

Development of an Air-Deployable Ocean Profiler

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Award Number: N00014-09-1-0381

LONG-TERM GOALS

Our goal is to develop an air-deployable ocean profiler (ADOP) that will make it feasible to rapidly deploy regional upper-ocean observing arrays.

OBJECTIVES

This project's objective is to develop ADOP to be deployed from aircraft through an A-sized (4.875 inch diameter, 36 inches long) sonobuoy tube. The performance goal is 200 dives to 500 m depth with a scientific payload of 1 kg. The float will use Iridium communication and GPS locating while at the surface. ADOP is intended to be the basis for air-deployed arrays that establish persistent area surveillance over regions O(100 km) on a side without post-deployment maintenance.

APPROACH

Our design approach is based on variable-buoyancy ocean vehicles developed previously by the Instrument Development Group that provide a basis for dividing the design of ADOP into the following related tasks:

- select a buoyancy engine that minimizes payload volume and weight and provides efficient electrical to mechanical energy conversion;
- select an air-drag device (e.g. parachute) to limit the shock-load hitting the sea surface and attach it to the float with a bridle that releases clear of the float immediately upon hitting the sea surface;
- provide an antenna, with minimum packing volume and above-surface volume, that extends above the surface far enough for reliable Iridium/GPS communication;
- determine if an external "damping" device is needed to limit vertical oscillations of the float in a seaway in order to achieve reliable communication, and then to provide any device needed;
- develop a light mechanical structure for the entire float that accounts for high shock loading;
- provide a flexible central controller so new sensor systems can easily be accommodated;
- avoid features that would be expensive to manufacture in numbers of 100 or more;
- minimize ADOP weight in order to maximize payload capacity for batteries and sensors.

The ADOP design was based on the Littoral Ambient Spectral Recorder, which detects and analyzes ambient sound, as a typical scientific payload, but our goal is a general-use platform,

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 2010		2. REPORT TYPE		3. DATES COVERED 00-00-2010 to 00-00-2010	
4. TITLE AND SUBTITLE Development of an Air-Deployable Ocean Profiler				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) University California, San Diego, Scripps Institution Oceanography, La Jolla, CA, 92093-0230				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 Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

WORK COMPLETED

We have completed prototype design of ADOP, begun small-lot prototype manufacture of all components, and tested many of the subsystems in the laboratory and field. Our status follows:

Buoyancy engine. The efficiency of converting stored electrical energy into pressure-volume work to change depth is critical to a float's payload capacity and duration. Different buoyancy engines are preferable in different operating environments. Generally, reciprocating or gear-motor hydraulic pumps excel for large, long-lived floats while single-stroke piston-cylinder pumps are better for small ones, particularly if subsurface depth control is needed. We have completed two pump designs for ADOP and, by comparative testing, have selected a small DC gear-motor driving a lead-screw and ball-jack to move a piston, whose outer surface is exposed to seawater, inside a cylinder. The alternative miniature gear motor we evaluated had higher theoretical efficiency but the necessary tolerances made manufacturing too expensive.

The prototype pump and motor have been tested successfully for 2000 cycles against pressures equivalent to 500-m operation at room temperature and 4°C. The pump's energy efficiency through typical pressure cycling was 45%, which depends mainly on the necessary gear reduction in the motor and, to a lesser extent, on the piston-to-cylinder seal. Necessary tests of the pump's resistance to corrosion in salt water will be completed in late 2010 to measure the effects of corrosion and biofouling on the piston and the dynamic seal.

Reduced fall rate through air. It is desirable to reduce fall velocity through the air in order to minimize shock-loading when the vehicle hits the sea surface. This must be done while limiting the shock as the package is slowed immediately after aircraft deployment at high speed and while minimizing the pre-deployment packing volume. Field and simulation tests led us to select a small parachute as preferable to rotating vanes (like helicopter blades) or ribbon streamers for reducing fall velocity. The design-target fall-rate target of 14 m/s can be achieved with a parachute that packs in a 220 cm³ volume. Because the deployment shock depends on aircraft velocity, the optimal parachute diameter also depends on this speed. Preliminary ground-level high speed tests have proven the design for deploying the chute. Final parachute selection depends on air tests to be completed.

Bridle and water release. After a float falls to the sea surface, its parachute threatens its operation. We use a bridle to attach a parachute to the float and a release, triggered by contact with water, that separates both the bridle and parachute from the float. The release was tested in local-pool drops.

Iridium/GPS antenna. Lifting an antenna out of the water for operation requires the buoyancy engine to increase float volume by the antenna's volume. Thus the energy needed for this depends on the volume of the antenna and its support, and these depend on how high above the surface the antenna must reach. Factors in selecting an antenna and support are: radiation pattern; durability under pressure cycling; and antenna displacement volume and volume in the deployment cannister. Inflating antennas pack well, but were rejected as unlikely to survive repeated depth cycling over months. Designs with patch, helical and dipole antennas elevated by static and "self erecting" supports were evaluated, leading to field trials of horizontal dipole antennas mounted on a short static support and a taller self-erecting "tape spring" support.

Damping skirt. An antenna's elevation depends on its support and the float's behavior in a seaway. Often, a damping plate is used to provide hydrodynamic drag resisting float's vertical motion through

the water, allowing a float on the surface to follow it. Laboratory tests of several different packable concepts have led us to prefer a “damping skirt” for resisting ADOP vertical motion. The prototype, shown in Figure 1, collapses along the float pressure case before deployment.

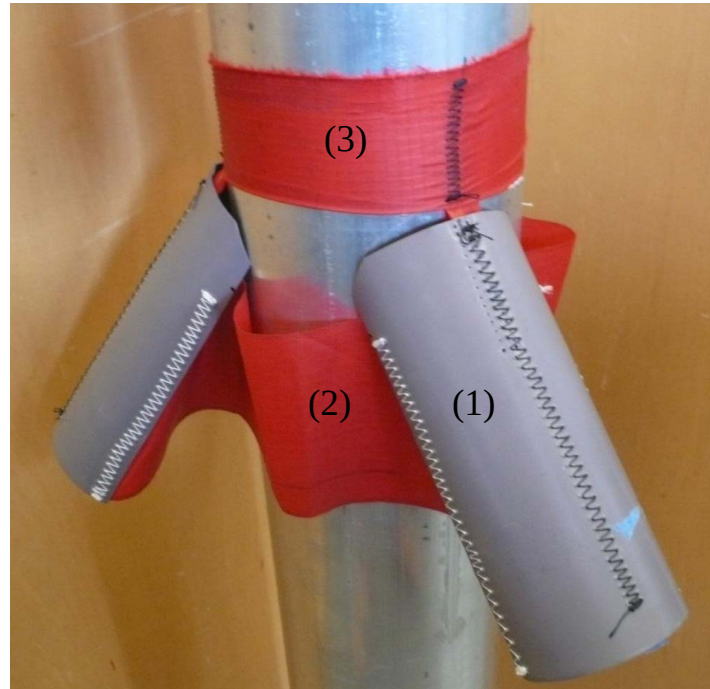


Figure 1. Mock-up of the wave-motion damping-skirt developed to help a float at the surface follow wave motion. Before deployment the semi-rigid “blades” (1) conform to the pressure case. The fabric (2) connecting the blades prevents them from folding too far up and increase drag area. This, the attachment collar (3), and the hinges to the blades are tentatively made from rip-stop fabric.

Electronics. The ADOP will be most useful if it can be easily adapted to various sensor packages. Rather than add valuable weight providing true modularity, our approach is to provide a flexible architecture to which a large class of sensor payloads can be adapted. The central controller, a Persistor CF2, provides communication with Iridium and GPS, controls all float functions, polls some sensors, and provides serial communication with “guest” sensor packages. Both the Iridium 9601 SBD transceiver and a ubox GPS system have been field tested. The pump motor is controlled with an ST Microelectronics H-bridge motor driver. A 12-bit Analog-to-Digital (A/D) converter senses float functions (pump-motor current, internal vacuum, battery voltage and a leak detector) while a Linear Technology LTC2486 provides 4 channels of A/D conversion for sampling the float’s pressure and temperature sensors and “guest” analog channels.

System architecture. Figure 2 illustrates the assembled float. The internal mechanism is rigidly connected to the lower end cap through which the buoyancy-engine piston protrudes. The bridle is designed to limit shock loads on this assembly. The lighter top-cap and pressure case are connected to this assembly by the upper chassis which bolts to the top cap. The antenna is shown in its post-deployment configuration and no drag-skirt is shown. The pump is surrounded by the C-cell battery pack. The duration goal is based on using alkaline cells but science payload and duration could be expanded by using lithium batteries

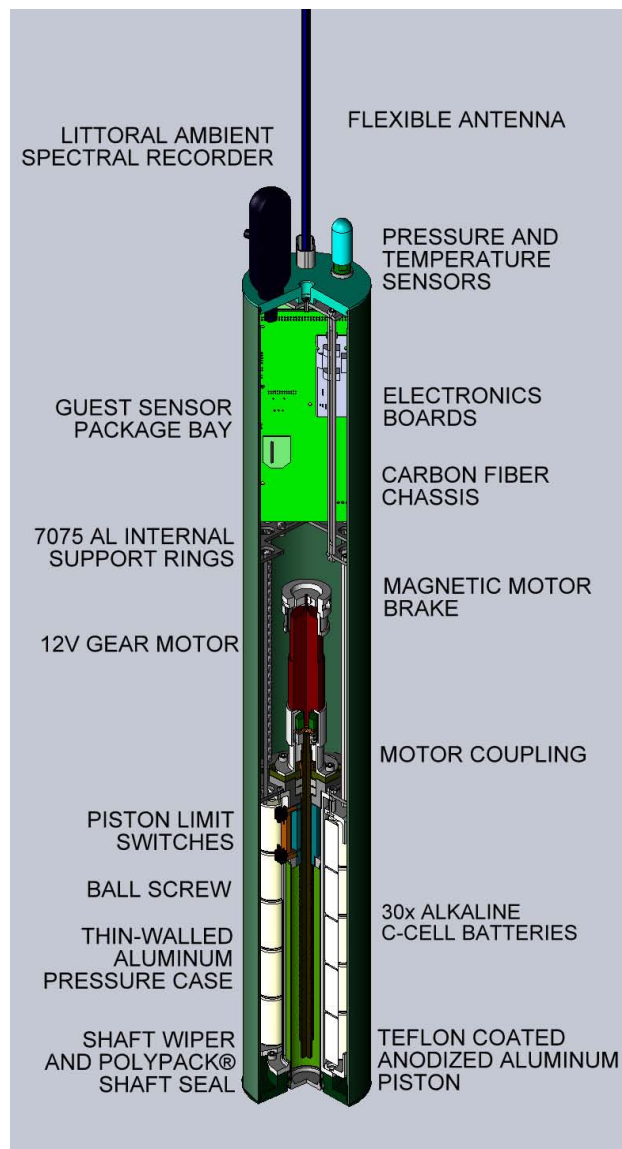


Figure 2. The internal structure of the ADOP. Various sub-assemblies are labeled.

RESULTS

Twenty months into what we expect to be a three year project, prototype designs have been developed for all subsystems and most designs have been laboratory tested.

Three otherwise identical floats, simulating ADOP in its surface configuration, are undergoing field tests of satellite communication with different antenna and damping-skirt combinations. Two have horizontal dipoles mounted on 40-cm ‘tape spring’ supports, one with a 35-cm equivalent diameter damping skirt and one without any damping skirt. The third float has a horizontal dipole on a 10-cm fixed support without damping skirt. Figure 3 shows the histogram of the time required to obtain a GPS fix. This shows that the short-support antenna is unacceptable, the undamped float with long-support antenna has acceptable performance, and the damping skirt’s performance improvement is

statistically significant, but not large. Iridium performance is robust enough to be equally good for damped and undamped floats.

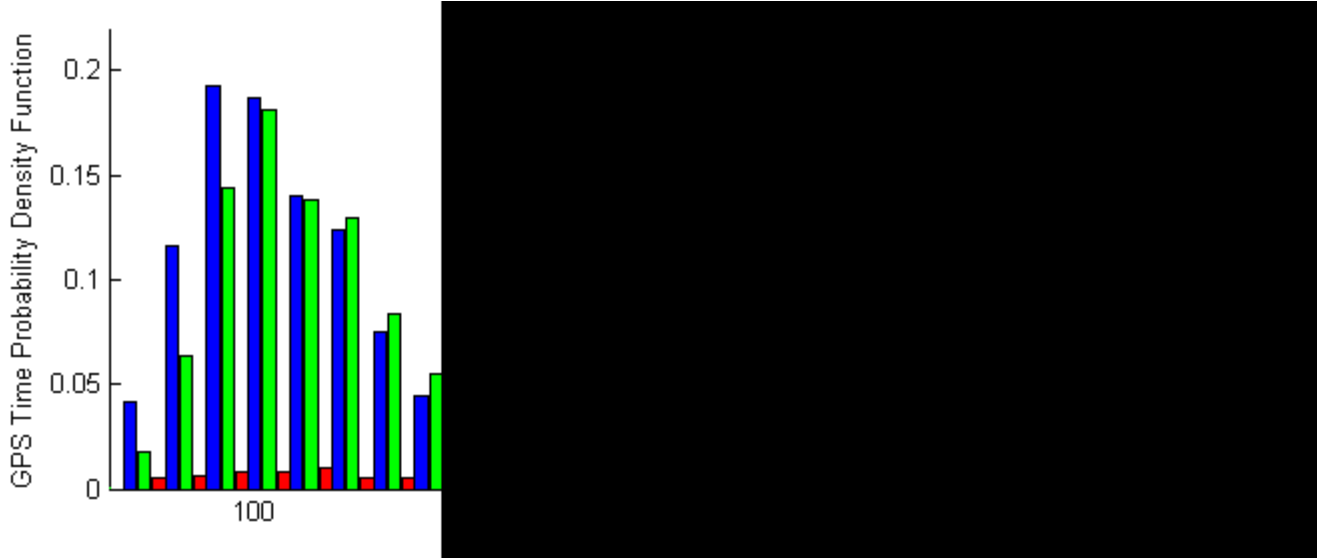


Figure 3. The probability density of time-to-GPS-fix for different float/antenna combinations. The short antenna is unacceptable. The 40-cm antenna works well, and slightly better on the float with a drag skirt.

In short, the design and fabrication process is on schedule for a full-scale field test of in-water performance in late 2010 and air-deployment tests in 2011.

IMPACT/APPLICATIONS

We hope that a general-use profiling float executing 200 cycles to 500 m, supporting GPS and Iridium communication, with payload capacity of O(1 kg), and capable of air-deployment through an A-size sonobuoy tube will find broad use in Navy research and operations.

RELATED PROJECT

This effort is related to the project “Expanded Development of a Float for the Measurement of Ambient Noise and Air-Sea Interaction Processes” supported by grant N00014-03-1-0746 awarded to Eric J. Terrill of Scripps Institution of Oceanography.