This proposal is being submitted under the Office of Naval Research Broad Agency Announcement 01-012, DEMONSTRATION OF UNDERSEA, AUTONOMOUS, OPERATION CAPABILITIES AND RELATED TECHNOLOGY DEVELOPMENT.

**BAA subject areas being proposed** (appropriate areas checked):

- Maritime Reconnaissance
- Undersea Search & Survey
- ✓ Communications/Navigation Aid
- ✓ Related Technology Area
  - ✓ Energy
  - ✓ Navigation
  - ✓ Autonomy
  - Sensors
  - Communications

**Submitting Institution:** Monterey Bay Aquarium Research Institute (MBARI)
7700 Sandholdt Road, Moss Landing, CA. 95039

**Title of proposal:** **Underwater Docking of AUVs - Docking for a wide range of vehicle systems and dimensions.**

**Abstract:** MBARI, as a collaborator with Bluefin Robotics, will take an active part in the design, build, install, and test of a docking system for AUVs. The program will be in two phases to take advantage of the WHOI proposal (P.I. Al Bradley) for a docking system they will be building. MBARI is collaborating on the WHOI dock also and together the final design is expected to accommodate 21"diameter Dorado style vehicles, WHOI vehicles (ABE, SAGE) and down do a new 12"diameter AUV systems proposed for the Navy by Bluefin as part of this proposal. Phase one (year 1) will demonstrate dock acquisition, latching, AUV sleep mode, AUV waking, detachment, and return to the launch platform. Phase two in the following years will complete any updates, install and test communications and power transfer capabilities. These tasks will be done in conjunction with MBARI's in-house observatory efforts to include docking as part of sub-sea science observatories. Upon successful testing of the system it will be used to launch survey missions as outlined in the Bluefin demonstration objectives section of the proposal. It is anticipated that MBARI will be able to buy future docks from Bluefin along with spares and they will offer these to the greater ocean science community.

**Principal technical personnel:** William J. Kirkwood, 831.775.1707, kiwi@mbari.org
Dr. James G. Bellingham, 831.775.1731, jgb@mbari.org

**Principal business personnel:** Tayeko Yamada, 831.775.1803, grants@mbari.org

**Signature of official authorized to obligate the institution:** _____

C. Michael Pinto
Chief Financial Officer
831.775.1776, pinto@mbari.org

**Date of submission:** July 20th, 2001

**Period of Performance:** October 1, 2001 through September 31, 2004

**Total Cost:** $553,936

Monterey Bay Aquarium Research Institute

# INSTITUTIONAL ENDORSEMENT

| | |
|---|---|
| **Subaward Proposal Submitted To:** | **Bluefin Robatics, Inc.** |
| **Prime Agency:** | **Office of Naval Research** |
| **Project Title:** | **Underwater Docking of AUV's – Docking for a wide range of vehicle systems and dimensions** |
| **Support Requested:** | **$553,936** |
| **Duration of Project:** | October 1, 2001 through September 31, 2004 |
| **Submitted By:** | Monterey Bay Aquarium Research Institute<br>7700 Sandholdt Road<br>Moss Landing, CA 95039 |
| **Principal Investigator:** | **William J. Kirkwood** |

## INSTITUTIONAL ENDORSEMENT:

Marcia McNutt 7/16/01
Marcia McNutt Date
Executive Director and CEO

7/16/01
C. Mike Pinto Date
Comptroller and CFO

Marcia McNutt 7/16/01
Keith Raybould Date
Chief Operations Officer

7/16/01
Ed DeLong Date
Director of Science

7/16/01
Jim Bellingham Date
Director of Engineering

Judith L Connor 7/16/01
Judith Connor Date
Director of Information and Technology Dissemination

7/16/01
Steve Etchemendy Date
Director of Marine Operations

*In the event that this proposal is accepted, the signatures on the proposal constitute acceptance of and compliance with statutes and regulations of the U.S. Government and U.S. Department of Commerce.*

Underwater Docking of AUVs:
Docking for a wide range of vehicle systems and dimensions

Technical description:

Autonomous underwater vehicles and the operations of them are a critical technology to the Navy but also the ocean science community [1]. Extended autonomy is required to fill in gaps present in both science [2] and military applications. Placing AUVs in the ocean for extended stays and operations will assist in correcting current limitations in capability.

Sub-sea docking allows AUV systems to be present on site, thus reducing overhead costs for mission programming, execution, and data recovery. Docking systems kept low in the water also protect the vehicle systems from damage. However docking also presents a series to technical problems. Universal docking of various AUVs, commonality of interfaces for power and data transfer, and the demonstration of those systems is the MBARI technical goals of this proposal.

The docking system will be designed in conjunction with Bluefin and their proposed docking concepts. The systems will be made as common as possible to prevent duplication of efforts and to maximize the commonality of latching solutions. MBARI will collaborate on the design of the latching mechanisms along with power and data transfer development. In phase one MBARI will assist with the build of a latching system that accommodates the 21" Dorado style AUV systems and the 12" Small AUV proposed by Bluefin. The phase one testing will take place in the Monterey Bay area, selected to take advantage of the MBARI Ocean Observatory System (MOOS) program which will be installing moorings that can be used as platforms for this program. MBARI also offers easy access to the ocean with a variety of local platforms for dock installation and AUV testing. MBARI has a new ship coming online that is customized for the launch and recovery of AUV systems, the R/V Zephyr. In phase one of the proposal MBARI will test the variety of vehicles available at the time for successful dock location, docking, sleep mode, waking, dock release, and return to the mission start position / platform.

Phase two will include similar testing to phase one but include the data and power transfer components. The hardware components for this phase will be in the design and lab test phase. MBARI has a new saltwater test facility (Fig.1) capable of placing a dock sub-surface and working this phase MBARI Planned top take place approximately one year later. The basic concepts for the power and data transfer are based on previous work at MBARI and testing already completed. The baseline concept for power transfer is a direct connection, however a trade study and lab testing will be done to see how inductive couplings have progressed. The baseline design for data transfer will be an extension of work previously completed at MBARI, and other institutions such as MIT, in infra-red data connections underwater. The hardware is readily available,

industry has highly reliable standards, and systems are robust to misalignments while still giving low error rates [2]. Once these systems have completed testing the system will be made available to Bluefin for further demonstration of the small AUV system completing a series of survey missions as outlined in the proposal test plan. Ultimately the goal is to make the docking system available commercially to the science community and NAVY through Bluefin as the industrial collaborator.

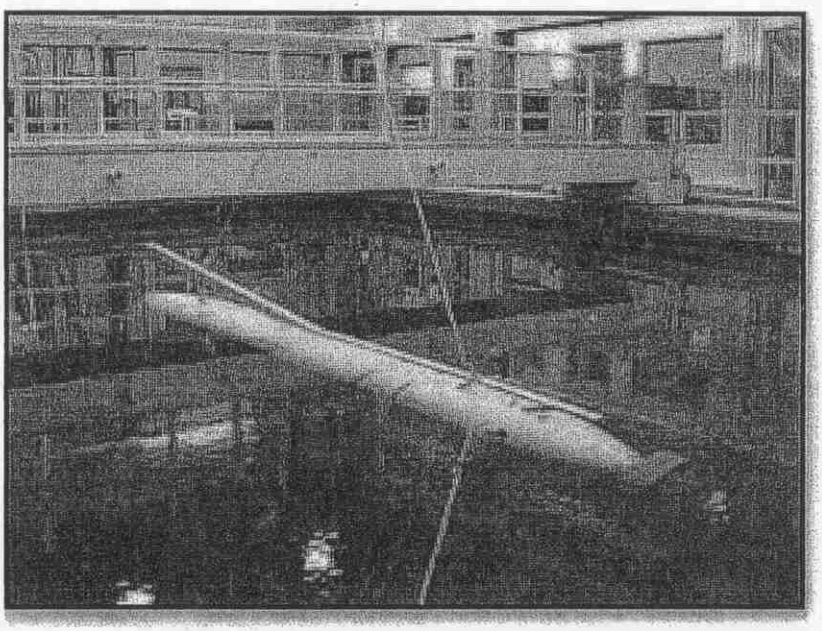


Fig.1- MBARI Test Tank

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

[2] Bellingham, J. G., K. Streitlien, J. Overland, S. Rajan, P. Stein, J. Stannard, W. Kirkwood, D. Yoerger, "An Arctic Basin observational capability using AUVs", *Oceanography*, vol. 13, no. 2, pp. 4-70, 2000

[3] Manson, Graham, 1998. "Practical environmental controls using new advanced low cost technology", *TIDE Third Congress Papers*, Helsinki, 1998

## Statement of work:

Scope of work: MBARI will work as a collaborator with Bluefin Robotics in the development of a fully functional docking system. That system will include latching, power transfer, data transfer, and vehicle release through a well defined system specification that accommodates a variety of autonomous underwater vehicles. The vehicles will include the 21" diameter Dorado modular AUV and the proposed 12" AUV included by Bluefin as part of this proposal response. MBARI will assist in the definition, component and technology selection, design, build, testing, and publication of results.

1.0 Concept Review (*January 2002*)
- 1.1 Meeting at Bluefin and MBARI – system interface definition and conceptual design
- 1.2 Concept review at MBARI with MBARI Ocean Observing System team
- 1.3 Specification modifications and replies to concepts

2.0 Design Process (*February 2002 through April 2002*)
- 2.1 Concept drawings
- 2.2 Build and test any components of concern
  - 2.2.1 Latches
  - 2.2.2 Homing system
  - 2.2.3 Mooring connections
  - 2.2.4 Software
- 2.3 Design review

3.0 Project Meeting to commit to design (*May 2002*)
- 3.1 Design presentation with Bluefin
- 3.2 Modifications to drawings
- 3.3 Detail Drawings
- 3.4 Build to Drawings
- 3.5 Software
- 3.6 Contingency for design difficulties

4.0 Assembly and Integration (*June 2002 through September 2002*)
- 4.1 Purchasing of components
- 4.2 Build of mooring components to interface to MOOS Mooring
- 4.3 Dock build
- 4.4 Integration
- 4.5 Tank Test of Docking
- 4.6 Contingency for build difficulties / test modifications

5.0 Installation and Test at Sea (*October 2002*)
- 5.1 Mooring installation with dock
- 5.2 Survey dock in and test homing system
- 5.3 Vehicle testing to demo docking functions

5.4 Contingency for vehicle modifications and dock re-test

6.0 Bluefin field tests of Small AUV / Survey mission with Dorado style system (*Dec 2002*)
- 6.1 Vehicle testing to demo docking functions
- 6.2 Contingency for vehicle modifications and dock re-test

7.0 Phase II development (*January 2003*)
- 7.1 Outline plans based on test results
  - 7.1.1 Trade studies for power transfer / lab testing
  - 7.1.2 Trade studies for data transfer / lab testing
- 7.2 Modify dock designs as needed
  - 7.2.1 Power transfer component design concepts
  - 7.2.2 Data transfer component design concepts
  - 7.2.3 Software
- 7.3 Tank testing of new dock modifications
  - 7.3.1 Prototype testing in tank environment with vehicle
- 7.4 Concept reviews of original power and data communications concepts

8.0 Design of Data and Power connection for vehicles (*February 2003 – April 2003*)
- 8.1 Detail drawings
  - 8.1.1 Power transfer component design
  - 8.1.2 Data transfer component design
  - 8.1.3 Power transfer system housing
  - 8.1.4 Data system housing (possibly integrated with power)
- 8.2 Build and test of critical path components
  - 8.2.1 Data connection
  - 8.2.2 Power Connection
  - 8.2.3 Materials / Anti-fouling capabilities
  - 8.2.4 Power storage system / cables
- 8.3 Software
- 8.4 Design review
- 8.5 Contingency time for difficulties in design process

9.0 Project meeting (*May 2003*)
- 9.1 Design and project performance status of team
- 9.2 Bluefin Small AUV progress / modifications
- 9.3 MBARI / Bluefin System tests / communications and power transfer

10.0 Assembly and Integration (*June 2003 through September 2003*)
- 10.1 Purchasing of components
- 10.2 Build of mooring components to interface to MOOS Mooring
- 10.3 Dock build
- 10.4 Software
- 10.5 Integration

10.6 Tank Test of Docking
10.7 Contingency for build difficulties / test modifications

11.0 Installation and Test at Sea (*October 2003 – November 2003*)
11.1 Mooring installation with dock
11.2 Software checkout
11.3 Survey dock in and test homing system
11.4 Vehicle testing to demo docking functions
11.5 Contingency for vehicle modifications and dock re-test

12.0 Bluefin field tests of Small AUV / Survey mission with Dorado style system (*Dec 2003 – January 2004*)
12.1 Vehicle testing to demo docking functions
12.2 Contingency for vehicle modifications and dock re-test

13.0 Test of other vehicles (*Included with the Bluefin or MBARI Dorado vehicle sea trials*)

14.0 Project final reports / dock manufacture (*February 2004 – May 2004*)
14.1 Final report to ONR
14.2 Clean up drawings to as built condition
14.3 Paper preparation
14.4 Conference attendance / presentation

Logistics analysis:

The docking system is being designed to maximize the use of commercially off-the-shelf technologies as applicable. The system will be built such that normal mooring system maintenance cycles would include the dock, no special tooling or techniques will be required. The docking system will also be versatile enough to be configured in a variety of manners as dictated by a moored and/or bottom based application. The system is intended to be fully autonomous, however provisions will be made for health and status monitoring by a remote station (MBARI infrastructure already in place) which enables two way communications to the Dorad0 vehicle systems, a capability already in the system for mission modifications and mission data downloads.

Organization capabilities:

The Monterey Bay Aquarium Research Institute (MBARI) was established in 1987 by David Packard and is primarily funded through the David and Lucille Packard Foundation. The institute has operated numerous deep sea assets since that time with two ship and two remotely operated vehicles. MBARI has been an autonomous underwater vehicle collaborator and developer for three years with programs involved in new energy systems (pressure tolerant fuel cells), data

buoys launching, high latitude navigation, and long endurance mission AUVs. MBARI was a principal contributor in the ONR sponsored AOSN program. MBARI is currently developing the ALTEX vehicle for under-ice missions funded by ONR and NSF.

MBARI has completed over 2300 deep ocean science missions with ROVs. MBARI equipment and/or personnel have operated in every major ocean around the globe and have successfully collaborated with most major science institutions such as WHOI, IFREMER, JAMSTEC, ONR, NSF, and others. MBARI has completed over 300 AUV dives in test dives and on 4 cruises. MBARI will be leading a cruise to Arctic as part of the ALTEX program in October of 2001. The ALTEX vehicle will be in engineering tests above Norway and testing is expected to include MBARI's first under ice operations of AUVs.

Key Personnel:

MBARI has a dedicated staff of engineering and operations personnel working on the development of AUVS and AUV support systems such as docking and navigation.

**William J. Kirkwood**

Associate Director of Engineering

## EDUCATION:

- University of California Los Angeles, BSME, 1979
- University of Phoenix, MSCIS, 1999

## EMPLOYMENT HISTORY AND ACCOMPLISHEMENTS:

### Present Position:

1991 - Present: Associate Director of Engineering, Project Manager of the ALTEX program, Project Manager of the Dorado AUV development program. Project Manager and mechanical designer of the Tiburon ROV from 1991 to 1996.

### Past Positions:

1986 - 1991 Supervisor, Lockheed Missile and Space Co. , Advanced Systems Division.
Responsible for 30 engineers and the design of land, marine, and flight packages for high energy laser systems including active optics, electronics, software, test, and integration. Mirror systems included actively cooled, deformable wave front control, and beam walk targeting systems.

1983 - 1986 Supervisor, Research Engineering for Leach Relay Corp. Developed hybrid electronics and smart switching devices for military and commercial aircraft, the Space Shuttle, and satellites. Worked on pilot loading issues and automated systems for emergency response on the F-16 Fighter, Blackhawk and Apache helicpoter power systems. Designed and built high voltage electronics amd switches for the US Fleet Ballistic Submarine Sonar Systems.

## PROFESSIONAL SOCIETIES:

American Geophysical Union - Member

IEEE - Member

**James G. Bellingham**
Director of Engineering

**Professional Positions:**

Engineering Director — *Jan 1999 - present*
Monterey Bay Aquarium Research Institute

Laboratory Manager, — *Jan 1989 – Apr 2000*
Autonomous Underwater Vehicles Laboratory
MIT Sea Grant College Program
Massachusetts Institute of Technology

**Education:**

| | | |
|---|---|---|
| Massachusetts Institute of Technology | Ph.D., Physics | *Sept 1988* |
| Massachusetts Institute of Technology | S.M., Physics | *Sept 1984* |
| Massachusetts Institute of Technology | S.B., Physics | *Sept 1984* |

**Cruises and Field Operations with AUVs:**

Have lead AUV operations in 20 field experiments between 1992 and the present, including serving as Chief Scientist for seven cruises at least one week long.

**Honors and Awards:**

*R&D 100 Award*
Awarded to MIT for commercialization effort of Ph.D. thesis, 1992.

*Antarctica Service Medal of the United States of America*
Awarded by NSF, August 1993.

*Antarctica Service Medal*
Awarded by Department of the Navy, August 24, 1993.

**Five Relevant Publications:**


Bellingham, J. G. and Consi, T., "State Configured Layered Control," *Mobile Robots for SubSea Environments, International Advanced Robotics Programme*, Monterey CA, pp 75-80, 1991

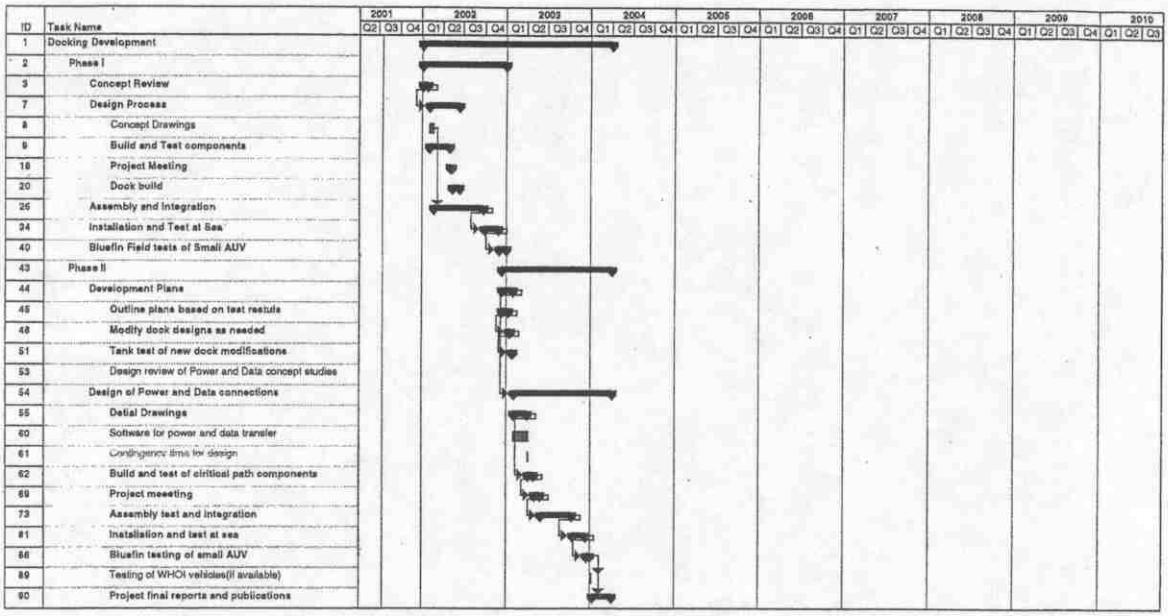
Curtin T., Bellingham, J. G., Catipovic, J., and Webb, D., "Autonomous Ocean Sampling Networks," *Oceanography*, Vol. 6, No. 3, pp 86-94, 1993.

Bellingham, J.G., "New Oceanographic Uses of Autonomous Underwater Vehicles," *Marine Technology Society Journal,* Vol.31, No. 3, pp. 34-47, Fall 1997.

Bellingham, J. G., Streitlien, K., Overland, J., Rajan, S., Stein, P., Stannard, J., Kirkwood, W., and Yoerger, D., "An Arctic Basin Observational Capability using AUVs," Oceanography, Vol 13, No. 2, pp 64-70, 2000.

Willcox, J. S., Bellingham, J. G., Zhang, Y., and Baggeroer, A. B., "Oceanographic Surveys with Autonomous Underwater Vehicles: Performance Metrics and Survey Design, " accepted for publication in *IEEE Journal of Oceanic Engineering*, 2001.

# Schedule:


ID
Task Name
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3
1 Docking Development
2 Phase I
3 Concept Review
7 Design Process
8 Concept Drawings
9 Build and Test components
18 Project Meeting
20 Dock build
26 Assembly and Integration
34 Installation and Test at Sea
40 Bluefin Field tests of Small AUV
43 Phase II
44 Development Plans
45 Outline plans based on test results
48 Modify dock designs as needed
51 Tank test of new dock modifications
53 Design review of Power and Data concept studies
54 Design of Power and Data connections
55 Detial Drawings
60 Software for power and data transfer
61 Contingency time for design
62 Build and test of critical path components
69 Project meeting
73 Assembly test and integration
81 Installation and test at sea
86 Bluefin testing of small AUV
89 Testing of WHOI vehicles(if available)
90 Project final reports and publications

# Office of Naval Research
# Docking Proposal
# William Kirkwood
# Budget sheet: Oct. 1, 2001 - Sept. 31, 2003

| A. SALARIES AND WAGES | Time requested (Hours) | Funds | Basis of Esti |
|---|---|---|---|
| 1. Senior Personnel | | | |
| a. Principal investigator | 800 | | engr estimate |
| 2. Other personnel | | | |
| a. Engineering time (Director) | 580 | | engr estimate |
| b. Mech Eng III | 1,200 | | engr estimate |
| c. S/W Eng IV | 1,200 | | engr estimate |
| d. Elec. Engineer II | 1,400 | | engr estimate |
| e. Post Doc | 2,080 | $37,000 | engr estimate |
| | **Subtotal Salaries** | **$233,192** | |
| **B. BENEFITS** | | | |
| 1. Fringe benefits on Salary (46.84%) | | $91,896 | |
| 2. Fringe benefits on Post Doc (35.84%) | | $13,261 | |
| TOTAL SALARIES, WAGES AND BENEFITS | | **$338,349** | |
| **C. EQUIPMENT > $5000** | | | |
| TOTAL EQUIPMENT | | **$0** | |
| **D. SUPPLIES and EQUIPMENT < $5000** | | | |
| Support equipment / expendables | | $10,000 | engr estimate |
| TOTAL SUPPLIES and EXPENDABLE EQUIPMENT | | **$10,000** | |
| **E. TRAVEL** | | | |
| 3 trips/ yr to Bluefin - 4 folks | | $31,176 | engr estimate |
| TOTAL TRAVEL | | **$31,176** | |
| **F. PUBLICATION AND DOCUMENTATION** | | | |
| Conference Publication | | $1,500 | engr estimate |
| Conference Fees | | $1,000 | engr estimate |
| TOTAL PUBLICATION | | **$2,500** | |
| **G. OTHER DIRECT COSTS** | | | |
| TOTAL OTHER DIRECT COSTS | | **$0** | |
| **H. PROJECT TOTALS** | | | |
| TOTAL DIRECT COSTS (A through G) | | **$382,025** | |
| INDIRECT COSTS (45% of A through G, excluding C) | | $171,911 | |
| **TOTAL COST of PROPOSAL** | | **$553,936** | |

MBARI Labor Cost Estimates by Statement of Work Tasks

| Work task | Hours | | S&B + Indirect Cost | |
|---|---|---|---|---|
| **Total Labor** | **7260** | **hrs** | **$** | **490,606** |
| ***Docking Development Phase I*** | ***3060*** | ***hrs*** | ***$*** | ***206,784*** |
| ***Concept Review*** | ***100*** | ***hrs*** | ***$*** | ***6,758*** |
| ***Desgin Process*** | ***2960*** | ***hrs*** | ***$*** | ***200,027*** |
| Concept Drawings | 850 | hrs | $ | 57,440 |
| Build and Test components | 860 | hrs | $ | 58,116 |
| Project meeting | 200 | hrs | $ | 13,515 |
| Dock Hardware Build | 350 | hrs | $ | 23,652 |
| Assembly and Integration with Tank Test | 260 | hrs | $ | 17,570 |
| Installation and Test at Sea | 320 | hrs | $ | 21,625 |
| Bluefin Field tests of Small AUV docking | 120 | hrs | $ | 8,109 |
| ***Docking Development Phaseli*** | ***4200*** | ***hrs*** | ***$*** | ***283,822*** |
| ***Development Plans*** | ***1250*** | ***hrs*** | ***$*** | ***84,471*** |
| Outline plans based on test restuls | 300 | hrs | $ | 20,273 |
| Modify Dock desings as needed | 500 | hrs | $ | 33,788 |
| Tank test of new dock | 200 | hrs | $ | 13,515 |
| Design Review fo Power and Data Transfer | 250 | hrs | $ | 16,894 |
| ***Designing of Power and Data Connectior*** | ***1950*** | ***hrs*** | ***$*** | ***131,774*** |
| Detail Drawings | 750 | hrs | $ | 50,682 |
| Software for Power Transfer | 800 | hrs | $ | 54,061 |
| Contingency Time | 100 | hrs | $ | 6,758 |
| Build and Test Critical Path components | 300 | hrs | $ | 20,273 |
| ***Project Meeting*** | ***160*** | ***hrs*** | ***$*** | ***10,812*** |
| ***Assmebly and Integration with Tank Test*** | ***160*** | ***hrs*** | ***$*** | ***10,812*** |
| ***Installation and Test at Sea*** | ***320*** | ***hrs*** | ***$*** | ***21,625*** |
| ***Bluefin Field tests of Small AUV docking*** | ***80*** | ***hrs*** | ***$*** | ***5,406*** |
| ***Testing of WHOI vehicles (MBARI cost sha*** | ***0*** | ***hrs*** | ***$*** | ***-*** |
| ***Project Final Reports and Publications*** | ***280*** | ***hrs*** | ***$*** | ***18,921*** |

**Travel Estimates**

| | FY 02 | FY 03 | FY 04 |
|---|---|---|---|
| Air Fare | $ 1,700.00 | $ 1,800.00 | $ 1,900.00 |
| Per Diem | $ 266.00 | $ 266.00 | $ 266.00 |
| Number of Trips | 1 | 1 | 1 |
| Number of Attendees | 4 | 4 | 4 |
| Number of days /trip | 3 | 3 | 3 |
| **Cost** | **$ 9,992.00** | **$ 10,392.00** | **$ 10,792.00** |

**Total Travel $ 31,176.00**