

Design Review #1:  
Water Strider

Design of Experiments  
Professor Girard  
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**BAAM!**  
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!

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## **I. Introduction:**

Water striders are small insects that have the unique ability of being able to glide on the surface of calm water supporting themselves by surface tension. Some the larger of the 320 species of water striders can move as fast as 150 cm/sec without breaking the surface of the water. Their small hydrophobic legs act similar to oars, with a tarsal segment acting as an oar blade. The only difference is that the tarsal segment never breaks the surface tension, but rather pushes against the meniscus formed under its own weight. This rowing motion repels the water strider forward, enabling it to move rapidly and turn quickly on the water's surface.

The primary goal of this project is to duplicate as closely as possible the motion of real water striders. Both MIT and Carnegie Mellon University have built robotic water striders that will be used as models for this project. Beyond replicating water strider motion, the next level of design is to control the robot's motion. Through the use of accelerometers and off-board controls, straight-line motion can be achieved. Additionally, the speed at which the strider would move on the water would be improved with increasing its ability to simulate a real water strider's motion. Beyond this level of design, other features can be added to the robotic water strider. Adding wings that would allow the strider to lift several centimeters off the water, incorporating onboard power, and adding carbon nanotubes as a hydrophobic coating are all possible additions to the water strider.

The final device would have a wide variety of applications. As a research device, a robotic water strider could travel over the surface of calm water, taking measurements and detecting contaminants. Inside water towers or at the base of large floating structures, the strider could look for damage and take pictures. As a reconnaissance device, the water strider could move, virtually undetected, into hostile environments and take pictures and measurements.

## II. Specifications:

Several criteria must be met in order for the final design goals to be met. Many of the materials and dimensions listed are based upon the CMU water strider and the MIT Robostrider. These specifications may be modified during the design process to meet specific criteria that develop.

For a more complete analysis, see section V. Problem Analysis.

- **Body**
  - Weight: ~3g
  - Dimensions: No bigger than needed to accommodate actuators and sensors
  - Material: Fiberglass (Level 1), Garolite (Level 2), or carbon (Level 3)
- **Legs**
  - Weight: ~3g
  - Dimensions: front = short, rear = long, middle (rowing legs) = body length
  - Material: .2mm stainless steel wire (MIT Robostrider)
  - Coating: Varnish or Teflon wax (Level 1/2), carbon nanotubes (Level 3/4)
- **Propulsion**
  - 2 Miniature Rotary PiezoMotors, *Polytec PI*
  - Weight: ~10g total
  - Dimensions: 3mm x 6mm each
  - Operational Voltage and Current: 3.5V, 30mA
- **Sensors**
  - Accelerometers (2: x,y) (Level 2/3)

- Heat, light, toxin etc. (Level 3/4)
- **Overall**
  - Light weight (~20g total)
  - Straight line motion (Level 2)
  - Onboard controls / sensors (Level 3)
  - Low power: mW range – leaves potential for high efficiency onboard power
  - Stable platform to which many sensors and attachments can be mounted

### **III. Applications:**

- Surveillance : equipping the water strider with a camera so it could engage in reconnaissance against enemy targets.
- Remote sensing : Putting thermal, light, or chemical sensors on the water strider.. The water strider would then be used to check for contamination or other defects.
- Decontamination: the water strider is equipped with a small amount of decontamination chemical. Large numbers would then be released on a contaminated site such as an oil slick or other spills and neutralize it.

### **IV. Concept Selection Method:**

As much of this project involves primary research, the design criteria are largely based upon a potential client. Therefore, the goal of this project is more of an exploration of nature and a design of a robot for a specific task. The main constraints arise from simple physical constraints associated with creating a robot that will not break the surface tension of the water. This project will use a modified House of Quality to account of this difference. This House of Quality matrix will include only the technical requirements matrix, the roof matrix, and the target

matrix. Further information on design constraints will be provided by interviews with faculty and graduate students who are working in relevant areas of study.

## **V. Plan & Milestones:**

Given time to complete this project, a timeline with specific milestones and associated dates has been constructed. The project has been broken down into several levels. The milestones along with more specific dates are described in the Gantt Chart below.

### **Levels:**

#### **Level I:**

- Replicate CMU design
- Create fiberglass body
- Build steel legs with hydrophobic coating for water walking
- Construct piezoelectric actuation

#### **Level II:**

- Implement control system for straight line motion (accelerometer)
- Improve propulsion with propellers, wings, or more efficient legs

#### **Level III:**

- Add turning ability, (360 degrees)
- Explore other hydrophobic coatings for walking on water (Carbon Nanotubes)
- Add ability to jump and increase speed (wings, propellers, magnetic levitation)

#### **Level IV:**

- Onboard control and power
- Flee mechanism: turns away from heat light
- Contaminant sensing capability

### **Gantt Chart**

TEAM BAAMI GANTT CHART				January				February				March				April				May																	
1/25/2005		Duration	Who	18	20	25	27	1	3	8	10	15	17	22	24	1	3	8	10	15	17	22	24	29	31	5	7	12	14	19	21	26	28	4			
OBJECT PLANNING & TEAM STRUCTURE																																					
Complete Individual Project Concept Memos	2d	all																																			
Complete Project Planning	2d	all																																			
Organize Team Structure	2d	all																																			
Complete Executive Summary & Specs	5d	all																																			
Complete First Team Task Tracking Summary	5d	all																																			
Design Web Site & Consistently Update Site		ah, mk																																			
SIGN/IMPLEMENTATION OF PROJECT PLANNING																																					
Complete Design Review #1 (DR1)	1w	ah, af																																			
Complete Written Reports for DR2	2w 2d	ah, af, mk																																			
Complete Design Review #2 (DR2)	3w	bb, mk																																			
Feedback on Other Team's DR2	1w	ah, mk																																			
VELOPMENT/CONSTRUCTION																																					
Level I: Complete Working CMU Design	1w 5d	all																																			
Build Glass Fiber Body	1w 5d	bb																																			
Construct Legs with Hydrophobic Coating	1w 5d	af																																			
Construct Piezoelectric Actuation & Propulsion	1w 5d	mk, ah																																			
Level II:	2w	all																																			
Improve Control System-Maintain Straight Line Motion	2w	mk, bb																																			
Improve Travel & Speed	2w	af, ah																																			
Level III:	2w 5d	all																																			
Fast 360 Degree Turning Ability	2w 5d	mk																																			
Explore Hydrophobic Coatings on Wires (CNT)	2w 5d	af																																			
Add Ability to Jump, Add Wings, Propellers	2w 5d	ah,af, bb																																			
Level IV:	3w 2d	all																																			
Onboard Control & Power	3w 2d	mk																																			
Flee Mechanism to Heat	3w 2d	af, ah																																			
Sensors for Leaks/Contaminants	3w 2d	bb,																																			
Complete & Present Electronics, Sensors, & Control Logic	3w 5d	mk, bb																																			
Layout & Manufacture Mechanical Components	6w 5d	af, ah																																			
Complete Manufacturing & Assembly	2w 2d	all																																			
Complete Evaluation of Mechanics	2w 2d	all																																			
STING & DEMONSTRATIONS																																					
Final Testing & Problem Solving	1w 6d	all																																			
Prepare for "In-House" Demonstration	5d	all																																			
Complete Course & Peer Evaluations	1d	all																																			
Prepare Presentation for Practice Design Expo	1w	all																																			
Revise Presentation for Design Expo	6d	all																																			
FINAL REPORT																																					
Compile Plans to Analysis of Project into Written Final Report	3w	all																																			

/: af = Allan Fong  
 ah = Adam Hurst  
 bb = Brandon Basso  
 mk = Malcolm Knapp

Time  
 Milestone  
 Completed

## VI. Problem Analysis:

Developing a robotic water strider has several inherent constraints. As water striders are supported mostly by surface tension (and partially by the buoyancy force), the largest constraint is the weight of the robot. The largest water strider, *Giagantometra gigas*, weighs on average 10g and is supported by four legs. The size of the tarsal segment of the leg (the part of the leg on the water) will scale directly with the weight of the strider. No specific limit to the weight of

water striders exists. However, calculations performed by Bush et. al. suggest a finite limit to the size of water striders before they become too massive to accelerate through the water without breaking the surface tension with their driving legs (Nature). This limit most likely exists for water striders two to three orders of magnitude larger than *Giagantometra gigas*. Therefore, a robotic water strider with a total weight of 20g, twice that of the largest water strider, should be able to support itself and move through the water, so long as the legs are scaled accordingly.

Accelerating a robotic water strider through the water is a significant challenge. The applied force must not exceed 140 dynes/cm, after which the driving legs will pierce the surface of the water. The species *Gerris remigis* applies a force per unit length of 80 dynes/cm, weighs 10g, and can move along the surface at 100 cm/s. MIT's Robostrider applies a force of 55 dynes/cm and moves approximately 5 cm/s. More than an order of magnitude improvement is needed to more closely mimic the motion of real water striders.

MIT's Robostrider is powered by an elastic band and CMU's water strider is powered by lightweight piezoelectric actuators. Possible improvements in propulsion may be made by selecting a higher power-to-weight device that also can more closely mimic a real water strider's movements. A piezoelectric rotational motor may supply this range of motion while still fulfilling power and weight requirements. So long as the rotary motion of the motor can be translated into the elliptical motion that is more characteristic of a real water strider's driving legs, a robotic water strider may be able to mimic the performance of its natural counterpart.

Developing a lightweight, maneuverable platform will allow for additional electronics and sensors to be added to the robotic water strider. In addition to onboard propulsion devices, onboard sensors, such as accelerometers will be required to send speed and direction information back to the control system. Mounting accelerometers to the water strider may present additional

challenges and will most likely necessitate further ‘slimming-down’ of the legs and body. The accelerometers will have to be interfaced with an off-board control system and then control information will be sent back to the bug via overhead wire. Each system (power, propulsion, control, sensing) will be designed with the ultimate goal of complete autonomy in mind. Therefore, developing a lightweight, compact control system will be a significant challenge. After all the propulsion, controlling, and sensing electronics have been added, whatever leftover weight left in the weigh budget can be allotted to onboard power and wireless communication. This level of development may be out of the scope of this particular project, but designing the water strider with these constraints in mind from the beginning stages will allow for the demonstration of a system that could potentially be 100% autonomous.

## **VII. Literature Search & Information Sources:**

### ***A. Patent Search:***

In searching for patents in existence for mechanical water striders, none were found specifically for the mechanical water strider already in existence. One prototype was built at MIT by David Hu and Brian Chan. However, no patent appears to have been completed as of yet, however, the invention was published in August of this year, making it possible that the patent is being processed.

A patent was filed for mechanical bugs in general. This patent, application number 20040119435, was filed based upon a mechanical device that had insect like behaviors with at least six legs. The project at hand would normally fall under this patent, however, since it has a walking on water ability it is significantly different mechanisms of floatation and motion as well as applications. The patent states that the “mechanical bug includes a housing; a gear mechanism within the housing; and at least six legs extending from the housing, each leg having

a first end operationally associated with the gear mechanism such that movement of the gear mechanism also moves the leg” (Pinney, 20040119435, 1). In contrast, the water strider has 4 to 6 legs that are solely used for support or floatation rather than movement. These legs are not connected to gear mechanisms for movement, as the patent specifies, but rather solely attached to the body to provide the walking on water ability. Based upon the specifics of the patent, outlining bugs that have moving legs that support themselves as they traverses hard surfaces, the water strider does not fall under these specifications. Therefore, the idea and specifications of the water strider has not been patented as of yet.

United State. Patent and Trademark Office. *Mechanical Bug*. Steve B. Pinney. Washington: GPO, 2004.

### ***B. Literature Search:***

- Sun, Taolei et al. Control over the wet ability of an aligned carbon nanotube film. *J. AM. Chem. Soc.* 125, 14996-14997 (2003).
- Sun, Wang, Feng, Jiang, and Zhu demonstrated that a film of aligned carbon nanotubes coated with fluoroalkylsilane showed superhydrophobic properties. It was demonstrated that a water contact angle larger than 150 degrees could be achieved on the surface. It was also shown that the thickness of nanotube films and the spacing between the tubes can affect water’s behavior to its surface.

- Tseng, M. and Rowe, L. Sexual dimorphism and allometry in the giant water strider *Gigantometra gigas*. *Can. J. Zool.* 77, 923-929 (1999).

There appears to be a constraint on the relationship between the middle and hind leg lengths of water striders, possibly because of the biomechanics of locomotion. The mean lengths of the leg-components and body of giant water strider are listed as follows

(lengths are in mm):

Forefemur	7.26
Foretibia	6.16
Total foreleg	15.20
Middle femur	48.57
Middle tibia	44.28
Total middle leg	98.39
Hind tibia	74.91
Hind femur	48.51
Total hind leg	126.40
Body	34.08

(The femur is the part of the leg that is closer to the body and the tibia is the part of the leg that is in contact with the water.)

Looking at the developments in nature is often a good place to start when deciding on design criteria.

- Hu, David et al. The hydrodynamics of water strider locomotion. Nature 424, 663-666 (2003).

This article summarized the basic behavior of water striders. Water striders move by rowing its legs. The vortices generated underneath the water allows the strider to move rapidly across the water surface. Robostrider was able to move its legs at speeds of 18 cm s<sup>-1</sup> through the use of an elastic thread and pulley system.

- Lau, Kenneth et al. Superhydrophobic carbon nanotube forests. Nano Letters 3, 1701-1705 (2003).

A stable superhydrophobic surface was created using a vertically aligned carbon nanotube forest coated with a thin, hydrophobic polytetrafluoroethylene.

Superhydrophobicity was achieved on the microscopic level using this technique.

- A research team lead by Carnegie Mellon engineering assistant professor, Metin Sitti, built a tiny robot that can walk on water. The robot has a body of a little more than a half-inch made of carbon fiber and eight 2-inch steel-wire legs coated with some kind of water-repelling material. The legs are controlled using piezoelectric actuators.

- ZMUC <http://www.zmuc.dk/EntoWeb/Halobates/HALOBAT2.HTM> (2004)

This page studies the anatomy of Halobates, sea skaters or water striders. Halobates have an elaborate network of hair-layers that protect them from being wetted when occasionally submerged or sprayed by rain. Water striders are also equipped with three pairs of legs, each with a different function. The two front legs are primarily used to hold

on to prey. The two middle legs are used as oars for movement and the two hind legs are often used to steer and maintain stability.

- Vassar College  
<http://faculty.vassar.edu/suter/1websites/sutersite/Locomotion/images.htm> (2005)
- Roach, John. New water-repellent material mimics Lotus leaves National Geographic News  
[http://news.nationalgeographic.com/news/2003/02/0227\\_030227\\_lotusmaterial.html](http://news.nationalgeographic.com/news/2003/02/0227_030227_lotusmaterial.html) 27  
February 2003.
- GE. Hydrophilicity and hydrophobicity  
[http://www.gewater.com/library/tp/772\\_Hydrophilicity\\_and.jsp](http://www.gewater.com/library/tp/772_Hydrophilicity_and.jsp) 2003

## **VIII. Conclusion:**

Building a robotic water strider is a challenging project due to weight limitations and fitting the necessary electronics within this weight budget. With these challenges, certain levels will be reached in completing it. Several levels may require alterations to the idea as a whole but in the end the general goal of a water strider that can support some load and move along the water with some ability to control its direction will be reached. Constructing the robotic water strider presents significant engineering challenges and inherent limitations. First, there are limited applications for a mechanical device that can only hold a very small load, and potentially have to

have off-board power. In addition, the water strider will require light, micro devices that will be hard to work with as well as costly due to their size and weight. Along with these limitations, there are also advantages to this robotic water strider which include the fact that this is a newly discovered area of study, the fact that there is a high fascination factor involved with a mechanical device that can walk on water, and there are anti-bioterrorism applications involving the examination of water for contaminants. Possibly the greatest advantage of this water strider project lies in the fact that it will be a great proof of concept ; it will demonstrate each group member to demonstrate their knowledge of fluids, materials, controls, mechatronics, design, as well as the ability to learn.