GhostSwimmer™: Tactically Relevant, Biomimetically Inspired, Silent, Highly Efficient and Maneuverable Autonomous Underwater Vehicle

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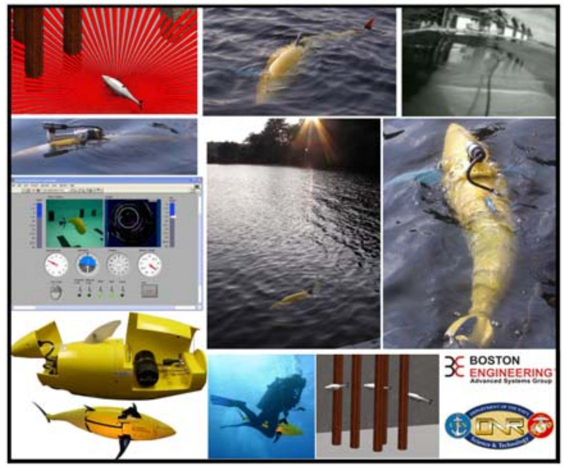

PROBLEM STATEMENT

GhostSwimmer™ is responsive to the needs of current covert, riverine, and littoral missions and endeavors to attack the problems facing current UUVs. There is an increasing interest in the use of long range/long duration Unmanned Undersea Vehicles (UUVs) for littoral observation, military surveillance and river search missions. Existing UUVs are commonly torpedo-shaped and exhibit poor maneuverability, especially in shallow areas. Small rotary propellers driven by electric motors almost universally power these UUVs; the energy for which is stored in either rechargeable or one-shot batteries depending on the vehicle and its mission. The small diameter propellers typically operate at fairly low efficiencies (in the range of 45% for commercial thrusters) and suffer serious lag times in transient response.

The space required to store the batteries for significant mission times often approaches 70% of the hull volume. Low efficiency of propellers and their slow response coupled with large hull volume devoted to batteries leads to short mission times, restricted payloads, and control problems. In a littoral or river environment, the lack of control authority caused by a single propeller based system could prevent the execution of a critical mission. To overcome these problems, attempts could be made to develop better propeller or battery technology, but propeller improvements are limited by the maximum practical diameter that can be mounted on a small vehicle and current battery technology is frozen on a plateau awaiting a future breakthrough. For the moment, both endeavors offer only the hope of modest gains.

To explore the possibility of substantial gains, Boston Engineering is developing the GhostSwimmer™ Autonomous Undersea Vehicles (AUV) based on the design of comparably sized biological systems (fish and cetaceans) for inspiration. There is a large body of experimental data that suggests oceanic biological systems achieve high propulsive efficiencies (to 87%), and have extraordinary abilities to maneuver at both high and low speeds, far in advance of any conventional man-made vehicle. They do so using a flexible, streamlined body propelled by a single oscillating tail foil, an appropriately placed set of pectoral (and auxiliary) fins and a finely tuned muscular/sensory/control system.

The GhostSwimmer™ strives to significantly advance UUV technology by modeling it after fish because they have already solved the propulsion and maneuverability problem that plagues UUVs. In a strictly engineering sense where speed, maneuverability and endurance are crucial to survival, fish are very close to an optimal design. The distinguishing factor between GhostSwimmer™ and other biomimetic systems is tactical relevance. This vehicle is built to be functional, useful, payload carrying, robust, user-friendly, and optimized for mission performance. The Phase I prototypes are shown in the next figure.

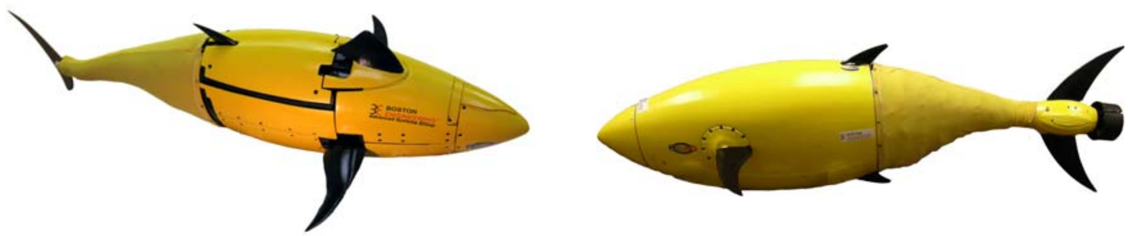

Figure 1: GhostSwimmer™ PH I Prototypes (Propulsion Vehicle (left) and Maneuverability Vehicle (right))

WHO CAN BENEFIT?

Per conversations with several end users in the Department of Defense (DoD) and the Department of Homeland Security (DHS) the GhostSwimmer™ is taking the right approach for littoral and other missions. Its modularity and payload capability as well as potential for low cost align it for riverine Intelligence Surveillance, and Reconnaissance (ISR), Very Shall Water Mine Countermeasures (VSW MCM) , pier-side Explosive Ordnance Disposal (EOD), harbor craft detection, persistent surveillance, covert sentry missions, infrastructure protection, and hull inspection (EOD). Due to the potential for long mission times as well as high speeds (straight line and during maneuver), the GhostSwimmer™ platform is ideal for the range of missions envisioned and corroborated by many customers including United States Coast Guard (USCG), Navy Expeditionary Combat Command (NECC), and more.

The Boston Engineering Advanced Systems Group has developed the GhostSwimmer™ while tying it into Navy Future Plans. The technical portions as well as the overall system concept leverage the Navy UUV Plan Master Plan (2004), the Naval Science and Technology (S&T) Strategic Plan (2007), Naval Research Advisory Committee Report (Science and Technology for Naval Warfare 2015-2020 (2005), as well as it's Supplemented Transition Plan.

The Navy desires systems that are; a) more flexible to varying applications/missions, b) more agile in blue to brown water sea environments, c) more energy efficient to enable longer mission times and unattended mission execution. These needs are even more apparent when considering harbors, ports and the many miles of coastal littoral zones around the world. The GhostSwimmer™ (GS) platform is expected to increase AUV efficiency by a factor of 2-3X, increasing the range of use considerably. The following table shows some mission areas in which GhostSwimmer™ excels.

End User Mission Requirements Examples	GhostSwimmer™	BIOSwimmer ™	Conventional UUV
Extremely Long Duration, High Maneuverability Missions (i.e. Harbor Defense, Extended Duration Littoral MCM)	✓		
Shallow Water, Complex Environment Missions (Mapping, ISR, MCM, EOD, Up-river Ops)	✓	✓	
High speed, rapid movement (burst and accelerate) Missions (cluttered space operations, rescue operations, unstable environments (thermal vents, etc.)	✓		
Silent Operation, Covert Ops (ISR, tagging, ASW, non-detection)	✓		
Hull Inspection, Tank Inspection, Pier-side and other EOD, Sentry, Swimmer Defense, Etc.		✓	
Deep Water Oceanographic Missions	*Future Capability*	*Future Capability*	✓

Figure 2: GhostSwimmer™ Mission Table (Note that BIOSwimmer™ is a variant of GhostSwimmer™ that uses conventional propulsion)

Relative to riverine operations, the GhostSwimmer™ platform might be the only evolving solution that can address the needs within the typically confined spaces, increased water flow rates, and/or need for changes in direction (winding). The ability to send a GhostSwimmer™ platform far upriver might provide the ability to take water samples or conduct ISR missions in highly hostile areas or where significant threats might be evolving, such as nuclear or chemical operations by unfriendly nations.

To combat new types or forms of threats, naval forces need to attain a higher-level awareness with an increased flexibility of missions. GhostSwimmer™ can respond dynamically to mission changes and re-deploy to other areas of interest. In addition, the highly maneuverability of the GhostSwimmer™ platform allows closer to real-time assessment of targets.

Another application could be the ability to send "schools" of GhostSwimmer™ platforms in front of a vessel(s) or a fleet with the flexibility of changing AUV focus quickly and efficiently to investigate or react to incoming threats. A GhostSwimmer™ platform can be deployed and can make severe maneuvers to increase the probability of interception of lethal threats approaching US vessels. Additionally, state-of-the-art AUVs require considerable energy in comparison to make 90 degree turns and the GhostSwimmer™ platform achieves the same in a shorter span and with minimal impact to normal operating energy usage.

In addition to defense and security specific applications, Boston Engineering is pursuing interest from the Oil and Gas (O&G) Industry on the use of the technology for ISR, mapping, and surveillance for natural energy sourcing and pipeline operations.

BASELINE TECHNOLOGY

The REMUS 100 represents a close comparative platform in size, weight, mission space, etc. Built by Hydroid Inc., the REMUS 100 is the standard platform in this class for various missions. However, as missions evolve and more challenging areas need AUV access, current vehicles such as the REMUS 100 lack the speed, maneuverability, and stealth to attack these littoral and riverine missions. Current systems, like REMUS, cannot access other areas that are becoming critical such as between "screws", or propellers, on large surface vessels for EOD inspections and through pier pilings. Complex environments with many obstacles and unsteady flows demand high maneuverability with rapid response at mission-relevant speeds. This simply is not achievable with current systems.

The price for REMUS 100 varies but can be up to $250k each. This varies depending on the capability included in the package. Its strengths include a simple, non-complex design that is based on a tubular pressure hull, ability to extend the length of the vehicle to add payloads, and the expanse of available autonomy solutions already developed for or by the Navy.

TECHNOLOGY DESCRIPTION

During Phase II, the GhostSwimmer™ will be compared to the REMUS 100 in many areas with a focus on speed, endurance, acceleration, maneuverability, noise, and modularity. It is anticipated that in Phase II, the speed can be twice as fast as the REMUS [10 knots as opposed to 5 knots] and that the propulsive efficiency will be superior to the REMUS due to lower drag, improved vortex management, and optimization of foil motion. With respect to acceleration, "burst swimming" capability is anticipated as well as immediate propulsion upon motion due to minimal drag. Maneuverability can be superior to that of a torpedo-shaped vehicle as GhostSwimmer™™ can perform 360 degree maneuvers at flank speed in approximately 1 body length diameter circles.

GhostSwimmer™ is being developed to be man-portable and deployable from small crafts such as rigid-hulled inflatable boats (RIHB) . Therefore, interfacing equipment is inline with current AUVs of this size. The Operator Control Unit (OCU) is intended to be a ToughBook style laptop-controller with a Graphical User Interface (GUI) designed per standard AUV use. At this time, end-user input for improved operability over existing OCU's is being secured.

This following Table represents a first-order estimation of GhostSwimmer™ endurance. This is in process of being fully defined. Direct comparison values are based on a 1 KW-hr energy source. This assumes a straight line constant swimming at this speed with drag as the main differentiator. GhostSwimmer™ can show greater advantage if maneuvering (energy losses during turning etc.) is taken into account. The maneuverability of GhostSwimmer™ far exceeds that of most torpedo shaped UUVs and can perform much more efficiently while maneuvering than these competitors.

Additionally, at speeds other than optimal, standard UUV propeller efficiency drops off, therefore, the relationship between the endurance at speeds for UUVs is NOT directly proportional to the forward speed cubed (U^3), it actually is additionally reduced by the reduced efficiency of the propeller while operating at non-optimal speeds. GhostSwimmer™ can maintain high efficiency over the speed range.

Parameter	GhostSwimmer™ Estimates		REMUS 100 (from spec)	
Speed	✓	GS PH II goal: ~10knots *(Potential Max = 15 knots)*		5 knots maximum
Endurance: 3 knots	✓	~66 hours *(assumes same onboard energy*		22 hours

		source)		
Endurance: 5 knots	✓	~14 hours		~8 hours
Endurance: 10 knots	✓	~2 hours		Not Applicable (Max speed is 5 knot)
Operational Range	✓	~339 miles *(Assuming 3 knots endurance)*		~76 miles *(Assuming 3 knots endurance*
Detection Avoidance	✓	Intrinsically covert; emulates fish (tuna), virtually undetectable acoustic signature (no propeller)		None Known
Acceleration	✓	Immediate propulsion upon motion-“burst swimming”		High inertia, slow transients, large added mass
Maneuverability	✓	Can turn about center point (radius ~1/2-1 body length) at flank speed, fins provide banking; reduced turning losses		Small cruciform control surfaces at rear have large turn radius, slow reaction. Hull shape causes large turning resistance
Noise	✓	Internal actuators, skin deadens noise, low frequency vortex shedding		External actuators (high frequency servo noise into water). Large, vehicle disturbances
Modularity	✓	Payload sections can be added and main components including propulsion are modules	✓	Payload sections can be added to the center and main components are modules
Cost	✓	Cost minimized with creative design and manufacturing techniques (estimate ~$150k)	✓	Despite large asking price (~$250k), simplicity may enable lower cost
Payload Fraction	✓	Modular payload bay, versatile system electronics for easy integration. Volume available: ~750in³ (~12L), ~500in³ in payload bay (balance in nose)	✓	Adds sections to vehicle center allows almost unlimited payload with more length but with serious efficiency and maneuver negative impact
Depth	✓	100m	✓	100m; larger REMUS vehicles can go deeper

Figure 3: GhostSwimmer™ vs. REMUS 100

CURRENT STATE OF DEVELOPMENT

GhostSwimmer™ feasibility was demonstrated in Phase I during which time Boston Engineering produced two prototypes (one specifically for propulsion development and the other for maneuverability development) and included in-water testing. The prototypes proved the system’s maneuverability and potential for high efficiency as well as stealthy operation. During Phase II (currently ongoing), Boston Engineering is combining the two technologies into a prototype and working to test straight line swimming, drag, base efficiency, basic maneuver, and 2D maneuver via the control system to characterize the GhostSwimmer™™ compared performance to Hydroid’s REMUS 100.

In Option I, the Phase II prototype will be tested and the control system advanced and further compared to the REMUS 100. During Option II, the team will further development towards a fielded system by driving a neural controller with advanced capability (3D maneuverability) that can include obstacle avoidance and path following. The maneuver capability of the vehicle in 3D space is intended to be demonstrated by performing high speed, high maneuver paths through an obstacle course simulating a complex tactical environment (desired output of Option 2).

Activities post Phase II will require at least the following tasks; continued and extended field testing, generation of a basic configuration specification sheet (with end users), specific mission payload testing, OCU development and optimization, transport equipment specification, spares and maintenance designation and documentation, final manufacturing plan implementation, and tasks related to the fielding of the systems as a product.

REFERENCES

The following individuals are familiar with our work.

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WHEN THE TECHNOLOGY WILL BE READY FOR USE

The GhostSwimmer™ AUV overall is expected to be at TRL 6-7 at the end of Phase II expected Q2 2013. Some subsystems within the GhostSwimmer™ will be at or closer to TRL 7 before the end of Phase II development activities.

It is expected that the GhostSwimmer™ AUV will need to go through a series of field tests and demonstrations post-PH II as well as applicable Navy acceptance procedures before it is deployed in any of the target mission areas. Boston Engineering, the PI's, and their partners are qualified to support these efforts.

ABOUT THE COMPANY

Boston Engineering Corporation is a well-established engineering services organization that delivers leading-edge products and system solutions to customers for over 15 years. The company is a multi-disciplined, cross-functional organization with approximately 40 employees. Since its inception in 1995, hundreds of high-technology systems and products have been successfully developed and brought to the market through the efforts of Boston Engineering. As a product development firm, the company is exposed to the latest technologies and, as a result, is well positioned to capitalize on new innovative opportunities. Given its extensive experience, the company is actively pursuing the development and commercialization of some of its own evolving technologies.

The company is significantly well-positioned to deliver complete solutions. Boston Engineering has built a solid reputation for delivering complex solutions on time and on budget. Traditionally, the company has serviced the commercial marketplace and in the last three years has been working directly on government sponsored projects. The company received ITAR registration in 2008 and has staff with either existing or past Secret or Special Access clearance. Boston Engineering's success in developing products and systems requiring Design for Manufacturability (DFM) and Design for Serviceability (DFS), coupled with the company's methods for rapid time to market delivery, reduces risk for its customers and partners.

Boston Engineering's Advanced Systems/Robotics Group (ASG) is engaged in various technology development programs. Current customers include the Office of Naval Research (ONR), the Naval Sea Systems Command (NAVSEA), the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC), and the Department of Homeland Security and programs include advancing Unmanned Vehicle technologies, developing advanced AUVs (Autonomous Underwater Vehicles), creating advanced intelligent Unmanned Ground Vehicle (UGV) payloads, non-conventional actuation technologies, integrated sensing solutions, and more. ASG leverages its technology and relationships to create world-class teams/solutions including teammates that hail from industry, government labs, universities, and is also involved in National Defense Industry Association (NDIA), Association for Unmanned Vehicle Systems Integration (AUVSI), FIRST USA, Institute of Electrical and Electronic Engineers (IEEE), the Small Business Association of New England (SBANE), and the Massachusetts Technology Leadership Council – Robotics Cluster.