design Speed	16 nm
Propulsion Motor	4.0 kW
Maximum Capacity	12
Dry Weight	4000 lb

Figure 25: *EcoTour 24* Viewed from Starboard Stern Quarter

Figure 26: *EcoTour 24* Viewed from Starboard Bow

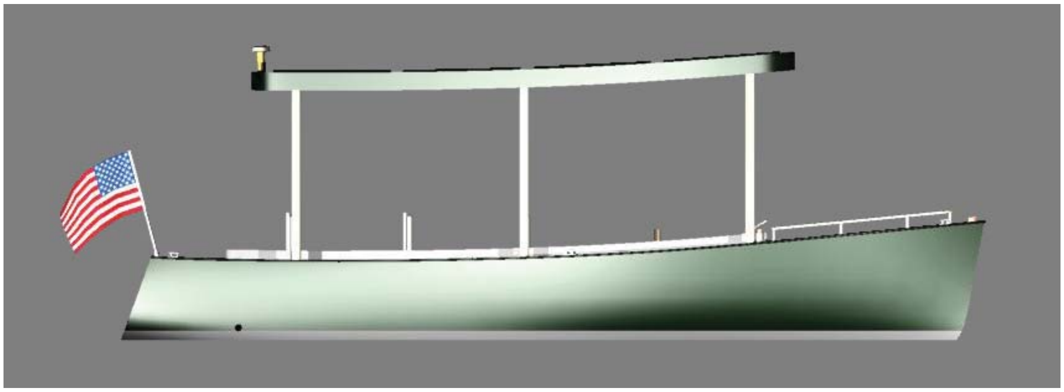

Figure 27: Outboard Profile of *EcoTour 24*

LESSONS LEARNED

Beyond the accomplishment of completing the *EcoTour 24's* design, learning about wooden boat construction, and delivering construction drawings and specifications, this project afforded the thesis team the opportunity to develop a design with the feedback of a real-world client. This experience provided a few lessons that would not have been possible while working in the classroom.

Exercising the design process outside of the safety and comfort of the classroom brings new challenges beyond just getting the job done. Students are accustomed to receiving printed requirements at the beginning of academic projects. These requirements typically outline the design objectives, the project timeline, and the means of assessment. In the real world, printed requirements are not guaranteed, and the legalese of contracts can make deciphering the actual requirements difficult.

Regardless of whether real-world requirements come printed or coherent, real-world requirements are subject to change, unlike requirements from the classroom. In this project, the CRMC initially indicated that the launch should be accessible to handicapped passengers and comply with the Americans with Disabilities Act (ADA). ADA compliance posed a moderate challenge, and several solutions were discussed in an early design review meeting. As the project continued, less emphasis was placed on ADA compliance, and eventually the requirement was removed entirely. Designing in the real world requires patience and an ability to adapt and to respond to a client's needs.

The Webb Institute curriculum rightfully emphasizes applications of solid engineering principles; however, aesthetics are often a low priority relative to analytics. During the conceptual design review, a pregnant pause followed a long string of questions and design suggestions. The silence was broken by one of the CRMC trustees, "I think the elephant in the room is [sic] the aesthetics."

Although the design met the draft requirement, was stable, and could achieve the design speed, the trustees could not see beyond how the renderings depicted the vessel. The same trustee emphasized, "Every design image should be a thing of beauty." From that point forward, more time was committed to ensuring that aesthetics played a larger part in the design process, while sound engineering principles still were followed.

The final lesson is applicable to all design work, be it academic or professional. As with most collaborative projects, communication among project stakeholders is critical. The client must relay design expectations clearly to the designer. A vessel's mission objective is a major factor in design considerations, and an uncertain or conflicting mission objective can delay or derail a project. The designer is responsible for ensuring that the expectations are heard and understood.

At one point, this project suffered from a lack of mission clarity. Uncertainty surrounded whether or not the vessel should be capable of crossing the Great South Bay. Some CRMC members were also uncertain what effect the canopy would have on viewing the wildlife. The vessel's mission was unclear to the designers, and a key structural member for the inclusion of solar panels was on the line. In order to move forward, the designers submitted a list of eight mission objectives and design goals for the CRMC trustees to rank. The survey returned with a consensus on the vessel's operating mission and the design priorities, and the project proceeded.

Just as the client must clearly communicate the design expectations, the designer is responsible for communicating any practical design limitations to the client.

RECOMMENDATIONS FOR FUTURE WORK

While the construction plans and design work have been completed for the project, there are additional opportunities to remain involved with the CRMC and the *EcoTour 24*.

This design has been completed as an undergraduate academic project, and it has been recommended that the design be reviewed by a qualified engineer before construction of the vessel begins. Coordinating the design review and amending the design as necessary could provide useful insight into the process of undergoing a professional design review.

Having Webb students available to answer questions during the construction process could form the basis for future thesis work. This would give a thesis team firsthand experience with wooden boat construction and the opportunity to solve construction challenges that may arise from differences in the design on paper and real materials and construction methods.

Once construction has been finished, future work could include a complete battery of sea trials. The design assumptions made in this project should be evaluated against the as-built condition. Suggested measurements include performance characteristics such as speed, power consumption, range, weight, and center of gravity, as well as an inclining experiment to determine the vessel's stability. These tests could also confirm the validity of manufacturer claims, particularly with regard to the propulsion motor and batteries. This investigation should include a follow-up discussion with the CRMC about the design, what changes were made during construction, and how the CRMC would approach future design processes after having gained the experience from this project.

Finally, a future thesis project may involve the designing and building of a laboratory apparatus to test the performance characteristics of solar panels and batteries in a marine environment. The apparatus could be used to conduct experiments with different battery technologies, system voltages, and charging configurations.

LIST OF REFERENCES

Adler, D. (1999). *Metric Handbook: Planning and Design Data*. Architectural Press, Oxford.

Ashley, J. (July 28, 2010). "I thought my boat was cool." *Stand Up Paddle Surfing*. Retrieved fromhttp://www.paddlesurf.net/2010/07/i-thought-my-boat-was-cool-til-i-saw.html

Baron, M. (2009). "Pump It. Don't Dump It." *Boating World*, November 2009.

Beys, P. M. (1963). Series 63 Round Bottom Boats. *Davidson Laboratory*, Stevens Institute of Technology.

Borg, P., and Shreeve, E. (1974). *The Carman's River Story: A Natural and Human History*. The Post-Morrow Foundation, Brookhaven, NY.

Brain, M. (2010). "How Lithium-ion Batteries Work." *How Stuff Works*. Retrieved from http://electronics.howstuffworks.com/lithium-ion-battery.htm

Carmans River. (2010). *Carmans River Maritime Center*. Retrieved from http://www.carmansrivermaritime.org/

Chapelle, H. I. (1994). *Boatbuilding*. W. W. Norton & Company, New York.

Chapin, D.M., Fuller, C.S. and Pearson, G.L. (1954). A new p-n junction photocell for converting solar radiation into electrical power. *Journal of Applied Physics*, Vol. 25, 1954.

Chodos, A. (2010). "April 25, 1954: Bell Labs Demonstrates the First Practical Silicon Solar Cell." *American Physical Society*. Retrieved from http://www.aps.org/publications/apsnews/200904/physicshistory.cfm

Davis, C. G. (1903). *How to Build a Launch From Plans*. Forest and Stream Publishing Company, New York.

Elco. (2010). *Elco, manufacturer of electric boats, launches, electric drive systems*. Retrieved from http://www.elcomotoryachts.com/

Gelpke, B., McCormack, P. (2006). *A Crude Awakening*. Docurama. DVD.

Gerr, D. (2000). *Boat Strength*. McGraw-Hill, Camden, ME.

Gerr, D. (2009). *Boat Mechanical Systems Handbook*. McGraw-Hill, Camden, ME.

GLREA. (2011). "How Do Solar Panels Work?". Great Lakes Renewable Energy Association. Retrieved from http://www.glrea.org/articles/howDoSolarPanelsWork.html

Gould, S. (Winter 2010). "The Boat Shop." Carman's River Maritime Center, Brookhaven, NY.

Gould, S., Maust, R., President, Vice President, Carman's River Maritime Center. (2010, April 11). [Interview]

Guzik, S., Kaiser, J., and Webster, C. (2003). *A Solar Boat Design For Solar Splash Competition 2003*. Senior Thesis, Webb Institute.

Harvald, Sv. Aa. (1991). *Resistance and Propulsion of Ships*. Krieger Publishing Company, Malabar, FL.

Knier, G. (2010) "How Do Photovoltaics Work?" *NASA Science*. Retrieved from http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

Koehler, H. W. and Oehlers, W. (1998). 95 Years of Diesel-Electric Propulsion Form a Mekeshift Solution to a Modern Propulsion System. Norwegian Society of Chartered Engineers. Retrieved from http://www.manbw.com/files/news/filesof2549/%C3%89lectric%20Propulsion.pdf

Lead Battery Recycling. (2009). "Lead Acid Battery Recycling." *Lead Battery Recycling World*. Retrieved from http://www.lead-battery-recycling.com/lead-battery-recycling.html

Leather, J. (1973). *Clinker Boatbuilding*. Adlard Coles Ltd, London.

Lenardic, D. (April 8, 2010). "History of Photovoltaics." *Photovoltaic Applications and Technologies*. Retrieved from http://www.pvresources.com/en/history.php

Lewis, E. (1988). *Principles of Naval Architecture, Vol. II: Resistance, Propulsion and Vibration*. The Society of Naval Architects and Marine Engineers, Jersey City, NJ.

Lifeline. (2010). “Marine & RV Deep Cycle Batteries.” *Lifeline*. Retrieved from http://www.lifelinebatteries.com/

Long, D. (March 29, 2010). *Wertheim National Wildlife Refuge*. Retrieved from http://www.fws.gov/northeast/longislandrefuges/wertheim.html

McIntosh, D. C. (1987). *How to Build a Wooden Boat*. WoodenBoat, Brooklin, ME.

Munson, B. R., Young, D. F., and Okiishi, T. H. (2006). *Fundamentals of Fluid Mechanics*. John Wiley & Sons, Inc., 5th ed.

Nexus Marine (2011). “Custom Cold-Molded Wooden Boatbuilding – The Nexus 29.” *Nexus Marine Corp*. Retrieved from http://www.nexusmarine.com/nexus_29_construction1.html

Nicholson, I. (1983). *Cold-Moulded and Strip-Planked Wood Boatbuilding*. Stanford Maritime, London.

Nicholson, I. (1985). *Boat Data Book*. Sheridan House Inc, Dobbs Ferry, NY.

NREL. (2005). “Best Research Cell Efficiencies.” National Center for Photovoltaics, *National Renewable Energy Laboratory*. Retrieved from www.nrel.gov/ncpv/thin_film/docs/kaz_best_research_cells.ppt

Peters, K. (2009). *Duffy Electric Boat Company*. Retrieved from http://www.duffyboats.com/

Photowatt. (2007). “How PV Works.” *Photowatt Technologies*. Retrieved from http://www.photowatt.com/en/learn-about-solar/how-pv-works/

Plug In America. (2010). “Why Plug in Vehicles?”. *Plug In America*. Retrieved from http://www.pluginamerica.org/why-plug-vehicles

Rössel, G. (1998). *Building Small Boats*. WoodenBoat, Brooklin, ME.

Sharp Corp. (2010). "1963: Mass Production of Solar Cells." *Sharp History*. Retrieved from http://sharp-world.com/corporate/info/his/h_company/1963/index.html

Skene, N. L. (2001). *Elements of Yacht Design*. Sheridan House, Dobbs Ferry, NY.

Smaalders, M. (2000). Wooden Boat Construction. *Good Old Boat, Sept/Oct 2000*. Retrieved from http://www.smaalders.net/yacht_design/gobboatconst.html

Solarbuzz. (March 2011). “Module Pricing.” *Solarbuzz: Solar Market Research and Analysis.* Retrieved from http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices

Torqeedo. (2010). *Catalog 2010*. Torqeedo, Starnberg, Germany

Von Wentzel, C. (2005). “Comparing Marine Battery Technologies.” *vonwentzel.net*. Retrieved from http://www.vonwentzel.net/Battery/index.html

Wertheim. (2010). “Wertheim National Wildlife Refuge.” *Fish and Wildlife Service*. Long Island National Wildlife Refuge Complex. Retrieved from http://www.fws.gov/northeast/longislandrefuges/wertheim.html

Whitney, R. (December 18, 2007). “Nellis Activates Nation’s Largest PV Array.” *Nellis Air Force Base*. Retrieved from http://www.nellis.af.mil/news/story.asp?id=123079933

Woodwork Forums. (2010). “Starting Out.” *Woodwork Forums*. Retrieved from http://www.woodworkforums.com/f32/starting-out-128271/