Comparison of Passive Acoustic Marine Mammal Monitoring with the ZRay Flying Wing Autonomous Underwater Glider, the Wave Glider Autonomous Surface Vehicle, and a Bottom-Mounted HARP

25-31 May, 2013

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Sponsored by: The Office of Naval Research

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Objectives

The major objectives of this sea trial are 5-fold:

1. To test the recent engineering changes to the ZRay flying wing underwater glider, including those designed to significantly decrease its hotel load:
   - Determine the performance and total energy consumption of the LPC-3250 micro-computer;
   - Evaluate the ability to power ON/OFF certain subsystems in the glider (RMS, PMS, Flaps, BE(?), Benthos modem, Aquadopp, and CTD pump) through the flight software and measure the resulting energy savings;
   - Validate the improved performance of the modified pitch mass system;
   - Evaluate the data quality of ZRay’s onboard CTD sensor by comparing its data to those collected on site prior to glider deployment.
   - Demonstrate controlled flight at L/D significantly greater than 20/1 by changing the wing camber with the inner flaps.

2. To collect high quality measurements with the SPAWAR GTAS array while being towed by ZRay:
   - Measure the ratio of the received levels in acoustic space to those in non-acoustic space while being towed in order to determine the detection gain at endfire;
   - Evaluate the ability of the leading-edge hydrophone array to break the left-right ambiguity of the GTAS array using phase-coherent processing;
   - Compare measurements of the ocean sound field while the GTAS array is oriented horizontally (being towed) to those when the array is vertical (when the glider is near neutral buoyancy), particularly with respect to the possible existence of a mid-frequency noise notch;

3. To quantitatively compare the marine mammal passive acoustic monitoring performance (primarily detection) of the data acquisition systems on ZRay and the mini-HARP system on the SIO Wave Glider with the bottom-mounted HARP at Site P:
   - This comparison requires long-duration passive monitoring near Site P in order to obtain statistically meaningful results;

4. To conduct continuous multi-day missions solely through the Iridium satellite communication system:
   - This objective helps satisfy the requirement in objective #3;
   - An important goal of this objective will be improving the newly-developed SBD packets for transmitting specific information on various glider subsystems to enable remote system diagnosis.

5. To demonstrate launch and recovery of ZRay from a platform of opportunity:
   - This launch and recovery system and procedure is exactly the same as that used for launch and recovery from a land-based facility.

These objectives can be accomplished by flying two main missions:
• Fly to the corners of a polygon, for example a square or an “X” closed on the top and bottom, centered on HARP Site P:
  o Requires reasonable heading control;
  o Allows the GTAS array to remain mostly horizontal;
  o Tracks can be plotted end-to-end to demonstrate total distance traveled over period of mission;
  o More energy consumptive;
• Fly to the same waypoint (Site P) on descent and become approximately neutrally buoyant at a prescribed depth (e.g., below the thermocline at about 50 m):
  o GTAS array will become vertical during neutral buoyancy (the GTAS array will be ballasted to be slightly negative using aluminum foil wrapped around the outboard end of the array – re below);
  o Provides lowest self-noise conditions for passive monitoring.

Regarding objective #3, the marine mammal monitoring performance analysis will be based primarily on post-processing the data from the ZRay, Wave Glider, and HARP passive acoustic systems in an identical way so that the results can be quantitatively compared. In addition, a small number of controlled, low-level acoustic source transmissions may be conducted to evaluate the detection and localization outputs on the various autonomous platform systems. The results of this test will be used to demonstrate the readiness of the participating technologies for a future fleet demonstration test.

The specific objectives of the Wave Glider operations are:
• Record marine mammal vocalizations.
• Collect data for testing real-time algorithm performance on a single board computer.
• Demonstrate its station-keeping capabilities near the bottom-mounted HARP.

In addition to these objectives, the existing HARP system at Site P will be refurbished during the experiment so that its data are immediately available for analysis. These operations will take place from the Hildebrand RHIB boat.

Figure 1. The location of HARP Site P 6 nm (11 km) west of La Jolla is marked by a green push-pin and the ZRay deployment location 12 nm off the coast is indicated by a yellow push-pin. The red line connecting the ZRay location to shore is 12 nm in length. All underwater acoustic source ops will be conducted west of the yellow push-pin site.
Operational Area

- ZRay testing: 32d 54.0m N, 117d 30.5m W
  - 12 nm = 22 km offshore
  - Initial ZRay testing will be conducted around this site
  - All underwater acoustic source ops will be conducted west of this site.
- HARP Site P: 32d 53.550m N, 117d 22.859m W
  - 6 nm = 11 km west-northwest of La Jolla – about 1-hr transit time.
  - Wave Glider will be deployed from Hildebrand 18-ft RHIB at this site.

Schedule, May, 2013 Sea Test

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<tr>
<th>Date</th>
<th>Activity</th>
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<tr>
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<tr>
<td>Wed, 22 MAY</td>
<td>9 am Pre-Cruise meeting at Marfac – D'Spain, Stevenson, and Griswold.</td>
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<tr>
<td>Thu, 23 MAY</td>
<td>Load AUV van, LARS, and ZRay onto New Horizon (NH). Verify that Res Tech small boat is onboard. Hook up van. Test deployment and retrieval of ZRay off NH using ship’s crane. Pete Brodsky arrives. SPAWAR loads GTAS array using ship’s crane &amp; conducts connectivity test of GTAS array.</td>
<td>HARP deployment at Site P will be done from Hildebrand (JAH) RHIB. All JAH RHIB ops will be staged from the SIO pier, so no need to load HARP or JAH RHIB. Time of ZRay test deployment/retrieval from NH is flexible.</td>
</tr>
<tr>
<td>Fri, 24 MAY</td>
<td>Sean McPeak and Sonia Brugger arrive. Continue van hook-up and ZRay checkout.</td>
<td></td>
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<tr>
<td>Sat, 25 MAY</td>
<td>Depart port for ZRay site. Deploy CTD or XBT. Ballast GTAS to be slightly negative. Deploy ZRay for engin. tests, including neutral buoyancy.</td>
<td></td>
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<tr>
<td>Sun, 26 MAY</td>
<td>Conduct NH runs for known acoustic source xmissions to ZRay towing GTAS array. Start ZRay 24-hr ops as soon as possible.</td>
<td>Deploy Wave Glider from JAH RHIB. Monitor Wave Glider ops from NH.</td>
</tr>
<tr>
<td>Mon, 27 MAY</td>
<td>Continue ZRay ops, flying in closed pattern around Site P.</td>
<td>Continue Wave Glider ops.</td>
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<tr>
<td>Tue-Thu, 28-30 MAY</td>
<td>Continue ZRay ops, switching to flying to single waypoint (site P) and becoming neutrally buoyant, as well as flights in simple closed pattern as energy efficiently as possible.</td>
<td>Continue Wave Glider ops.</td>
</tr>
<tr>
<td>Fri, 31 MAY</td>
<td>Complete ZRay ops. Recover ZRay and any other equipment &amp; RTP.</td>
<td>May not need to use this ship day – may save it for later in the year.</td>
</tr>
<tr>
<td>Mon, 3 JUN</td>
<td>Offload NH.</td>
<td>Tue morning contingency.</td>
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Scientific Personnel

R/V New Horizon
- Gerald D’Sain (MPL/SIO) - chief scientist, ZRay ops;
- Mark Stevenson (SPAWAR SSC Pacific) - GTAS towed array ops, ZRay ops, Wave Glider ops;
- Pete Brodsky (APL/UW) - co-PI, ZRay ops;
- Dennis Rimington (MPL/SIO) - ZRay ops;
- Dave Price (MPL/SIO) - ZRay ops;
- Sean McPeak (APL/UW) - ZRay ops;
- Ryan Griswold (MPL/SIO) - Wave Glider & HARP ops;
- Sonia Brugger (APL/UW volunteer) – ZRay ops;
- Madeline McGoldrick (MPL/SIO volunteer) – ZRay ops;
- Milo Vejraska (MPL/SIO volunteer) – ZRay ops;
- Wes Holland (MPL/SIO volunteer) – ZRay ops;
- Andrew Funk (MPL/SIO volunteer) – ZRay ops.
- James Turnbull, Resident Technician (SIO), help with all operations.

Shore Support at MPL/SIO
- Richard Zimmerman (MPL/SIO);
- Scott Jenkins (MPL/SIO).

List of Acronyms

APL/UW – Applied Physics Lab, University of Washington
DMON – Digital Monitor autonomous detection classification system from WHOI
GTAS - Glider Towed Array System
HARP – High (actually wide) Frequency Acoustic Recording Package
MPL/SIO – Marine Physical Laboratory, Scripps Institution of Oceanography
NOAA – National Oceanographic and Atmospheric Administration
ONR – Office of Naval Research
PAAM – Passive Acoustic Autonomous Monitoring program
SPAWAR SSC Pacific – Space and Naval Warfare Systems Center Pacific
WHOI – Woods Hole Oceanographic Institution
Background

The Liberdade Flying Wing Glider program began in 2005, with the design of the first fully autonomous flying wing underwater glider XRay. The design and construction of the 2\textsuperscript{nd} generation flying wing glider, ZRay, was performed over the 2009-2010 time period. This 2\textsuperscript{nd} generation glider was first deployed at sea in the January, 2011 Range Validation Test west of San Clemente Island. The results from this sea test demonstrated the original promise of the flying wing glider technology, with inherently stable flight at sustained lift-to-drag (L/D) ratios of 20/1 (without using the trailing-edge flaps to change camber). Subsequent at-sea trials demonstrated This upcoming sea test provides an opportunity to test the very low power performance and persistence passive acoustic monitoring capabilities of the glider by conducting multi-day-duration flights with remote operation through the Iridium satellite system.

In 2007, ONR started the Passive Acoustic Autonomous Monitoring (PAAM) of Marine Mammals program to develop near-real-time monitoring systems on autonomous underwater vehicles. The program is focused on passive acoustic systems for autonomous detection, classification, localization, and tracking of marine mammals on Navy exercise areas for periods in excess of a month.

This sea test will allow quantitative comparison of autonomous vehicle-based PAAM systems with a bottom-mounted HARP package at Site P. The HARP systems presently are used for passive acoustic monitoring of marine mammal populations off the west coast of California. Two types of PAAM mobile platforms will be evaluated in this test, the ZRay buoyancy-driven autonomous underwater glider and a Wave Glider autonomous surface vehicle:

1. Buoyancy-Driven Autonomous Underwater Glider:
   - (1) Marine Physical Laboratory, Scripps Institution of Oceanography (MPL/SIO) and Applied Physics Laboratory, University of Washington (APL/UW) flying wing underwater glider, ZRay, equipped with a 27-element hydrophone array all along the leading edge of the glider wing whose outputs are connected to a real-time detection/localization and recording system. In addition, ZRay will tow a 32-element Glider Towed Array System (GTAS) array designed and built by SPAWAR SSC Pacific, and will be equipped with a 3-channel Digital Monitoring (DMON) system from WHOI.

1. Autonomous Surface Vehicle:
   - (1) A Liquid Robotics Wave Glider equipped with a single 100-kHz wide hydrophone (“HARP”) and odontocete detector-classifier system.

Details on these systems are given in the Instrumentation section below.
Instrumentation

The following equipment is planned for deployment in this sea test.

**ZRay Flying Wing Underwater Glider (1):** The ZRay/Liberdade flying wing glider, a buoyancy-driven, 20-ft wing span, autonomous underwater platform.

Figure 2 shows a photograph of the ZRay glider. The flying wing glider project is a joint effort between MPL/SIO and APL/UW. The outer shape of this glider is based on a flying wing design in order to optimize horizontal transport efficiency, i.e., minimize propulsion energy consumption traveling in the horizontal. The outer shroud is made of ABS plastic and is mounted to a titanium inner strength structure. All subsystems (also mounted to the titanium structure) are identical, or nearly so, to those in XRay, our first flying wing glider that was fully tested at sea during three field seasons. The glider has a maximum design depth of 300 m and has a dry weight over 1600 lb.

![ZRay glider](figure2.png)

**Figure 2.** ZRay on the fantail of R/V Sproul during the Range Validation Test on the SCORE Range, January, 2011.

The CAD/CAM drawing of ZRay in Fig. 3 shows the locations of the various passive acoustic sensor systems that can be installed inside the glider. Inside a sonar dome all along the wing’s leading edge is a 27-channel hydrophone array with 15 kHz per channel bandwidth. A low-power single board computer running a real-time detection and localization algorithm string designed for humpback whales has been connected to the output from this hydrophone array. In addition to this PAAM system, a 3-channel (1 low and 2 mid-frequency) Digital Monitoring (DMON) system from Woods Hole Oceanographic Institution will be installed inside the nose of ZRay (an export license for the DMON has been obtained from the U.S. Dep’t of State). The self-contained mini-HARP system, with a single, extremely wide band (10 Hz to 100 kHz) hydrophone and
associated real-time processing designed for odontocete detection and classification, will not be installed in ZRay in this experiment; rather, it will be towed by the Wave Glider.

**Figure 3.** CAD/CAM drawing of ZRay with the starboard hatch covers removed. Labels illustrate the locations of the glider’s passive acoustic monitoring systems. Only the 27-element leading edge hydrophone array and the WHOI DMON system will be deployed inside ZRay (in its nose) in the upcoming sea test.

In addition, ZRay will tow a 32-element GTAS array from SPAWAR SSC Pacific, with a total length of 28.33 m.

**Figure 4.** A 32-element GTAS array (left) and a close-up of its elements (right).

The pre-launch sequence for ZRay requires about an hour. Deployment and retrieval of the glider from a ship of opportunity such as the New Horizon requires the use of a small boat. A small boat also will be required to attach and detach the GTAS towed array.
Wave Glider (1): The Wave Glider, an autonomous surface vehicle (ASV) manufactured by Liquid Robotics.

**Figure 5.** Wave Glider from Liquid Robotics on the fantail of R/V Sproul during the Range Validation Test on the SCORE Range, January, 2011.

The Wave Glider propels itself forward using the differential wave motion of a float at the ocean surface and a glider at depth. The operation of this USV is described in Fig. 6.

**Figure 6.** Description of the Waveglider sold by Liquid Robotics.

As shown in the left-hand plot of Fig. 6, water particles move in approximately circular orbits of decreasing diameter as depth increases. The float pulls the glider upward with a
rising wave crest, but the water around the glider remains relatively stationary. This action provides the necessary energy for forward propulsion of the glider/float assembly.

The basic Wave Glider components are labeled and described in the right-hand plot in Fig. 6. Massive components are positioned in the submerged glider where they are protected from the winds and sea surface action. The surface float is light, low drag, and rugged. The tether connecting the glider and surface float typically is 5-15 m in length. The communication systems attached to its surface float allow the Wave Glider to be operated continuously under human control.

During the upcoming sea test, the Wave Glider shown in Fig. 5 will be equipped with a single very wideband hydrophone (10 Hz to 100 kHz) towed behind the glider along with a mini-HARP data acquisition system.

**The Lubell LL916 Underwater Acoustic Source (1):** The Lubell source may be deployed from the R/V New Horizon at 1-3 km ranges from ZRay and the Wave Glider. All source operations will be conducted west of the ZRay site in Fig. 1 (marked by a yellow push-pin). The source can be hand-deployed and recovered by one person. It will be deployed to near its maximum depth of 10 m – the actual source depth will be measured by markings on the source cable. The 5-min waveform to be transmitted is described in Appendix 2. At the start of a 5-min transmission, the start time and ship position will be recorded by a GPS receiver and written into a log. The GPS position and time at the end of the transmission also will be recorded. The source level will at all times remain below 150 dB re 1 uPa @ 1 m. During each 5-min transmission, the ship will remain either dead slow (1 kt) or freely drifting.

During the upcoming sea test, any Lubell source transmissions will only occur west of the ZRay site (marked by a yellow push-pin in Fig. 1), and will be restricted to daylight hours.

![Lubell LL916 Underwater Speaker](image)

**Figure 7.** A picture of the Lubell underwater acoustic source to be used to transmit signals for detection, localization, and array gain measurements.
Communications during the Test

Ship-to-Shore Operations: What is the situation with internet connectivity and the New Horizon satellite link? What about verbal communications – are we in cell phone range?

1. Satellite phone – need the Iridum phone number for the AUV van.
2. Cell phones (connectivity of Verizon, ATT, T-Mobile off La Jolla?)
3. Channel 82A VHF marine band radio

Technical and Logistic Support Requests

Below is a list of tasks to be completed before the sea test.

BEFORE the TEST:

1. Submit Notice to Mariners and notification to other local Navy activities.

DURING the TEST:

2. Deploy CTD once on site, before glider ops, and at very end of sea test.
3. Deploy 1-2 XBTs per day.
4. ZRay and GTAS towed array deployment/retrieval dependent upon use of small boat.

Information on Ships

R/V New Horizon - http://shipsked.ucsd.edu/Ships/New_Horizon/
• To be used to deploy/recover ZRay and GTAS array for at-sea operations.

Vessel Assist San Diego - http://vesselassistsandiego.com/
• 1-800-391-4869, (619) 235-8273
• P.O. Box 6778
• San Diego, CA 92166
APPENDIX 1 - Ship to Shore Communications for SIO Ships

Voice, data and fax communications are available between ships and shore. These change from time to time as improved technologies and more cost-effective service plans arise. We attempt to keep the following information current, but if in doubt please contact the Marine Facility (858-534-1641) or Shipboard Technical Support (858-534-0193).

Email is available on a near real-time basis 24 hours per day and is the primary and preferred method of contact for business and personal purposes (see EMAIL below).

EMERGENCIES

In case of emergency a responsible person at MarFac can be reached as follows:

**Marine Facility:** 858-534-1644 during regular workdays (Monday through Friday, 0800-1700).
**Marine Facility Guard:** 858-534-1639 at other times

The person answering the phone will be able to assist with contacting a ship. Note that the on-duty guard may be away from his desk making rounds of the facility -- if your call is not answered, please leave a message and the guard will reply as soon as possible.

CELLULAR

Cell telephones can sometimes connect when vessels are working near shore, and, if so, you can call embarked individuals directly. SIO ships carry cell phones for ship business and are not intended to receive personal calls from shore. If you need a ship's cell phone number, contact MarFac for help (see EMERGENCIES above).

IN PORT, SAN DIEGO

When at the Nimitz Marine Facility, ships are connected to the regular UCSD land-line system as follows:

*Melville:* 858-534-1646  
*Roger Revelle:* 858-534-1647  
*New Horizon:* 858-534-1648  
*Robert G. Sproul:* 858-534-1649

R/P FLIP: 858-534-1650  
Nimitz Marine Facility - general office contact: 858-534-1641
APPENDIX 2 – Lubell Source Waveform – 5-min Duration

30 sec
  6-tone comb
    150, 300, 600, 1200, 2400, and 4800 Hz

5 sec gap

150 sec
  10 10-sec-duration LFM sweeps over 200 Hz band, each separated by a 5 sec gap
    200 - 400 Hz
    700 - 900 Hz
    1200-1400 Hz
    1700-1900 Hz
    2200-2400 Hz
    2700-2900 Hz
    3200-30 Hz
    3700-3900 Hz
    4200-4400 Hz
    4700-4900 Hz

42 sec
  6 unique humpback whale units recorded by Hildebrand's HARPs, each approx. 2 sec duration and separated by a 5 sec gap

70 sec
  10 unique high SNR humpback whale units from Cornell's Macaulay library, each approx. 2 sec duration and separated by a 5 sec gap