

# Proposal for a Design of a Autonomous Bridge-Mapping Hydroplane

Group 2

Proposed for: 2.017 Design of Electromechanical Robotic Systems  
Professor Franz Hover      Lab Instructor Harrison Chin  
September 29, 2009

## 1. Objective

This project aims to create an autonomous surface vessel which will be able to investigate under and around the supports of a bridge, specifically the Harvard Bridge located in the Charles River of Boston, MA. The design will encompass various settings for the speed and level of control used for different portions of the mission and will also optimize the energy use and speed of the mission.

## 2. Project Description and Approach

### 2.1 Background

The use of autonomous surface vehicles allows the surveying of large areas of water without the need for directed operation. The researcher may use an unmanned vehicle in situations where it is impractical or dangerous for a human operator to be present. High-speed unmanned vehicles also allow a larger area to be surveyed in a shorter amount of test time, a valuable resource in both research and industry.

### 2.2 Specific Goals

In this project, the vehicle is being designed to survey the footings of the Harvard Bridge which spans the Charles River. The mission sees the vehicle steering itself to the bridge and photographing a bridge piling at multiple perspectives. The team is modifying a commercially available, high-speed electric hydroplane to run smoothly at differing optimal speeds. The vehicle, a Pro Boat Miss Elam, will be outfitted with a range of sensors.

The energy consumption during the mission is also of concern. Although the vehicle will most likely meet its power requirements with additional batteries, the will also be a proof-of-concept for meeting these needs with an attached solar collector. Further, the motors and main power drawing elements of the system will be optimized to conserve energy where possible. This complex autonomous system will require both a rigorous control system and a rugged, waterproof design.

### 2.3 Functional Requirements

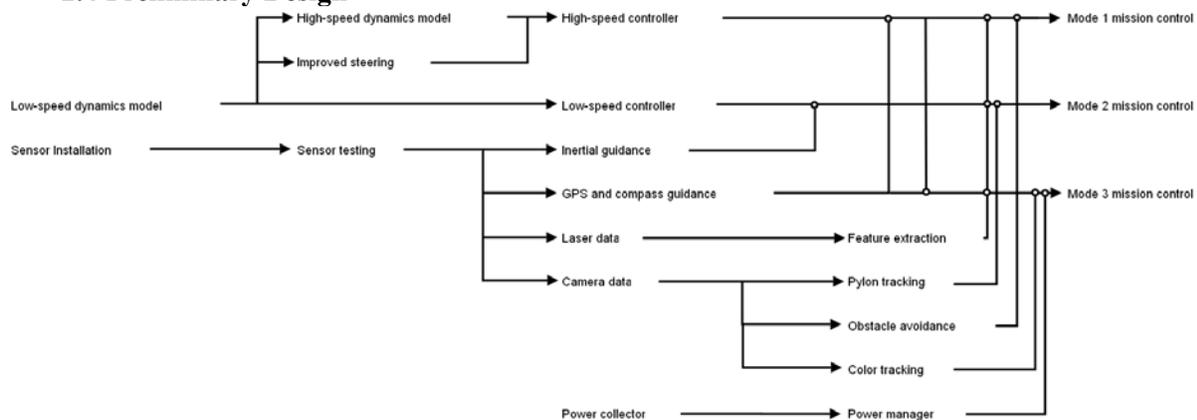
Much more than just a camera and a means to trigger will be necessary for the successful completion of this mission. One major challenge will be ensuring the proper positioning of the boat with respect to the bridge pilings. To this end, the boat will be outfitted with a range of sensors such as gyroscopes, accelerometers, and a GPS system to assist in the navigation of the river to the bridge. A laser range sensor will be used in positioning the vehicle while it surveys near the bridge, as GPS data will be unreliable beneath the bridge.

Another key ability is the power use-optimizing “modes” mission plan the team has identified as critical to the completion of the mission. The boat is quite small and can only carry so much on-board power. Far from the bridge, high speed will enable the boat to get to the bridge as quickly as possible. However, near the bridge speed is much less necessary and more power will need to be routed to the sensors. The team plans to use “modes” as a scheme for the speed of the mission and the power allocation within the vehicle.

The robustness of the boat and the component attachments is perhaps the most crucial aspects of the mission, despite its mundane nature. The wave environment in the Charles River is roughly 1ft

waves at around 1hz, which is probably the worst-case environment for the Pro Boat Miss Elam. Sensors, such as the gyroscope and the compass, will help to gauge and compensate for these forced motions of the boats.

## 2.4 Preliminary Design



**Figure 1: Block Diagram of Planned Tasks**

The mission requires the boat to act as a stable platform, capable of carrying a large array of sensors, batteries and power collectors even at high speeds. To that end, several vehicle modifications have been planned to make room for the equipment and ensure that it is optimally positioned.

Sensors such as the gyroscope, accelerometer, compass, and the Arduino microcontroller will need to be housed in a waterproof housing, so the geometry of the boat must be altered. The removable cowling currently encloses a mostly empty space, but this space will not be large enough to accommodate these sensors plus the additional batteries required to power them so it will need to be enlarged. The gyroscope and accelerometer will be mounted as close as possible to the center of mass of the vehicle, to try to minimize the lateral motion the gyro will experience and the rotational motion the accelerometer will experience.

The laser rangefinder and camera will be mounted as high on the vehicle as possible, to minimize the impact of waves on the readings. If possible, the existing spoiler will be used as the mounting point. However, if the spoiler proves to be too far back, or structurally incapable of sustaining the required load, the camera and laser can be attached to the extended cowling. To allow the vehicle to both follow the walls of the supports by “looking” at the wall from the side of the boat and to avoid obstacles by seeing them from the front, the laser rangefinder will be mounted to a small servo which will rotate the components as needed.

It is currently unknown whether the steering ability of the boat will be sufficient for this mission. Experiments are planned to test this aspect of the boat control and if it is deemed insufficient, the first step will be to add bow planes to increase the ship stability in pitch and roll.

Finally, the ability of the hull to cut through waves may also need to be improved. As currently designed, the boat seeks to ride over waves instead of cutting through them. This is a good design for a 900 Watt boat with no purpose or ballast other than speed, but it will not work for this mission. The heavy components will weigh down the ship and the position sensors would be quite confused by the wave motion of the ship. The front of each pontoon will be made sharper and less sloped to allow the boat to cut through the waves.

## 3. Project Plan

### 3.1 LTI Modeling

To successfully complete the mission, a robust control system must be developed that takes into account both the dynamics of the boat and the wave characteristics of the Charles River. The design such

a complex control system will require several steps. Once the close-loop model is developed and integrated into the control system, its performance will be tested in the tow tank and the Charles River to assess its performance. Adjustments will be made accordingly to improve vehicle performance.

First the team must develop a model of the boat dynamics. The model will relate the speed and yaw of the boat to propeller speed, rudder position, and outside disturbances such as the waves and wind using basic hydrodynamic principles. If need be, tests will be performed in the MIT Tow Tank to obtain characteristics used by the model such as the boat's moment of inertia and viscous drag coefficient. The tow tank will also be used to conduct experiments to determine the boat's open loop response to different sea states. One such experiment would involve mounting the boat at different angles in the tow tank and measuring the torque exerted on it by waves of varying frequency and amplitude. These measurements would then be use to determine the relationship between sea-state and disturbance torque.

Once the boat dynamics have been determined, a closed-loop model to take desired speeds and headings and adjust the boat's rudder and propeller speed based according to sensor readings and the boat's response can be developed. Part of building this model will involve incorporating the boat's stock motor controller and rudder control. These controls have specific gains relating the RC signals used to control the boat to the rudder position and propeller speed. Once these gains are incorporated, the signals from the controller will be able to correctly adjust the propeller speed and rudder position.

The close loop model will utilize several sensors to report the real time speed, orientation and location. These sensors will include a 3-axis accelerometer, laser range finder and GPS and will be used in conjunction to determine the boat's speed, orientation and location.

Since the boat will be operating in the random environment of the Charles River, a wave spectra of the river will be a valuable asset because it will allow for optimization of control system gains. If no accurate data is readily available, we will deploy sensors in Charles River to obtain the wave height over time at several locations. This data can then be processed using the FFT function to determine the wave amplitude spectrum of the Charles.

### 3.2 Tasks and Responsibilities

<b>Table 1: Mission Tasks and Responsibilities</b>	
CMU Integration	Student A
Laser Range Finder Integration	Student B
Control System Design	Students A, C, D
Sensor Mounting and Boat Modification	Students C, E
Data Collection and Modeling	Students B, F
Energy Collection and Management	Student G
Mission Planing, Team Management	Student D
Testing, Administrative Work	All

### 3.3 Required Equipment

<b>Equipment Name</b>	<b>Function</b>	<b>Cost</b>
GPS	Positioning when ship not under bridge (incl. surge and sway)	\$0 *
Compass	Ship Heading (Yaw)	\$0 *
3-Axis Accelerometer	Measures Pitch and Yaw (removes DOFs from system)	\$0 *
Gyroscope	Pitch and Roll (Redundancy)	\$0 *
Laser Range Finder	Positioning Under Bridge	\$300-\$750
CMU Camera	Real-time image processing (navigation, retrieval, pillar recognition)	\$0*

- Item already available in the OETL

Most of the sensors to be used will be for navigation either on the river or underneath the bridge. These sensors include the GPS and gyroscope. However, two other pieces of equipment are currently being considered. The CMU camera allows for more precise navigation, especially near the bridge and the dock. A CMU camera performs on-board real-time image processing for object and color recognition. It could potentially be used to recognize a pillar of the bridge, or an object near the dock to simplify the recovery of the hovercraft at the end of the mission. The OETL would need to be purchased for this project, but it is probably prohibitively expensive. Finally, a laser range finder could be used to measure the distance between the craft and a pillar of the bridge, helping to maintain a precise, constant distance but would also need to be purchased.

### 3.4 Additional Resources

To create the 3D image of the bridge support envisioned by the team members, guidance/instruction will be needed on how to combine the images taken by the camera into a believable composite. Interpreting data from the laser range finder, and ensuring that we are able to communicate with the range finder that is purchased, is also expected to be a roadblock.

### 3.5 Potential Risks

The sources of risk in this project spring from two major possibilities: crashing the hydroplane into walls, the bridge, or regular boats and wave damage to the boat or the equipment it carries.

Before any modifications are made, the boat must be fully tested at its entire speed range and its maneuvering capabilities must be assessed to prevent overshoot. The boat may also continue to collect distance sensor data (from the laser range finder) even when not surveying the bridge, so that it can detect unexpected collisions elsewhere in the mission. The tests and mission runs will be performed when river traffic is at a minimum.

The wave spectrum of the Charles River will be measured and assessed and the hydroplane modifications will be made accordingly. However, in the case of unexpected turbulence, adequately waterproofed sensors and a robust watertight design for the payload of the boat will be critical. The hull geometry and stability will be assessed to avoid capsizing the boat.

### 3.6 Back-Up Plan

There are a few ways in which catastrophic failure could be encountered during a mission, the worst of which are GPS failure or loss of battery/ insufficient power. Every possible precaution will be taken to prevent either of these from occurring, but should any such event occur, there are plans in place.

### 3.6.1 GPS/Sensor Failure

If the plane either loses GPS or loses close-range sensor capacity when under the bridge, there are two options for recovery. One would use dead-reckoning and the acceleration/ gyroscopic data and use a program to estimate the plane's position from its past movement. The program could estimate the plane's past position and direction, although with a certain amount of error. Despite the error, the data would probably still be enough to direct the plane roughly to the side of the river where it could be recovered. A second option would be to retain the functionality of RC control, so that the plane could switch back if options were limited. This could also be useful if we could see the plane to be distinctly off-course or about to make an unexpected collision.

### 3.6.2 Loss of Battery/ Insufficient Power

Battery life will clearly be a great concern in the design, and some design measures have been proposed as possible power-safety features. The power consumption could be tracked over time and the mission aborted when the power reaches a critical level. Additionally, if the solar panels make it past the proof-of-concept stage, then the vehicle could enter a “charge mode” until it has enough power to complete the mission.

### 3.7 Schedule

Our tentative schedule over the course of the project will be as follows:

<b>Table 3: Tentative Schedule</b>	
<b>Dates</b>	<b>Activity</b>
9/21-10/4	Learn boat controls to find its response under RC control
9/21-10/4	Determine and purchase necessary sensors
10/5-10/18	Modify the boat to get desired response.
10/5-10/18	Correct for placement of sensors.
10/5-10/18	Collect data on river wave characteristics.
10/19-10/25	Develop a close-loop, LTI model of system
10/26-11/8	Test in controlled environment
11/9-11/15	Debug and retest
11/16-11/29	Field Test
11/30-12/6	Debug and Retest
12/07/09	Final Presentation

\* This schedule may change based on certain setbacks or difficulties, but sticking to as closely as possible should allow for the proper completion of this project.

MIT OpenCourseWare  
<http://ocw.mit.edu>

2.017J Design of Electromechanical Robotic Systems  
Fall 2009

For information about citing these materials or our Terms of Use, visit: <http://ocw.mit.edu/terms>.