Project Number: 900723

Project Start: Jan. 1, 2008 **Project Duration (in years): 1**

Please indicate what type of project is being proposed (mark only one).

[ ]	[X]	[ ]	[ ]	[ ]
Feasibility/Scoping [Less than 100 days effort]	**Development**[1]	**Research**	**Infrastructure**[1]	**Education**
	[ ]	[ ]		
	Time Series	**Institute Initiative**		

Project Manager/PI: Hamilton

Project Title: Wave-Energy Extraction for Vertical Profiling

[1] Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).

1) ABSTRACT

In 2007, a feasibility study for harvesting wave-energy on-board profiling platforms has not identified any fundamental reasons this technology cannot be successful. The most important feasibility test performed in 2007 examined how much energy can be extracted from the wave-field without adversely affecting the vertical profiling platform operation. These results indicate that there is sufficient energy available for extraction to allow the profiler to operate continuously and indefinitely. Success does depend on optimizing the efficiency of the energy harvesting mechanisms and there are a several engineering challenges that must be met to achieve the performance needed. The 2007 feasibility study identified the two most poorly understood aspects of the conceptual design, studied possible solutions, prototyped these solutions in the lab and performed testing to quantify the efficiencies attainable. This work has verified that the needed efficiencies are achievable and has provided data that will guide the solution selection and design. In addition to the technical examination, the 2007 feasibility study included an effort to identify appropriate technology transfer mechanisms. The recent end of MBARI's role as the CGSN implementing organization has eliminated a convenient technology transfer pathway, but opportunities still remain. As part of the 2007 feasibility study a meeting has been planned with the developers of the Bedford Institute of Oceanographic (BIO) to better understand their recent efforts to upgrade and expand the capabilities of the SeaHorse profiling platform. A visit to MBARI by the two relevant Bedford personnel is planned for fall 2007, a date has not yet been confirmed.

The work proposed for 2008 is to develop a prototype of the wave-energy extraction device and deploy it on the existing SeaHorse profiler which is expected to be located at the M0 mooring site in 2008 for a science deployment (see Chavez proposal). The development work will refine the conceptual design of the system and will include further design and development, preliminary design review, critical design review and manufacture of the required mechanical and electrical components. This work will build on a conceptual design review planned for late 2007.

Improved technologies for harvesting environmental energy sources have the potential to make a dramatic improvement in the ability to make oceanographic measurements. The proposal includes a continued effort to explore and understand these technology development opportunities. An example of this type of effort in 2007 is the synergy between the wave-energy feasibility study and the planned DARPA tests of station-keeping buoys that rely on environmental energy sources (wind/wave/solar) to maintain position. Fundamental issues about how much energy is available in the environment sources and the efficiencies required to make use of these sources are common between these two projects.

2) PROPOSAL

a) Statement of the problem

An effective, elegant, and cost-effective engineering solution that provides long-term upper-water-column profiling has not yet been developed. Although this sampling capability remains desirable, current and proposed solutions all require expensive infrastructure and/or frequent servicing. The profiling solutions proposed for the ORION project highlight this situation, even profilers that make only basic oceanographic measurements often require a seafloor power connection and the associated expensive EOM moorings and seafloor cables. Battery operated profiling platforms that have sufficiently long term service intervals are limited to the benign sub-surface profiling regime where surface-wave effects are non-existent. Although the proposed platforms do have some advantages and can be effective in the highly-supported OOI environment, limitations of these designs will keep them from becoming as ubiquitous in oceanographic research as sampling platforms such as gliders and Lagrangian floats which can be replicated in larger quantities due to their simplicity and low operational costs.

MBARI's experience with the SeaHorse profiler over the past few years indicates that this technology is an upper-water-column profiling solution that has some potential to perform well in extended deployments. This profiler operates below a surface buoy and utilizes the motion of the mooring cable induced by surface waves to travel up and down the cable. Although its motion is wave-powered, it uses batteries for communications and on-board instrumentation, limiting the profile frequency and service interval.

A feasibility study was performed in 2007 to evaluate a wave-energy extraction concept that would extract further energy from the wave motion to power the profiler electronics. The proposed device is to be mounted on board the profiler platform and has the potential to recharge the profiler batteries without electrical connections to a surface buoy or seafloor cable. Used in conjunction with inductive modem communications to the surface buoy and solar panels on the surface buoy for long-range radio communications, the resulting system would operate indefinitely without service trips being required for battery replacement. Biofouling would still limit the service intervals that could be achieved, but experience at MBARI has indicated that the profiling platform suffers from significantly less biofouling than buoy mounted instruments due to limited exposure to sunlight.

As described below, the testing to quantify the factors that limit the ultimate performance of the proposed device has been performed as part of the 2007 feasibility study. This work indicates that at least enough energy can be harvested to power the existing suite of instruments, and that an expansion of the on-board instrumentation may be possible. Because the energy generation and usage both occur on a per-profile basis, the profiling frequency in this system will only be limited by the rate of profile travel and the profile distance, not a need to conserve batteries. Because of this, continuous operation should be possible with no dwell time between measurement profiles.

Testing to date indicates the proposed wave-energy extraction device shows promise but the technology transfer process does not follow the laws of physics as closely and is harder to guarantee. The end of MBARI's role as an implementing organization for the OOI has eliminated a convenient option for technology transfer. Nevertheless there appears to be applications for this technology within the OOI and elsewhere, particularly if the technology provides a significant capability increase in an affordable platform. Efforts will continue in 2007 to explore a possible collaboration with Bedford Institute of Technology and their commercial partner Brooke Ocean Technology. Other unexplored opportunities may exist with the PICO mooring system developed by Hugh Milburn at PMEL. Because this development project does carry some technology transfer risk, the proposed effort is limited to the development of an advanced proof-of-concept prototype. The intention of this approach is to limit the scope of the project to a level that convincingly demonstrates the concept in a relatively short time-frame and increases the chances of successfully exporting the technology.

This project contributes to the execution of MBARI's mission and strategic plan most directly by developing technology that has the potential to change and expand how oceanographic measurements are made. In addition, the execution of this project helps develop an expertise at MBARI in the field of wave-energy harvesting and renewable energy. The current debate and (potentially misplaced) enthusiasm for wave-energy plants off the California coast should involve a cost-benefit analysis that is based upon ocean engineering principles, measurements and statistics of wind and wave-fields, comparison with competing renewable energy technologies, and the environmental impacts of wave-energy plants in coastal ecosystems. These are all factors this project faces and wave-energy expertise at MBARI has the potential to have broad societal impacts should MBARI choose to contribute a voice.

b) Approach to the problem

Project Background and Status

Figure one shows the arrangement of a wave-powered profiler below a surface buoy. Surface waves cause the buoy and mooring wire to bob up and down in a motion that nearly follows the surface wave elevation. The profiler is ballasted to be buoyant, and has a ratchet mechanism that clamps onto the mooring wire while it is moving downward relative to the profiler, but allows the mooring wire to move freely upwards. The profiler climbs down the wire when the wave motion is sufficient to overcome the buoyancy of the profiler, descent rates of 0.1 to 1.0 m/s have been observed in the Seahorse system. For the measurement phase of the profile, the instrumentation is turned on and the ratchet clamp is disengaged from the mooring wire. The buoyancy of the profiler causes it to rise back to the surface, the Seahorse is ballasted about 6 lbs buoyant and ascends at about 0.5 m/s.

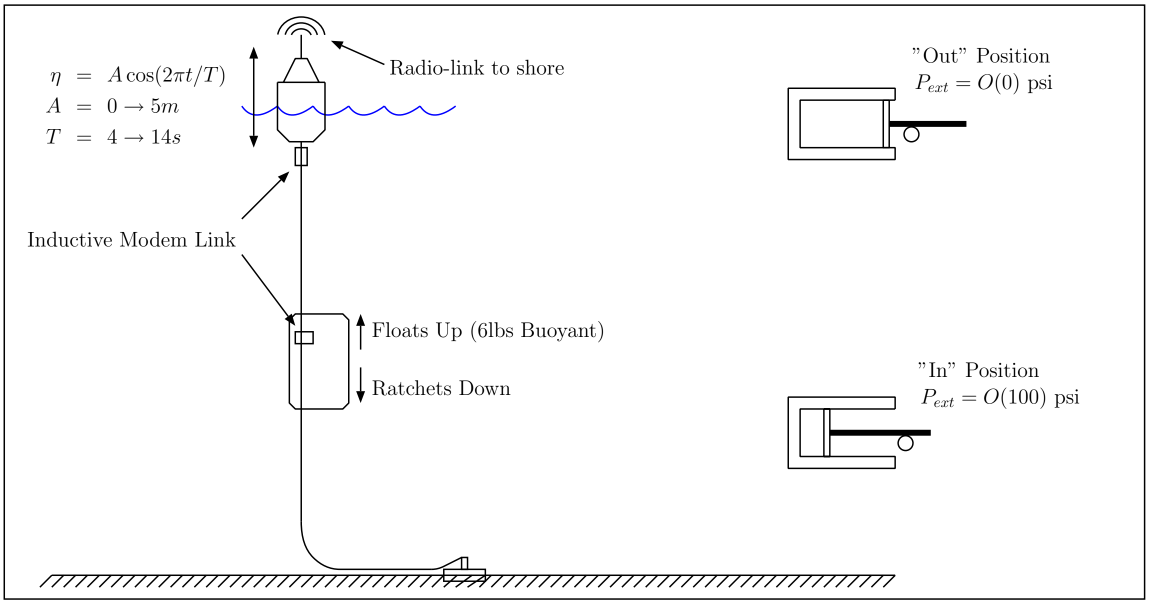

Figure 1: Arrangement of typical wave-powered profiler below surface buoy.

The proposed wave-energy extraction device collects potential energy in the form of an evacuated volume as the profiler descends. The ratchet mechanism must overcome the additional buoyancy of this volume as it descends. At depth, the evacuated volume is allowed to collapse and the resulting kinetic energy is converted to a form that is suitable to drive an electrical generator (high-speed rotational motion). For this mechanism to provide enough energy to power instruments on-board the profiler, the ratchet mechanism must be capable of submerging sufficient buoyancy to provide for the profiler electrical needs after all inefficiencies in the mechanical to electrical conversion process are accounted for. Other techniques have been considered as part of the feasibility study but analysis indicates that this approach minimizes the energy loss due to friction. The concentration of potential energy before the conversions step minimizes parasitic losses in the system.

Two tests are required to determine the final amount of energy that can be extracted by this mechanism. First, the capability of the ratchet mechanism to overcome buoyancy must be quantified, and second, the efficiency with which the resulting potential energy can be converted to electrical energy must be determined. Tests were performed as part of the feasibility study in 2007 to establish these two parameters.

An at-sea test was performed to determine the maximum amount of the energy that can be extracted from the mooring wire without adversely affecting the profiler operation. This was performed by adding buoyancy to the SeaHorse profiler currently deployed at Shepard Meander. Three pounds of buoyancy were added on July 19th and the profiler has successfully descended in time for each of its scheduled profiles since. Measuring the exact change in the descent rate as a result of the added buoyancy is complicated by changing wave conditions. Currently, no statistical difference in descent rate is evident due to the addition of the buoyancy. As more data is collected in various sea conditions, confidence in the descent rate estimates will increase. This result indicates that the profiler is quite capable of operating against the added buoyancy and that there is significant headroom in the capabilities of the ratchet mechanism. In an attempt to identify the limit of the system capabilities, plans are in place to add another three pounds of buoyancy later this year and measure the effect on descent rate.

The other critical factor in the proposed systems performance is how efficiently the stored potential energy can be converted to electrical energy. This process consists of three steps; mechanical conversion of the kinetic energy released when the evacuated volume is allowed to collapse to a form suitable to drive a generator, conversion of the kinetic energy to electrical energy via a generator, and the subsequent storage of the electrical energy in a battery for later use.

Lab tests of prototype systems for the first two of these stages have been performed to estimate the efficiencies with which the conversion can be accomplished. The electrical generator stage is straightforward and well understood; efficiencies of greater than 90% can be attained easily if the rotational speeds are allowed to be high. At slower speeds the efficiency drops off and depends largely on the generator design and construction. Tests were performed to measure the efficiency curves of candidate commercially available generators.

The mechanical transmission stage has the opposite characteristic and is most efficient at slow speeds. As a result, the optimum configuration of mechanical transmission and electrical generator must balance the efficiency curves of both elements to identify the optimum design. Two separate designs of the mechanical transmission have been considered, a hydraulic system and a mechanical lead-screw system. The hydraulic motor system utilizes the high-pressure fluid directly to drive a motor and has performed better than anticipated with peak efficiencies above 85%. While not expected to be as efficient as a piston and lead-screw arrangement, the simplicity and robustness of this design is appealing. Testing continues on the piston and lead-screw arrangement, analysis and manufacture data indicates that efficiencies greater than 90% should be achievable at the speeds and loads required for maximum generator efficiency.

While not complete, these tests indicate that the conversion process can be done efficiently enough to make the system effective. For reference, the SeaHorse uses about 6 Joules of energy per meter of profile and each pound of submerged buoyancy represents 5 Joules of energy per meter. The SeaHorse appears to be capable of operating against at least three pounds of buoyancy. In this configuration, the total conversion efficiency must be 40% which is easily achievable based upon the test results. Current engineering estimates of the total conversion efficiency achievable fall in the range of 50%-80%. Furthermore, if further testing indicates the ratchet mechanism can tolerate additional buoyancy, the efficiency requirements are relaxed further and it becomes likely that the energy available for instrumentation on the profile may be significantly increased.

Also in 2007 a patent search was conducted to identify potential conflicts with previously patented concepts. A considerable number of patents have been filed for all manner of mechanisms related to large-scale wave energy conversion. None were identified that propose mechanisms or techniques similar to those explored here.

Plans for 2008

The proposed effort for 2008 consists of the development of a working prototype of the wave-energy extraction system and subsequent installation on the SeaHorse profiler at the M0 site, continued exploration of technology transfer opportunities, and a continuing effort to understand and evaluate energy harvesting opportunities and issues.

The engineering development proposed will build upon the experience gained testing prototypes of the various components of the system in 2007. The design and development effort is split between two main components. The mechanical transmission design is a critical part and will require some careful engineering to achieve optimum efficiency and tolerate the large forces and high speeds inherent in the system. The electrical generator and storage circuitry will also require some attention to detail. In addition to the raw generator component, this component must also contain circuitry to control the behavior of the device, react to changing conditions and log performance data. It is intended that the device will operate autonomously and not require communications to shore. Although each of these components represents a non-trivial engineering design problem, there are no fundamental reasons the needed performance in these designs can't be realized. Preliminary and critical design review meetings will be held at appropriate points in the development process. After lab testing, the completed prototype will be deployed and demonstrated on the SeaHorse profiler at the M0 site.

c) Specific deliverables

The primary deliverable in 2008 will be a wave-energy extraction prototype operating on the SeaHorse profiler to be deployed at the M0 site. The deployment and maintenance of the profiler itself will be performed by the Chavez project and it is not expected that this device will jeopardize the science data collection.

The project duration is currently aimed to be a single year and the goal is an advanced proof-of-concept prototype. It is intended that technology transfer opportunities will then dictate the degree of further development and optimization of the system in subsequent years.

d) Project team

Hamilton – Project management, mechanical design of prototype, technology-transfer explorations
Mellinger – Electrical engineering design of prototype
Software Engineer - Personnel undetermined but flexible

e) Project lab space

No additional space will be required beyond the lab areas currently available to the project team members. (ME Lab, EE Lab).

3) BUDGET JUSTIFICATION

Expense

- Piston/Pressure vessel materials = $2000
- Electronics/Battery pressure vessel materials = $1000
- Mechanical transmission materials = $2000
- Pressure sensor = $1000
- Batteries = $2000
- Syntactic foam = $2500
- Generator/Motor = $1500
- Electronics circuit card assembly = $2000
- Two trips (conference/meetings) = $3000
- Miscellaneous test equipment/contingency funds = $2000

Ship Time

- Zephyr (3 days) for installation/service trips.

Labor

- EE: 50 days (Mellinger)
- SE: 30 days
- ME: 60 days (Hamilton)
- EE Tech: 20 days
- SE Tech: 5 days
- ME Tech: 10 days
- Machine Shop: 20 days

4) MILESTONES

	Milestone 1	Milestone 2	Milestone 3	Milestone 4	Milestone 5	**Total Resources**[2] for each resource category for all milestones listed here
Milestone Date	**2/1/2008**	**3/15/2008**	**6/15/2008**	**7/15/2008**	**12/1/2008**	
Milestone Description	**Preliminary Design Review**	**Critical Design Review**	**Prototype Manufactured**	**Installation on Profiler at M0**	**Performance Evaluation**	
EE	**20**	**10**	**10**		**10**	**50**
SE	**5**	**5**	**20**			**30**
ME	**20**	**10**	**10**	**5**	**15**	**60**
Support Engineering						
EE Tech			**20**			**20**
SE Tech			**5**			**5**
ME Tech			**20**			**20**
Machine Shop			**20**			**20**

[2] This number should be the same number you entered on the resource requests for this particular resource.

5) RISK MATRIX

	Technical Risk	Organizational Risk	Tech Transfer Risk	Labor Estimate Risk
High				
Medium	X		X	
Low		X		X