Project Number: 901101

Project Start: Jan. 1, 2011 **Project Duration (in years): 5**

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

☐	☒	☐	☐	☐
Feasibility/Scoping [Less than 100 days effort]	**Development**[1]	**Research**	**Infrastructure**[1]	**Education**

☐	☐
Time Series	**Institute Initiative**

Project Manager[2]: David Caress

Principal Investigator:

Lead Scientist: Charlie Paull

Lead Engineer: David Caress

Project Title: Ocean Imaging

[1] Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).
[2] Not all projects will require all four titles to be filled in. Please indicate individuals only for those titles that are appropriate for your project.

1) ABSTRACT (new projects only)

The Ocean Imaging project began this year to develop a low altitude, high-resolution seafloor mapping capability combining multibeam sonar with stereo photographic imagery. The goal is to obtain spatially quantitative, repeatable renderings of the seafloor with fidelity at scales of 5 cm from altitudes of 2-3 m.

This year we will field a prototype system from ROV Ventana combining a 400 kHz multibeam with dual color cameras, strobes, and an inertial navigation system. The first survey sites will likely be rocky outcrops in the lower Soquel Canyon and on Portuguese Ledge; these initial data sets will provide a test bed for our development of data processing tools and for the adaption of vision and terrain aided navigation algorithms for realtime survey application.

For 2012 we propose to move the ROV-based system to the Doc Ricketts and to begin long-term monitoring of two sites in the deep Monterey Canyon (1,850 m bend and 2,800 m chemosynthetic communities). In collaboration with the Precision Controls project (600034), these surveys will field test real-time vision and terrain aiding to the ROV navigation. Our data processing development will proceed in concert with the related efforts at data interpretation and visualization in the Continental Margins project (901023). We also intend to scope the requirements and characteristics of an autonomous platform capable of fielding this survey system in areas of steep and rugged terrain.

During the following years of this project we expect to continue field operations at the prototype monitoring sites (and other sites, if requested), and to migrate our new survey system to an autonomous platform. Depending on the results of our year two scoping effort, we may propose to develop this platform internally or to purchase and adapt an existing system. At the conclusion of the Ocean Imaging project, MBARI will have an autonomous capability to repeatedly map and image the seafloor at scales of a few cm.

2) PROPOSAL

a) New Projects

b) Continuing Projects

If the proposed project includes multiple individual projects, please list each of these projects as a subheading in the proposal. For each subheading, please address the following:

Current status of project and results to date

The goal for the first year of Ocean Imaging is to design, construct, and test a combined multibeam sonar and stereo camera rig for ROV operations.

We have purchased and field-tested a 400 kHz Reson 7125 multibeam sonar on ROV Ricketts. The augmentation of the MB-System software for processing these data have been completed and tested.

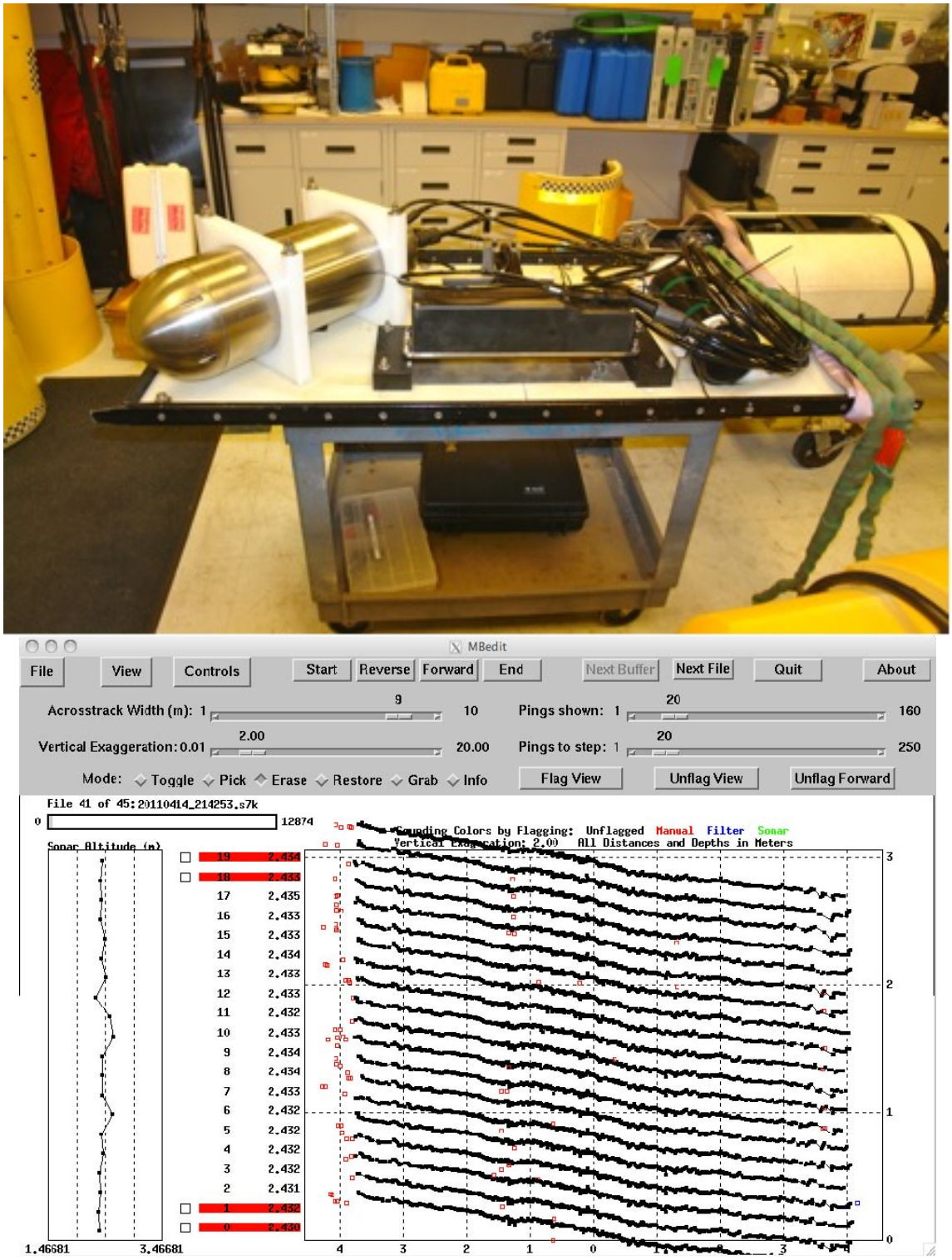

Figure 1. Top: 400 kHz Reson 7125 multibeam mounted on plate for successful April 14, 2011 testing on ROV Ricketts. Bottom: MBedit screen grab showing 20 pings of multibeam bathymetry collected at 2.5 m altitude while the ROV moved slowly ahead.

Two Prosilica GX1920 2.4 Mpixel color cameras and lenses have been purchased and installed in housings fitted with flat-port optics that provide a 55 degree field of view. To increase the visual swath during surveys and more closely match the multibeam acoustic swath, we are having custom corrective optics designed and fabricated to increase the cameras underwater field of view to 90°; the corrective optics will be delivered this summer. Linux-based camera control software has been obtained from Chris Roman of University of Rhode Island, adapted to operate our cameras, and bench tested. The development of post processing software for the stereo imagery is just beginning. The initial application is a stereo camera calibration tool. This, and the future tools implementing photogrammetric extraction of topography from stereo pairs, are being built on top of the OpenCV library, an open source computer vision package originally developed at Intel and now supported by Willow Garage and Google.

We are adapting an existing housing (originally used as the power can for Ventana-based Mapping AUV testing in 2004) to contain the power electronics, the strobe and camera control electronics, and the network link to the ROV tether. This survey system is being embedded in the Ventana cable laying toolsled, with all components mounted to a single plate.

We are currently scheduled for our first field tests on ROV Ventana at the end of August, followed by additional days in October. We expect to conduct our first operations on flat, rocky outcrops in the lower portions of Soquel Canyon and on Portuguese Ledge. These tests will be conducted in conjunction with Steve Rock and his students as they test the current versions of their vision and terrain aided navigation software.

The remainder of this year's efforts will be devoted to software development using the test data. In particular, we will focus on developing the tools needed for stereo camera calibration and for the calculation of photogrammetric topography from the overlapping regions of the stereo image pairs.

Significant changes from previous project proposal

We originally budgeted to purchase LED lighting, but have chosen to work with the Xenon strobes used in the Benthic Imaging AUV for this year. We instead used those funds to have custom corrective optics designed and fabricated to increase the camera's underwater field of view to 90°. We will budget in this proposal for new lighting elements in 2012, with our choice to be guided by our experience in this year's field tests.

Publications based on the results of this project only

None to date.

How does it relate/contribute to the Packard Foundation's Ocean Visions Grantmaking policies?
(See http://mww.mbari.org/oed/OED_Documents3.htm#Packard for documents.)

The Packard Foundation plans to focus its oceans grants on three interlinked objectives:

- Restoration of ecologically important fisheries

- Improved coastal management
- Enhanced scientific understanding of the functioning of marine ecosystems

The goal of this project is develop a seafloor mapping and imaging capability that can map topographic relief at 5 cm scales and accurately locate higher resolution imagery on that topography efficiently in the deep ocean. Whether fielded in an ROV or an AUV context, this high resolution mapping system will be a fundamental observational tool for understanding and monitoring benthic habitats and for understanding geological processes that impact the fine scale seafloor structure and character. As such, the Ocean Imaging project aims to provide a technology that can be key to meeting the Packard Foundations objectives with respect to benthic ecosystems.

c) New and Continuing Projects: Plans for 2012

Engineering/technology development

During 2012 we plan to adapt the survey system for use on ROV Ricketts. This should involve only minor adjustments to the differences in power and telemetry between the two ROVs. We will purchase new lighting elements to replace or augment the existing Xenon strobes.

In collaboration with the Precision Controls project (600034), we will implement realtime vision and terrain aiding to the ROV navigation. This capability will be tested at sea during our surveys to achieve full optical and acoustic coverage of the seafloor during "mow-the-lawn" surveys at altitudes of 2-3 m.

We will continue development of processing software to extract topographic information from the stereo imagery, merge it with the multibeam bathymetry, and construct 3D models of the seafloor. Much of the required functionality exists as part of the OpenCV library, an open source machine vision code base originally developed at Intel and more recently supported by Willow Garage and Google. Specifically, there are existing methods for stereo camera calibration and for photogrammetry of stereo pairs. Our data processing development will also proceed in concert with the related efforts at data interpretation and visualization in the Continental Margins project (901023).

We also intend to scope the requirements and characteristics of an autonomous platform capable of fielding this survey system in areas of steep and rugged terrain. Caress, Thomas, Hobson, and Rock conducted a set of meetings late in 2010 regarding the requirements for a low-altitude, optical plus acoustic autonomous survey platform (see appendix). We will revisit these requirements in light of our experience with the ROV based surveys, and consider whether we should adapt an existing MBARI platform, develop a new platform at MBARI, or purchase an existing platform from an external source. Our intent is to propose the development or purchase of a low-altitude survey AUV during 2013.

Imaging AUV:
On a separate, but related topic, we propose to support under the umbrella of Ocean Imaging continued engineering support of the Benthic Imaging AUV (901012). The Benthic Imaging project will formally end at the end of 2011 though due to scheduling and limited availability of the Kearfot INS the Imaging AUV team is not scheduled to have access to the AUV until the end of October, when most of the development test days are packed into two weeks of consecutive operations. Back to back days offshore

at the end of the year is not ideal for the development of new technology so we feel our ability to complete the final project goals may be at risk. Therefore, we are requesting time for Hobson and McEwen during 2012 (75 hours each) to complete the testing and development of this system. This work will be field tested on ship days requested under Continental Margins (901023) and Precision Control (600034).

Field programs (detail ship requirements/deployments/diver requirements)

Our Doc Ricketts field operations in 2012 will focus on two sites in the deep Monterey Canyon that have been identified as likely locations for detectable change over timescales of weeks to months. These are the same two sites that are the focus of the Benthic Imaging AUV operations requested under the Continental Margins program (901023). We also intend to begin long-term monitoring in the canyon axis at the 1850 m bend and of a chemosynthetic clam community in the canyon axis at 2800 m. These efforts are complementary because the BIAUV and MAUV are operating at a much larger scale than the more detailed site-specific goals of the Ocean Imaging project. We request six Doc Ricketts ROV dives in two sets of three dive-days each. These dives should be scheduled after the Zephyr's Gulf of California expedition and the BIAUV surveys. We would prefer to have these dive sets scheduled at least three months apart.

Specific deliverables

During year II we will field a seafloor imaging system capable of achieving 5 cm scale surveys combining topography and stereo imagery from ROV Ricketts. We will begin monitoring of two sites (1850 m bend, 2800 m clamfield) in the deep canyon with surveys repeated once at each site a few months apart; these surveys will be repeated in coming years to document fine scale changes in the seafloor and the benthic communities.

The sonar and image data processing software will be developed as part of the open source MB-System software package, and thus will be rapidly available to the external community through the frequent MB-System distribution updates.

Milestones (see last page for personnel classification list)

[Click here to enter text]

	Milestone 1	Milestone 2	Milestone 3	Milestone 4	Milestone 5	**Total Resources**[3] for each resource category for all milestones listed here
Milestone Date	**5/15/12**	**As scheduled**	**As scheduled**	**Fall 2012**		
Milestone Description	**Tank calibration and testing of survey**	**First set of surveys at 1850 m bend and**	**Second set of surveys at 1850 m bend and**	**Generation of 3D seafloor models combining multibeam**		

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

	system configured for Doc Ricketts	**2800 m clam field**	**2800 m clam field**	**bathymetry, photogrammetric topography, and photographic imagery.**		
EE						
SE	**200**	**190**	**100**	**230**		**795**
ME	**205**	**100**	**100**			**480**
EE Tech	**60**	**20**				**80**
SE Tech						
ME Tech	**75**	**25**				**100**
Machine Shop	**40**	**40**				**80**
Divers	**20**					**20**

Budget justification

Most of the expensive hardware for this effort has been purchased. During 2012 we will be upgrading the lighting system and computer system and migrate all the hardware from Ventana to Doc Ricketts.

Lighting:
We plan to take range measurements with the sonar at 2-4 Hz so we want the option to take stereo images at up to 2 Hz. This is too fast a rate for the strobes we've been borrowing from the Benthic Imaging AUV project so we'll need to buy strobes next year. We are budgeting for a commercially available strobe that should be able to meet our needs and will cost $26,300. For budgetary reasons, this expense can be postponed until 2013 if we use ROV lights during 2012, though we'd prefer to get experience with a lighting solution compatible with AUVs Before this purchase we plan to experiment with alternative systems that include LEDs and terrestrial strobes mounted inside glass spheres. We'll have to build 2-4 submersible light meters for tank testing. Several reflector designs will be tested along with the lighting options. This lighting test system will cost $5k

Doc Ricketts:
A high speed, gigabit telemetry system will have to be added to one of the spare optical fibers ROV Doc Ricketts' umbilical. The instrument package will be moved from Ventana and many new brackets and cables will need to be manufactured. We expect this part of the project to cost $5k.

Project team

Core Team:

- David Caress (Lead Engineer, Project Manager)
- Brett Hobson
- Hans Thomas
- Rich Henthorn
- Larry Bird
- Eric Martin
- Steve Rock
- Charlie Paull (Lead Scientist)

Responsibilities:

- David Caress
  - Project management
  - Sonar requirements and operation
  - Software development for data processing and display
  - 50 days (450 hours)
- Brett Hobson
  - Mechanical design
  - Camera system design
  - 38 days (342 hours)
- Hans Thomas
  - Electrical and software integration
- Steve Rock (+ Mike Risi + students)
  - Aided navigation algorithms
  - Implementation budgeted as part of Precision Controls project
- Charlie Paull
  - Survey specification and interpretation
- Eric Martin
  - Assist with mechanical, electrical, and software integration onto ROV
- Rich Henthorn
  - Modification of existing multibeam logging software
  - Help integrate with Rock team
  - 30 days (270 hours)
- Larry Bird
  - Payload integration and fabrication
  - Calibration gig fabrication
  - 15 days (135 hours)
- Rob McEwen
- IAUV terrain following algorithm development
- IAUV software support
- 8 days (75 hours)

Project lab space

We propose to take over the Imaging AUV project lab space.

Data availability outside project team, uniqueness

The test survey data will be used by Charlie Paull's group as part of their continuing research into sediment transport in submarine canyons. These data will be available generally within MBARI.

The sonar and camera data processing software developed by Caress will be rapidly available to the external community through MB-System distribution updates.

Risk matrix (development and infrastructure projects only)

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

Personnel Classifications

Engineer - Mechanical Engineer (Reg)	**Engineer - Electrical Engineer** (Reg)	**Engineer - Software Engineer** (Reg)	**Engineer - Mechanical Tech** (Reg)	**Engineer - Electrical Tech** (Reg)	**Engineer - Software Tech** (Reg)	**Observ Support Technician** (Reg)	**Science – Software Engineer** (Reg)
Jim Birch (2/3)	Mark Chaffey	Dave Caress	John Ferreira	Paul Coenen	Karen S	Mike Kelley	Mike Godin
Larry Bird	Scott Jensen	Danelle Cline	Frank Flores	Tom Marion		Open - TBD	Frederic Py
Jon Erickson	Chad Kecy	Duane Edgington(2/3)	Mike Parker	Jim Montgomery			
Dale Graves (2/3)	Denis Klimov	Kevin Gomes (2/3)	Jim Schofield	Jose Rosal			
Andy Hamilton (2/3)	Paul McGill	Kent Headley (2/3)					
Brett Hobson	Ed Mellinger	Rich Henthorn					
Bill Kirkwood	Craig Okuda	Bob Herlien					
Gene Massion	Alana Sherman	Brian Kieft					
Doug Pargett		Thom Maughan					
Farley Shane		Mike McCann					
		Rob McEwen					
		Tom O'Reilly					
		Wayne Radochonski					
		Mike Risi					
		Brent Roman					
		Carlos Rueda-Velasquez					
		Brian Schlining					
		Rich Schramm					

Appendix: Planning a Next Generation Nimble Survey AUV: Preliminary Functional Requirements for a Low-Altitude, Acoustic/Optical Survey AUV

Background

During late 2010 Steve Etchemendy asked David Caress, Hans Thomas, Brett Hobson, and Steve Rock to develop a concept for an autonomous survey platform appropriate for the sorts of near-bottom combined acoustic and optical seafloor surveying envisioned in the Ocean Imaging (901101) project. This concept could be used to help guide institutional planning related to autonomous platforms and vessels, and could also lead directly to proposals for platform development or purchase. This appendix summarizes the results of discussions held in late 2010 and early 2011. As noted in the proposal above, we expect to revisit these discussions as part of an AUV development/purchase scoping effort during the 2012 (year 2) increment of the Ocean Imaging project.

The Ocean Imaging project seeks to combine high frequency multibeam bathymetry with stereo photographic imagery, both datasets collected simultaneously from altitudes of 2-3 m. The goals for this near-bottom survey system include:

- Combine the multibeam bathymetry with photogrammetric topography to obtain the highest resolution 3D topographic model possible. The goal is to achieve a 5 cm lateral resolution, or better.
- Precisely collocate the optical imagery on the 3D topographic model.
- Implement both terrain and vision aiding to real-time navigation to support achieving full coverage during autonomous surveys.

Year 1 of the Ocean Imaging project involves developing a capability to conduct combined acoustic and stereo optical data from MBARI's ROVs, and year 2 will include the beginnings of fine-scale seafloor monitoring through repeated surveys. In later years, the project will seek to integrate the near-bottom survey system onto an autonomous platform. This discussion seeks to define the characteristics of an AUV optimized to perform these future surveys.

Some of the factors that should be considered in the process include:

- Capabilities of the existing Dorado and Tethys platforms
- Impact of the Antarctic iceberg autonomous mapping proposal submitted to NASA
- Capabilities of survey AUVs external to MBARI
- Desire to run 48 hour missions to enable running from shore to survey sites
- Who are the likely end users?
- What is the likely range of missions? (use cases)
- What additional sensors and uses should impact the design?

Some Basic Options

Some rather different options for obtaining a "nimble" near-bottom autonomous survey platform are available to use:

- Modify the existing Dorado AUVs by inserting lateral/vertical thruster sections into the torpedo-shaped vehicles
- Build a multi-body vehicle with lateral and vertical thrusters.
    - This might be two or three bodies

  - This might make substantial use of the Dorado codebase and existing Dorado and 1K ROV components. Or not…
- Purchase an externally designed vehicle, e.g. the SeaBed platform from WHOI, approx $500k for a 2km-rated system or $1m for a 5000m-rated system
- Lease/contract for external vehicle using our sensor package

Mission Cases

Near-bottom survey in Soquel Canyon:

- 1-2 m altitude
- Terrain can be vertical with overhangs (canyon walls)
  - Capability to turn in place
  - Capable to keep sensor package pointed normal to the seafloor
- Multibeam bathymetry (<5 cm lateral resolution)
  - >100% coverage
  - 120° swath width
- Stereo imagery
  - >100% coverage
  - ~90° field of view
  - Color imagery to 3 m altitude
  - Black and white to 10 m altitude
- Depth rating to deepest of plausible recovery assets (4000 m or 6000 m?)
- Realtime relative navigation good to <0.25 m
  - Vision aiding requires 50% overlap in subsequent frames
  - Terrain aiding requires non-flat terrain
  - Terrain aiding relative to pre-existing map places no requirement on survey design
  - Terrain aiding relative to current data requires 50% overlap in adjacent swathes

Preliminary Functional Requirements:

- Sensors provide 5 cm scale topography and co-located optical imagery
  - High frequency 1°x1° or better multibeam
  - Stereo color cameras w/ lighting (grayscale for altitudes > 3 m)
  - Sonar and cameras physically tied
  - Attitude sensor physically tied to sonar & cameras
- Navigation good to 0.05% distance traveled without terrain or vision aiding
- Sensor attitude accurate to 0.05° at 10 Hz (required for multibeam)
- Require 100% coverage in arbitrarily steep/complex terrain
- Need to be able to extricate itself from under an overhang
- Sensor package must be oriented normal to seafloor, even when surveying a vertical wall
- Operate from altitudes of 2-10 m
- Minimum depth requirement of 4000 m
- Minimum practical endurance 12 hours, aim for 18 hours or more
- Maximum speed 1 m/s (2 knots) for near bottom imaging
- Stable to within 3 degrees with rate less than 12 degrees / second

  - This is with respect to the terrain – sensors pointed normal to seafloor
- Minimize ascent and descent times – 30 m/minute minimum ascent descent rates
- Must fit in shipping volume of 4'x8'x18'
- Can be operated from future "coastal vessel"
- Ancillary sensors
  - CTD
  - Eh
  - Optical backscatter
  - Magnetometer
  - Flourometer and other dissolved gas sensors
  - O2?
  - Mass spectrometer?
  - ESP?

Implications

- Five independent degrees of control for the sensor package
  - Surge (fore-aft), heave (up-down), sway (lateral), yaw (heading), pitch
- Four degrees of freedom in vehicle controls
  - Surge (fore-aft), heave (up-down), yaw (heading), sway (lateral) (actuating sway is unusual)
  - Pitch and roll can be passive, but pitch control would improve ascent & descent efficiency
- Kearfott-class INS with DVL aiding
- Great emphasis on obstacle avoidance
- Great emphasis on SLAM using both multibeam and imagery
- Have to choose between having an articulated sensor package or a vehicle that can tilt arbitrarily
  - Preference for sensor package articulated with one rotational degree of freedom
- Enable use of dropweights for ascent and descent