

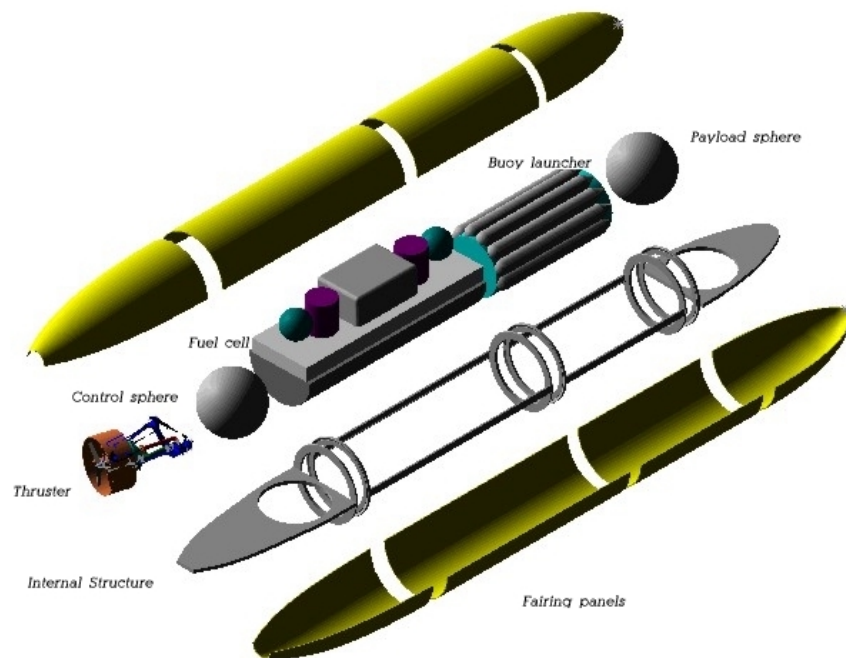
# Monitoring Arctic Ocean Hydrography Using Autonomous Underwater Vehicles

James G. Bellingham  
Massachusetts Institute of Technology, Sea Grant College Program  
292 Main Street; Bldg. E38-376  
Cambridge, MA 02139-4309  
phone: 617-253-7136 or 258-9476  
fax: 617-258-5730  
email: [belling@mit.edu](mailto:belling@mit.edu) - [auvlab@mit.edu](mailto:auvlab@mit.edu)  
Award Number N00014-98-1-0814

## LONG-TERM GOALS

Our goal is to greatly increase access to the Arctic Ocean by creating and demonstrating a safe and economical platform capable of basin-scale surveys. Specifically, we are developing a Autonomous Underwater Vehicle for Arctic research with unprecedented endurance, and the capability to relay data through the ice to satellites. We will provide a means of monitoring changes taking place in the Arctic Ocean and investigate its impact on global warming. The vehicle will also be capable of seafloor surveys throughout the Arctic basin. Such a capability is of national and global interest and importance.

## OBJECTIVES



AUV development is focused on an initial experiment, which is to track the Atlantic layer intrusion into the Arctic basin. We refer to the experiment as ALTEX for Atlantic Layer Tracking Experiment. ALTEX requires following the 1400m isobath of the Nansen Basin, with occasional north-south excursions to probe the extent of the warm water intrusion. The vehicle will run at a depth of 275 m, but will obtain a full water column profiles on at least a daily basis. For this mission, the vehicle may not be recovered - data is reported by telemetry buoy. Ice thickness measurements are obtained during the telemetry buoy launch phase.

# Report Documentation Page

Form Approved  
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>30 SEP 1999</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1999 to 00-00-1999</b>	
4. TITLE AND SUBTITLE <b>Monitoring Arctic Ocean Hydrography Using Autonomous Underwater Vehicles</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Massachusetts Institute of Technology, Sea Grant College Program, 292 Main Street; Bldg. E38-376, Cambridge, MA, 02139</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

To create the desired Arctic survey capability, a number of technical challenges must be mastered. These include developing:

- 1) An AUV capable of reliably operating fully autonomously for periods of up to two weeks.
- 2) A power source capable of driving a small vehicle at least 1000 km.
- 3) Communication systems capable of being deployed from a small AUV, melting through the ice, and transmitting data back via satellite.
- 4) Navigation systems capable of supporting extended high latitude AUV operations under ice.

While the ALTEX mission requires only a 1500 m depth rating, the depth rating requirement for core vehicle systems has been set at 4500m, to enable access to most of the Arctic Ocean basin.

## **APPROACH**

The highly interdisciplinary nature of the project is supported by a team of investigators and institutions with complementary expertise. These are:

Dr. James G. Bellingham	MIT Sea Grant and MBARI	AUVs, Project Lead
Mr. William Kirkwood	MBARI	AUV Design/Software
Dr. James E. Overland	Pacific Marine Environmental Lab.	Arctic Science
Dr. John Stannard	Fuel Cell Technologies, Ltd.	Fuel Cells
Dr. Peter J. Stein	Scientific Solutions, Inc.	Through-ice Communications
Dr. Dana Yoerger	WHOI	Navigation, Communication

A modular AUV with parallel mid-body sections is being developed. The general AUV design approach is to minimize the use of pressure housings, putting as many systems as possible in smaller, lighter oil-filled (pressure compensated) enclosures resulting in a small, deep rated system. The ALTEX vehicle is steered by an articulated tail section with a ducted propeller, in contrast with the more traditional control surfaces of previous vehicles. This approach is expected to be more robust to impacts (which usually occur on launch and recovery) and should have improved efficiency as well. Also worth noting is the fact that this system stays inside a 21" diameter.

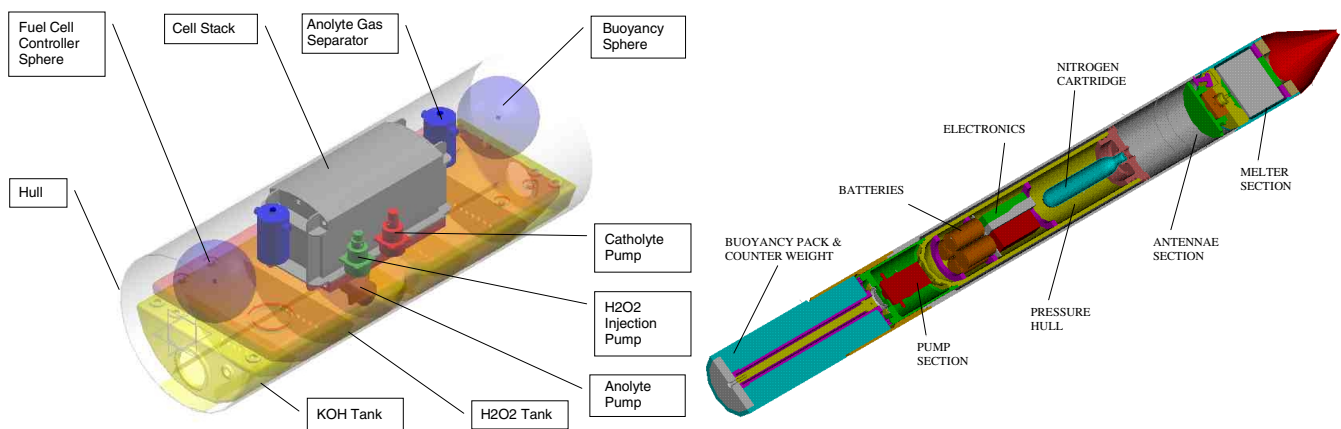
To achieve the desired range capability, we will employ a fuel cell energy system constructed by a team composed of Yardney Technical Products and Fuel Cell Technologies, Ltd. The system being developed is unique in that it will be pressure compensated and therefore deep-ocean rated. Communication will be provided by buoys designed to melt through the ice, and telemeter mission data via Argos. The buoys will also be equipped with GPS, so that a position fix can be obtained. Other components of the vehicle will be a mix of systems developed for earlier generations of AUVs by the partner organizations. While many new systems are being developed, the objective is to leverage existing technology to the degree possible.

The fuel cell vehicle section utilizes the high energy density of aluminum, and the oxygen content of 50% peroxide to produce a depth independent refuelable energy source. The complete system for 66 kWh of net energy packaged as a neutrally buoyant section is designed to fit in a 1.6 meter long by 0.51 meter diameter (21 inch) hull section. For this vehicle, the 66 kWh net allows a 1400km range at 3 Knots for 260 hours. Depth independence is achieved through storage of only solid or liquid reactants and wastes. Energy density for the fuel cell alone based on current tests of full size cells is projected to be over 350 (Wh/kg dry weight).

Efficient use of reactants is achieved using a two flow-loop system consisting of a KOH anolyte and a controlled concentration peroxide catholyte. Fuel cell reactants will be stored in two removable flexible storage tanks. Turn-around time for a complete refueling is expected to be 2 hours or less. Liquid reactants are low cost and significant portions of the cell stack will be re-useable, keeping total refueling costs low compared to replacement of primary batteries. Depleted cell stacks will be refurbished at the manufacturer by the addition of new aluminum anodes and replacement of gaskets.

Communication from the vehicle to shore is provided by a battery of 14 expendable buoys, launched from the vehicle, capable of melting through the ice and transmitting stored data files via Argos. The pre-launch activity of the AUV consists of downloading the data into the next buoy in the launch sequence, and locating a suitable launch site with an ice cover of up to one meter thick. The vehicle then reduces its speed, while maintaining a minimum depth of 50-meters to avoid obstacles such as ice keels. The launcher then releases the designated buoy from the AUV. In its launch configuration, the buoy is slightly buoyant to limit its ascent rate to 1 m/s. The launcher also releases a weight simultaneously with each buoy in order to maintain neutral buoyancy of the AUV.

Upon its release, the buoy ascends towards the surface where it comes to rest against the bottom surface of the ice. After a preset ascent time, the buoy is extended by means of pressurized nitrogen, which increases the separation between its heavy tail and buoyant nose. In this configuration, the buoy becomes stable in an upright orientation against the ice in cross currents of up to 15 cm/s. A pump brings seawater in contact with Pyrosolve-Z, which reacts exothermically, generating approximately 1500 watts of power for 30 minutes. The steam generated by this process is directed towards the underside of the ice, and as the ice melts, the buoy rises. When the Pyrosolve-Z is expended, a balloon containing GPS and Argos antennae is inflated. After the antenna deployment, the buoy obtains a GPS fix, and initiates its data telemetry via Argos.



**Figure 2: a) Fuel cell configuration and b) communication buoy cut-away.**

Since the total data which can be transmitted from the buoys via Argos is small compared to the total data acquired by the AUV, a “smart” data transmission software is under development. This routine will transmit data only when a satellite is within field of view of the antenna, thus preserving batteries on the buoy. This process continues until the batteries are expended. However, in the event that a

buoy might be recovered, a more complete set of data can be stored in permanent flash memory within the buoy's onboard computer.

A series of field tests during 2000 will incrementally test these capabilities, culminating in a long endurance full rehearsal for the target Arctic mission.

## **WORK COMPLETED**

*CORE VEHICLE:* A modular vehicle has been designed, which separates components into four functional sections: a forward payload section, the buoy section, the fuel cell section, and the tail section which contains propulsion, guidance, and control systems. Drawing on MIT experience with Odyssey, plastic fairings are being used for the ALTEX vehicle. However, ABS is being used instead of HDPE, to provide better dimensional stability during fabrication and greater strength. Test runs of the new plastic were conducted with the Odyssey fairing molds, and were determined to be satisfactory.

The prototype tail-cone section is in the first stages of dry testing on the lab bench at MBARI. The structure is constructed primarily of plastic and aluminum. The articulated tail-cone design is capable of +/- 20 degrees motions, which is 5 degrees greater control authority than demanded by mission specifications. The motor controller is also in place and running. The tail-cone electronics have been pressure tested and most have performed well. The test regime included 10 cycles to 10,000 psi in oil, a week-long soak in the compensation oil at 70 degrees C, and recycling the components to 10,000 psi. All of the critical components have passed except for a ceramic oscillator that does not maintain acceptable parameters after cycling. A work-around has been devised using already approved circuits from MBARI's Tiburon ROV.

*SOFTWARE:* The main vehicle software architecture has been established, and core elements of the code created. The decision was made to use Object Oriented technologies and to employ C++ and Java to implement the design. This results in software which is modular and easily modified, while taking advantage of the real-time operating system and multi-threading. The software is on hold in some of the architecture due to missing input information. This is understood and the selected work around is to use the current Odyssey vehicle navigation software and instrumentation structure for the January prototype testing at sea.

*ICE PENETRATING BUOY:* Subsystems related to extension of the buoy, ice-penetration, and some aspects of the GPS and ARGOS antennae deployment mechanism have been designed and built. Tests of ice penetration were carried out during the APLIS ice camp operated by ONR in early April 1999. The field test was conducted using a full-scale buoy. In order to test hydrodynamic stability of the buoy, these tests were conducted during windy days where water currents of greater than 10 cm/s were present. The penetration system performed as designed.

The work on the completion of the antennae section and the interface circuit board for power distribution and for switching various buoy components is in its final phases. The design and fabrication of the communication buoy is expected to be complete within the next two months. Our plan is to test the performance of all the systems of the ice-penetrating buoy in the Arctic during spring 2000.

*FUEL CELL:* Initial testing was carried out with reduced scale cells to economise on the use of materials and reactants. The tests resulted in a determination of the preferred anode material, which is an identical aluminium alloy to that used in previous FCT power sources, and an expanded silver mesh cathode. The effect of operating temperature on performance was also evaluated, since this system will operate at lower temperatures than previous fuel cell power sources. Based on overall system energy density, the goals for the ALTEX vehicle cell are 90% anode coulombic efficiency and 80% peroxide

utilization rate. To-date the anode coulombic efficiency has been met. In the combined April 12<sup>th</sup> and 20<sup>th</sup> tests, the anode coulombic efficiency achieved 96%. In several other test runs, the anode coulombic efficiency achieved was at least 90%.

Tests with large cells did not achieve the same peroxide utilisation efficiency results as found with the small-scale cells. The best overall peroxide utilisation rate achieved was 73%. The hydrogen peroxide utilisation efficiency must still be improved. Running time is now approaching the target of 260 hours, however improvements are still needed. Sufficient test data has been accumulated to concentrate the next set of tests on multi-cell operation.

*NAVIGATION:* The primary navigation system for ALTEX will be a COTS INS, which will be augmented with any available measurements or estimates of vehicle speed, geophysical measurements (e.g. seafloor bathymetry, and magnetic field direction and strength). The ice-buoys provide periodic navigation fixes by virtue of their GPS, however because there is no communication between the vehicle and the buoys, this information is not available to the vehicle. A candidate INS has been selected and ordered. Simulations have been carried out to evaluate its performance in high-latitude missions. While results are promising, high latitude tests of the system are expected to be necessary.

### **IMPACT/APPLICATIONS**

While the developmental effort is presently focused on Arctic Ocean hydrography, this advanced vehicle can be used for a range of oceanographic applications. Other applications in the Arctic Ocean include seafloor mapping. Furthermore, in many ocean regions, the range and navigation capabilities provided by this vehicle would allow shore-based operations. The depth rating of the system allows the vehicle to be used for deep sea vent studies, studies of the sea floor spreading, exploration of the Antarctic ice shelf, and coupled observation/modeling systems in coastal and continental shelf environments. A range of military applications are also enabled, for example early, wide area battlespace characterization from platforms of opportunity.

### **RELATED PROJECTS**

- 1) AOSN MURI - Real-Time Oceanography With Autonomous Ocean Sampling Networks: A Center for Excellence
- 2) The Battlespace Preparation AUV program, funded under the ONR Innovative Technologies for Organic Mine Countermeasure, is employing a number of the technologies and systems developed under this program.
- 3) Several STTR and SBIR efforts are coordinated with this program.

### **REFERENCES**

Curtin T., Bellingham, J.G., Catipovic, J., and Webb, D. 1993, Autonomous Ocean Sampling Networks. *Oceanography*, 6(3): 86-94.

AUV Laboratory home page:

<http://seagrant.mit.edu/~auvlab/>