EXECUTIVE SUMMARY

In February 1993, DoD technical needs, combined with ocean technology capability in Hawaii, yielded the National Defense Center of Excellence for Research in Ocean Sciences (CEROS). CEROS was established through a grant from the Defense Advanced Research Projects Agency (DARPA) to the High Technology Development Corporation (HTDC), an agency of the State of Hawaii attached to the Department of Business, Economic Development and Tourism (DEBDT). CEROS was funded

> **". . . for the purpose of conducting research and development activities of interest to the Department of Defense . . . and . . . to support and stimulate a broad spectrum of research in ocean science in the State of Hawaii."**

DARPA awarded MDA 972-94-1-0010 for $5,000,000 to HTDC for CEROS in May 1994. Total funding to CEROS for Grant No. MDA 972-94-1-0010 was approximately $18,737,796. This grant supported a core program of thirty-nine projects involving nineteen prime contractors during CEROS FY94, FY95, and FY96. All contracts were complete by the end of June 1999. This report describes the work done under the 1994 grant. Following is an outline of individual projects in the core program, and more detailed information is available in chapters 2 through 27 of this report.

- **Alliant Techsystems, Inc., now Raytheon Systems Company, Mulkilteo, Washington. -** *High-Resolution Bottom-Penetrating Acoustic Sensors and Signal Processing Algorithms for Reduction of False-Alarm Probability in UXO Hunting -* **Contract Nos. 38107, 39570, 41401 for $980,766, $990,083, $982,087 in FY94, FY95, and FY96, respectively.**

This project demonstrated increased resolution and reduced false alarm rates for a synthetic aperture sonar (SAS) added to the HAWAII MR-1, a towed sonar array and data processing system owned by the Hawaii Institute of Geophysics. SAS technology uses the forward motion of a small physical array to synthesize a much larger array. The long synthesized array produces a much higher along-track resolution and signal to noise ratio (contrast) than that of the physical array alone. Using SAS technology, the along-track resolution can be made constant independent of frequency and range. As a consequence, lower operating frequencies (lower absorption) can be used in an SAS to increase range or to penetrate the bottom without compromising resolution. This is the first known use of SAS techniques to image buried objects.

During the first year of funding, the data quality suffered from excessive towbody movements caused by the ship's movements. In subsequent years, the towbody was reconfigured to operate either as a heavy tow, or as a neutral tow that decouples the towbody from the ship's motions in heavier seas.

The system was improved significantly from FY94 to FY96. The improvements allow forming a SAS image equivalent to a 9m array which is a 6-fold improvement over the original 1.5m array. The FY96 system gives more resolution, more contrast, and detection of the deepest buried cylinder (2m). The SAS images achieve the 20cm limit set by the array spacing. The simulation results predict "resonances" in man-made cylindrical objects. With the SAS system it is possible to detect these resonances for the targets on the bottom.

The technology has wide potential application and relates directly to emerging programs in mine countermeasure technology at the Office of Naval Research and advanced sonar development at ARPA. Hawaii involvement is very high and potential residual benefits to Hawaii are great. The original contract was let to Alliant Techsystems which was purchased by Hughes Aircraft Company in March 1997. In December 1997 Hughes merged with Raytheon Systems Company.

- **Aquaculture Technology, Inc. Honolulu, Hawaii -** *Naturally Occurring Antibodies From Marine Algae Chaetoceros* **- Contract Nos. 38080 and 39604 for $171,485 and $206,960 in FY94 and FY95, respectively.**

In a breakthrough discovery, Aquaculture Technology, Incorporated (ATI) has isolated some naturally-occurring antibacterial compounds from the marine algae *Chaetoceros spp.*. **Aquaculturists had observed that certain algae could be maintained in a pure culture without the addition of antibiotics. Dr. Wang hypothesized that something in the alga itself acted as an antibiotic to prevent growth of other organisms. He identified several polyunsaturated fatty acids in the chemical composition of** *Chaetoceros spp.*. **He then demonstrated that these compounds are effective against** *Vibrio vulnificus*, *Listeria monocytogenes*, **methicillin-resistant** *Staphylococcus aureas,* **vancomycin-resistant** *Enterococcus* **and other bacteria in** *in vitro* **tests. ATI contacted Tripler Army Medical Hospital in Honolulu and Walter Reed Army hospital in Washington to review research methods and results.**

The discovery of new antibacterial substances from marine algae provides at least two avenues for commercialization: to license the production of the antibiotic, and to supply the algae to the pharmaceutical company for the production of antibiotics.

These compounds are nearly impossible to synthesize, so large quantities of *Chaetoceros spp.* **will need to be grown for drug production. Dr. Wang developed a revolutionary open system for large-scale production of marine microalgae without innoculation. The continuous marine algae production system will have applications beyond the supply of algae for medical purposes. Marine microalgae provide many important industrial products like food pigments and biosurfactants with billion dollar world markets.**

- **Detection Limit Technologies, Inc, Kailua, Hawaii. -** *Design and Deployment Of A Fiber-Optic Based Autonomous Buoy For In-Situ Monitoring Of pH, pCO2, Temperature, O2, and Water Quality In Seawater (Phase II); Solution+ In-Situ Ocean Sediment Chemical Analyzer* **- Contract Nos. 38194 and 41282 for $331,800 and $320,000 in FY94 and FY96, respectively.**

Detection Limit Technologies, Inc. (DLT) demonstrated for the first time the ability to detect oxygen in seawater based on the molecular composites incorporating tailored excited states of transition metal complexes and thin mono and multilayer films. To achieve this breakthrough technology, DLT developed a unique metal coating for the sensor. DLT developed a new palladium-porphyrin complex, immobilized a platinum porphyrin in a film of polycarbonate on a fused silica surface, and demonstrated oxygen sensitivity behavior of the coating. The dye is not susceptible to photobleaching and is particularly amenable to low-power, diode-based laser sources that would be required to use the instrument on a robust, remote ocean data buoy. This development allowed DLT to use Raman spectrographic techniques to measure oxygen. The original plan to deploy and test instruments on a buoy purchased from Woods Hole Oceanographic Institution was modified because of delays at Woods Hole in buoy development. DLT demonstrated alternative test scheme using instruments deployed from Makai Research Pier, Waimanalo, O'ahu in December 1995.

In FY96, DLT improved the *Solution* **instrument by adding a fluorescence mode to the Raman system. The improved instrument, trademarked** *Solution+,* **incorporated an ultraviolet excitation capability that allowed collection of Raman and fluorescence data simultaneously. The fluorescent capability increased the instrument's capability to detect additional classes of hydrocarbons (e.g. phenols) and to monitor and map site contamination directly using sediment probes. DLT developed stable Raman surfaces that could detect TCE in the 10 ppm range without interference from fluorescence, and to detect particular heavy metals down to 50 ppB. The** *Solution+* **is a rugged and versatile instrument with applications in environmental monitoring, process control, and teaching. DLT miniaturized the probe of the** *Solution+* **to fit into the SPAWARSYSCEN cone penetrometers to assess environmental contamination at DoD sites in an efficient and cost-effective manner. DLT has used CEROS developmental support to develop a variety of specialized measurement and control instruments based on the** *Solution* **and** *Solution+* **prototypes.**

DLT is actively marketing the commercial versions of the *Solution* and *Solution+* instruments for diverse applications.

- **Gateway Technology International, Inc. Honolulu, Hawaii -** *HIRADSIM Workstation Development Project. Continuation of Existing Work Advanced HIRADSIM Small Target, Time Domain, Maritime Radar Mode* - **Contract No. 38108 for $250,000 in FY94.**

Hawaii Radar Simulator (HIRADSIM) is an engineer's radar detection slant tracker design tool. The HIRADSIM model runs on a IIP UNIX or an HP 712/60 workstation and is mostly written in C+ except for the radar cross-section model, which is written in FORTRAN. The output of the model provides a radar engineer with the ability to make predictions of received radar-signal strength as a function of various marine environments including rain and sea state. The model is a basic research tool to help design better radar-detection technology for the small targets like instrument masts (periscopes), small boats, and ships that have special wake considerations. Gateway Technologies International Incorporated (GTII) validated the HIRADSIM model and demonstrated the model's effectiveness on a workstation platform, to realize the advances made in radar sensor data fusion and environmental modeling in the FY93 program. Work focused on practical applications of HIRADSIM and included comprehensive tests, evaluations, and demonstrations for qualified technical observers. GTII developed the graphical user interface and integrated it in the workstation. HIRADSIM was tested at the Pacific Missile Test Facility in conjunction with large-scale radar evaluations conducted by NRaD, San Diego laboratory. The workstation-oriented, time domain radar simulator has been improved with a larger area of consideration and reduced computational time (4 to 5 times faster). HIRADSIM demonstrates credibility and internal program capability for GTII and CEA Technologies, Inc., and commercialization is possible for specific applications. GTII and CEA Technologies, Inc. met both the technical and commercial objectives of this effort, namely developing an advanced radar simulator.

- **Innovations Hawaii, Inc. Honolulu, Hawaii -** *Extended-Source Apparent Motion (E-SAM) Lighted Signals for Protection of the Marine Environment* - **Contract No. 38195 for $177,180 in FY94.**

Innovations Hawaii, Inc. built and tested a pre-production prototype range light system based on the Extended-Source Apparent Motion (E-SAM) principle. E-SAM features a vertically-oriented array of sequentially operated optical flashtubes mounted on a central support tower (two towers for a range light system). When the lights are flashed in sequence they look like a moving light to a human observer, a phenomenon called Apparent Motion. This makes the light extremely conspicuous to the observer, particularly in the peripheral vision field.

Field tests conducted by Innovations Hawaii with experienced mariners as human observers at the entrance to Honolulu Harbor demonstrated that the E-SAM system is highly conspicuous, even against dense background shore lighting. Innovation Hawaii's use of flashtubes in the E-SAM also demonstrated a superior technological advance over the incandescent bulbs used by the Coast Guard in the majority of aids to navigation.

In this follow-on project also supported in FY93, Innovations Hawaii improved the design, assembled a pre-production working model, and tested it in the field. The E-SAM system's superior conspicuity was clearly demonstrated in the tests. Although the Coast Guard has professed no intention to pursue development of extended source light systems, Innovations Hawaii presented plans to discuss their specific results with Coast Guard technical representatives with a goal of further demonstrations of the E-SAM system. Innovations Hawaii provided a complete project summary to the Coast Guard R&D Center, Gorton, CT and the Coast Guard Office of Engineering in Washington, DC. There are several DoD applications for E-SAM technology, including mobile range or marking systems, mine field marking or navigation aids, and troop guidance on land. A provisional patent is being maintained.

- **KnappEngineering, Inc. dba Structural Solutions, Inc. Aiea, Hawaii -** *Finite Element Design of Cables* - **Contract No. 41490 for $145,000 in FY96.**

Knapp Engineering, Inc, doing business as Structural Solutions, developed the first finite element-based computer-aided design tool for cables. The resulting computer-aided design program is named CableCAD®.

The CableCAD® code consists of 3 modules: a finite layer solver; a new finite element solver; and graphical pre- and post-processors. The CableCAD® program was written for personal computers that use either the Microsoft Windows 95 or Windows NT operating systems. The CableCAD® preprocessor was written to simplify creation of finite element cable models. The principal feature of the preprocessor is an interactive graphical database that provides libraries of wire geometries and user-defined components. The graphical environment accelerates the modeling process and improves the accuracy of results. The CableCAD® post-processor produces plots of cable reactions and deformations that provide insight into cable performance and indicate potential design improvements.

Eighteen verification problems were solved with the CableCAD® program, and the CableCAD® predictions agreed well with results presented in the reference literature. The CableCAD® software is expected to advance cable design and manufacturing and prove especially useful in assessing cable performance during handling operations.

As a result of this project, finite element analysis for cable design is commercially available to the defense, scientific and commercial oceanographic cable communities. The CableCAD® software is being produced and sold from Hawaii. Structural Solutions estimates that several hundred cable and rope manufacturers and users will have immediate interest in the CableCAD® software product that was released on the market in Spring, 1999.

- **Knapp Engineering, Inc. dba Structural Solutions, Inc. Aiea, Hawaii.** *Low-Cost Prebuckled Cylindrical Pressure Hulls.* **Contract No. 38110 for $571,000 to Knapp Enginneering, and Contract No. 38203 to Oceanit Laboratories, Inc. for $91,000 in FY94.**

The FY94 effort built upon results of FY93 programs to further evaluate the commercial potential of polyhedrally-stiffened (prebuckled) cylindrical (PC) pressure hulls. The technical program from Knapp Engineering, Inc. (KEI) emphasized further development of the low-cost PC hull concept including detailed design, material selection, construction, and testing directly related to manufacturing and potential commercial applications. The goal of the project was to produce PC hulls that operate at 1500 foot depths and cost under $2500 each.

The result is the PC Hull™, a polyhedrally-stiffened cylindrical pressure hull. The PC Hull™ provides several advantages over traditional ring-stiffened smooth cylinders like a lower manufacturing cost, and a high buckling strength with a depth rating 2.5 times or greater than an equivalent smooth hull.

Knapp Engineering, Inc. applied computerized finite element analysis to determine the best shape for the PC Hull™. The optimal geometry depends on the properties of the composite material chosen for manufacturing. After extensive materials testing and considering both performance and cost, E-glass/epoxy was chosen. The finite element analyses selected a polyhedral geometry with an isosceles triangular facet. The shell surface is composed of six circumferential and six axial triangular facets. The designs were optimized to use the least amount of material for a hull to withstand the pressure at the design depth. The computerized studies predicted that a 0.5 inch thick polyhedral shell wall of E-glass/epoxy would withstand the hydrostatic pressure at a water depth of 1700 feet. The design effort focused on a generic AUV application with measurements of 21 inches diameter and 40 inches long.

Next, various manufacturing methods were studied for effectiveness and cost. KEI chose a filament winding process around an inner mandrel with a clamshell outer mold. Although structural imperfections occurred during prototype manufacturing, since the manufacturing process itself was also a prototype, all prototypes surpassed the computerized predictions. The prototypes were tested at Southwest Research Institute in San Antonio, Texas. When compared to an equivalent smooth hull, the prototype PC Hull™ operated at 2.5 times or greater depths.

Oceanit Laboratories, Inc. (Oceanit) conducted tow tank tests on a prototype to measure hydrodynamic properties of the PC Hull. The data compared well to computerized predictions run by KEI. Although the results show a 60% increase in axial drag over a comparable smooth cylinder, an external smooth fairing could be added to reduce drag.

In addition to increased pressure strength, several factors make the PC Hull™ less expensive to manufacture. Whereas the smooth cylinder must be formed accurately into a circular arc, the PC Hull™ can be formed by less critical molding techniques. Also, because the PC Hull™ is an inherently stiffened cylinder, the stiffening rings used in smooth cylindrical hulls are unnecessary.

The patented PC Hull™ has many uses. Defense applications include autonomous underwater vehicles (AUVs), torpedoes, antisubmarine warfare (ASW) target trainers, and sonobouys. Commercial applications include pressure housings for AUVs, remotely operated vehicles, submersibles, and ocean instrumentation.

A paper on the PC Hull concept was presented at the International Society of Offshore and Polar Engineering (ISOPE) Conference in Honolulu. U.S. Patent # 5,711,244 patent was awarded in January 1998, and KEI established the PC Hull trademark name through use. No commercial sales have resulted to date.

Located in Aiea, Hawaii, Knapp Engineering, Inc. is now called Structural Solutions, Inc..

- **Makai Ocean Engineering, Inc. Kailua, Hawaii -** *Development of a Cost-Effective GPS-Based Sensor for Measurement of Heave, Pitch, Roll and Heading on Oceanographic Platforms (Phase II)* - **Contract No. 38102 for $235,000 in FY94.**

The project developed and tested a sensor that measures roll, pitch, and heading of a platform using short baseline interferometric processing of signals collected from a compact array of GPS receivers. The sensor is intended for use in oceanographic applications where precise measurements of platform rotation are required *e.g.* survey vessels or directional wave buoys. Market analysis indicated a wide potential for commercial applications on ships.

Makai Ocean Engineering, Inc. (MOE) produced a GPS attitude sensor based on results from their CEROS FY93 Core project. The rugged, reliable prototype achieved an accuracy of 0.3 degree rms for the three attitude rotations using low-cost GPS receivers. To attain 0.3 degree resolution of roll and pitch, MOE used a 3 antenna array with 2 meter spacing. A model was developed to predict the performance of various 3 antenna configurations. MOE demonstrated the prototype system on the *R.V. Moana Wave*, an oceanographic research vessel operated by the University of Hawaii. The ship was at sea about half of the three month test period.

Software upgrades produced a sensor capable of tracking up to eight GPS satellites yet able to produce accurate results from as few as three. The sensor accepts a variety of antenna configurations and can work with either a gyrocompass or fluxgate compass to further reduce false solutions. Interface improvements make the system "user friendly."

MOE and the University of Hawaii Department of Ocean Engineering used results from this project to apply for and receive a FY96 Department of Defense (Army) Small Business Technology Transfer (STTR) award entitled "Development of a GPS Directional Wave Buoy". The resulting instrument produced significantly improved directional wave spectral data. The Army invited MOE to submit a proposal for a Phase II upgrade.

- **Makai Ocean Engineering, Inc. Kailua, Hawaii -** *Design, Construction, and Operation of a 50 kW Closed Cycle OTEC Plant and Application of Results to the Design of a One Megawatt OTEC Plant* - **Contract No. 38985 for $649,759 in FY94.**

This project was competed under the ARPA Mobile Offshore Bases BAA and the award was assigned to CEROS for management. The two-phase project sought to further the development of Ocean Thermal Energy Conversion (OTEC) technology. Phase I involved advanced R&D of the design, construction, and operation of a 50 kW closed-cycle (CC) OTEC plant at the Natural Energy Laboratory of Hawaii Authority (NELHA) facility. For Phase II, Makai Ocean Engineering would produce the conceptual design of a one megawatt CC-OTEC plant using the design and operational experience of the 50 kW plant. MOE

completed design of the 50 kW CC-OTEC plant and worked with PICHTR and NELHA to construct the plant.

Heat exchanger failure occurred in July 96 because of corrosive pitting to aluminum surfaces. MOE took an aggressive analytic approach to identify the specific causes of failure. The heat exchanger modules were returned to the manufacturer for further analysis, refurbishment, and repair. MOE investigations indicated that compounds released from the nitrile spacer pads in the heat exchangers may be significant factors in the corrosive failures. MOE worked with NELHA to maximize return from investment in CC-OTEC technology. Final report for the Phase I part of the project submitted in November 1996.

MOE delivered a report on the Design Basis and Rationale for a One MegaWatt Closed Cycle OTEC Plant in February 97. This report defines major plant subsystems in a preliminary plant design and is the first deliverable of the second phase of the CEROS-contracted effort. Important design constraints and assumptions are discussed for each subsystem and for the entire, integrated plant.

MOE developed a plan to reconfigure and operate the 50 kW CC-OTEC plant at NELHA using refurbished condenser modules and submitted the plan to the CEROS Research Advisory Board in March 97. This "rescue plan" included single module tests to meet original CEROS and (D)ARPA project goals. The RAB endorsed the proposal and the NELHA Board of Directors authorized up to $200k in additional funding to support the effort. For a time, MOE suspended design and procurement actions for proposed plant modifications pending resolution of the panel refurbishment issues. Replacement heat exchanger panels were delivered to NELHA in October 1998 and PICHTR began reassembling the plant in spring 1999. As of the date of MOE's interim final report, MOE expected to gain access to the plant for its final tasks later in 1999.

- **Makai Ocean Engineering, Inc. Kailua, Hawaii -** *Development of an Automated Control System for Deployment of Small Diameter Cables and Towed Bodies; Loop Avoidance Control for Submarine Cables* - **Contract Nos. 38111 and 41526 for $325,000 and $287,000 in FY94 and FY96, respectively.**

Led by Makai Ocean Engineering, a new generation of cable control software has come on the market. This software is able to account for the integrated time history of the cable lay and to calculate things like bottom tension, slack, and the shape of the cable in the water column, especially near the bottom. The system controls vessel course and speed, cable pay-out rate, solves the linear relationship, and forecasts what action is necessary to achieve desired cable placement. One focus is to minimize errors in "cable touchdown", *i.e.* **variations in the actual versus preplanned positions. The mathematical model behind this software is based on the "catenary" solution, or zero stiffness model, where the only force in the cable is tension which (by definition) acts along the axis of the cable. Prior to this project this software did not account for twist and torque developed prior to and during the lay.**

The results from this project suggest that a reasonably accurate prediction of cable loop formation under specific lay conditions can be provided. Furthermore the inclusion of stiffness into the cable model opens up a new area of market in the pipeline deployment field. Relatively simple measurements on cable can provide parameters that will allow prediction of cable loop formation to a reasonable degree of accuracy.

The final product is being marketed to DoD and commercial customers. When MOE sold and delivered a Cable Lay Simulator to Nippon Telephone & Telegraph in 1996, the software modifications to make the simulator more "user friendly" for NTT were applied to the CEROS effort.

- **Mission Research Corporation. Torrance, California -** *Ocean Doppler Lidar* - **Contract No. 40323 for $381,000 in FY95.**

In preliminary trials at a University of Hawaii facility, Mission Research Corporation demonstrated a new way to detect underwater moving objects at long range in shallow waters. For the first time, underwater moving targets were detected with a laser radar (lidar) using their Doppler signature. MRC developed a novel Moving Target Indicator (MTI) filter that rejects ocean optical clutter so Doppler

processing can be used to reject backscattered energy while passing the light scattered from moving objects.

Mission Research Corporation demonstrated the Ocean Doppler Lidar at the J.K.K. Look Laboratory Optical Test Range operated by the University of Hawaii at Kakaako Penisula, Oahu. Researchers observed unmistakable lidar signatures from an underwater moving belt target at 300 m range and 5 m depth. This initial detection of an underwater moving object with a laser achieved over 15 dB target-to-clutter ratio at shallow grazing angles. Previous tests at NRaD in 1978 achieved a 0.8 dB ratio. The results demonstrate that the Doppler filter is capable of rejecting clutter and passing the target signal, in ocean field conditions, thereby confirming the utility of the Ocean Doppler Lidar.

If verified, proven, and developed to a systems level, the Ocean Doppler Lidar concept could provide a means of long-range shipboard detection of underwater moving objects, such as torpedoes or, possibly, submarines.

- **Neptune Technologies, Inc. Kailua, Hawaii -** *Diver Homing Device* **-Contract No. 40295 for $200,000 in FY95.**

Neptune Technologies, Inc. designed, built, and field tested a prototype electro-acoustic system that allows a diver to home on an ultra-sonic transmitter. To improve directional sensitivity, the device is designed to use the diver's body and equipment as an acoustic shield.

The receiver and transmitter are compatible with other diver-carried accessories. An indicator light on the receiver illuminates only when the diver is aligned with the transmitter. The transmitter is small enough to be moved by a diver. The Diver Homing Device has an effective range of at least 20 times dive depth for depths not exceeding 25 meters; the maximum design range is 500 meters. Both transmit and receive units are powered by self-contained batteries with a minimum lifetime of 10 hours per unit.

A particular feature of the Diver Homing Device is the design that uses the diver's body and equipment as an acoustic shield to increase directionality. Neptune Technologies noted, however, that multipath reflections and reverberation from the sea surface or bottom may reduce directionality for some sea or bottom conditions. Several simple techniques were tried to adjust transmitter output to minimize reverberation and maximize directionality for various environmental conditions. Overall, the device proved efficient for a wide range of environments and conditions.

The Diver Homing Device met or exceeded all performance requirements and contract specifications. Neptune Technologies is preparing to test the device further in "real world" situations, with an eye toward commercialization and production of a final product. Neptune Technologies received a United States patent for technologies related to this CEROS-sponsored demonstration project.

- **Ocean Engineering Consultants, Inc. Honolulu, Hawaii -** *SWATH Motion/Structural Software Developmen* **- Contract Nos. 38081, 40464, and 41366 for $121,000, $168,000, and $161,372 in FY94, FY95, and FY96, respectively.**

Ocean Engineering Consultants, Inc. created and/or adapted engineering design software code to design and test Small Waterplane Area Twin Hull (Swath) ships. With funding in CEROS FY94, FY95, and FY96, OEC sought to develop and validate a software tool to calculate and visualize flow patterns around and in the vicinity of a Swath-type hull. OEC conducted an integrated software development to create a "numerical tow tank" for Swath and multi-hull vessels, to extend software capabilities, test and verify the software, and to provide a preliminary guide for finite element models. The software package has three analytic options: quasi-static, hydro-elastic, and rigid-dynamic. It is particularly useful for critical placement and flow alignment of hull appendages, and for analyzing Swath vessels in special situations, such as close running with another vessel or oceanographic instrument deployment. This sophisticated software decreases the time and cost necessary to design faster, more stable ships for the military and civilian markets. Ocean Engineering Consultants, Inc. markets its engineering design services worldwide and features Swath ship designs with its advanced software tools.

- **ORINCON, Hawaii, Inc. Kailua, Hawaii -** *Underwater Echolocation for Buried Objects* **- Contract Nos. 38082 and 39503 for $652,685 and $696,926 in FY94 and FY95, respectively.**

This three-year effort by ORINCON Corporation and the Hawaii Institute of Marine Biology (HIMB) of the University of Hawaii focused on attaining "dolphin-like" echolocation performance to detect and classify buried objects in cluttered environments using a prototype, real-time, automated broadband active sonar system. The ORINCON team defined dolphin echolocation performance criteria, developed the biomimetic signal and information processing system to match that performance, and demonstrated the system integrated on a bottom-crawling remotely operated vehicle (ROV). The real-time signal processing was performed with proprietary ORINCON software and commercial off-the-shelf (COTS) hardware provided to HIMB by the Office of Naval Research.

During this effort, ORINCON also implemented a signal processing model based on the dolphin cochlear system and quantified the model's performance. Overall, ORINCON demonstrated (1) that their biomimetic signal and information processing system could -- in real-time -- effectively represent, detect, and classify underwater echolocation returns from objects located on the bottom or buried in the sediment; (2) that a multifeature fusion classification system can achieve a level of performance greater than that of an individual feature-based system; and (3) that models, such as those based on wavelet transform and the dolphin cochlea, show particularly promising signal representation capabilities.

- **ORINCON Hawaii, Inc. Kailua, Hawaii -** *Advanced Real-Time Signal Processor* **- Contract Nos. 39571 and 41487 for $862,095 and $871,771 in FY95 and FY96.**

ORINCON Hawaii, Inc. provided automated mission support tools to improve the tactical sonar system capabilities available to the Commander Submarine Forces Pacific (COMSUBPAC). Additional functional capabilities, requested by COMSUBPAC, were developed and integrated into the ARTS processor. The ARTS processor is a compact, powerful, real-time signal and information processing system that was developed by ORINCON Hawaii, Inc. using commercial, off-the-shelf (COTS) hardware. Interfaced to submarine sensor systems, ARTS provides full azimuth, real-time display and alert of passive acoustic signals for U.S. Navy submarines. Sea tests on a Pacific Fleet submarine resulted in very positive feedback. Follow-on funding in later years transitioned the product from water to the air for the Maritime Patrol Aircraft.

- **ORINCON, Hawaii, Inc. Kailua, Hawaii -** *Submarine-Launched, Two-Way, Fiber Optics Linked Communications Buoy* **- Contract No. 41941 for $160,000 in FY96.**

This project addressed a generalized Navy need to provide capabilities to enable undersea platforms to communicate with war fighting commanders and Navy surface and air elements while remaining at operating depths. The need is for wide-band, two-way communications between the submarine and surface or air elements. In this CEROS-supported effort, ORINCON Hawaii and their subcontractor Sippican Corporation sought to demonstrate the feasibility of providing an optical fiber link to enable communications between a submarine operating at depth and an antenna buoy at the ocean surface. The effort included a feasibility study of optical fiber links, a spectral trade-off analysis to maximize performance, and a packaging study to show that the subsystem required could fit within the submarine signal ejector volume. The principal focus of the effort was to modify an AN/BRT-6 transmit antenna and demonstrate its radio frequency functionality. The antenna's functionality was demonstrated in June 97. The results of this effort point the way to a follow-on project to address critical submarine data processing and communication system requirements. Such a project was funded in the CEROS FY97 Core program.

- **Pacific Marine & Supply Co. Honolulu, Hawaii -** *Tri-strut Ship Research, Development and Test Model: MidFoil* **- Contract Nos. 38242 and 39797 for $365,400 and $780,000 in FY94 and FY95.**

Pacific Marine & Supply Co. combined funds from CEROS, the Hawaii Electric Vehicle Development Program, and MARITECH of DARPA to design, test, and build a manned model of a new ship design called "MidFoil." Rather than a traditional v-hull or even a catamaran-style SWATH, the MidFoil has a foil-shaped body placed amidships to provide displacement. CEROS supported the computerized design and testing with computational fluid dynamics, small-scale physical model tests, and construction of the unique foil for the 65-foot manned model. The 50 ton vessel was launched in Honolulu Harbor in January 1998 and ran successfully. The vessel exhibits an extremely smooth, stable ride even in rough seas and at speeds over 20 knots. The design can be scaled up to 10,000 tons for various DoD applications and commercial applications like shipping and ferries. Results have direct application to ARPA and ONR advanced fast ship programs. Benefits from the Tri-Strut effort were applied to the Pacific Marine SLICE program.

- **Sea Engineering, Inc. Waimanalo, Hawaii -** *Development of a Technique to Identify Pollutant Sources and Impacts in Coastal and Oceanic Waters* **- Contract No. 38103 for $146,000 in FY94.**

Sea Engineering, Inc. with subcontractors from CalTech studied whether Inductively Coupled Plasma Mass Spectrometry (ICP-MS) could be used to measure freshwater discharges into saline coastal waters in Hawaii. Although previous work had applied ICP-MS to fresh and slightly saline waters, this was the first trial of the technique on samples from fully saline or oceanic waters. The ICP-MS technique is capable of identifying elements and suites of elements in discharge sources. However the unique spectral "fingerprints" that have been identified for mainland streams and rivers were not found in stream samples from O'ahu. Furthermore, the low concentrations of elements in the O'ahu discharges were masked by high concentration of "salt" ions in saline samples. Differences in rare earth elements between freshwater and saline samples provided a "reverse tracer" that enabled Sea Engineering to develop an accurate measure of dilution to trace effluent discharge plumes in the ocean. The project provided important fundamental data for applying the powerful ICP-MS technique to oceanic environments.

- **Sea Engineering, Inc. Waimanalo, Hawaii -** *Development of a Broad-band FM Sub-bottom Profiler for Seafloor Imaging and Sediment Classification* **- Contract No. 38109 for $223,870 in FY94.**

This work demonstrated the function and utility of the broadband FM sub-bottom profiler developed with FY93 CEROS support. Sea Engineering developed and tested a state-of-the-art broadband, sub-bottom acoustic profiling system for shallow water surveys. The system provides rapid and accurate bottom classification and characterization. It is uniquely capable of distinguishing consolidated and unconsolidated coral sands, as demonstrated during field tests off Waikiki Beach. The contractors developed expert system classification rules and interactive interface for the subbottom profiler system. The classification algorithms were upgraded using fuzzy logic rules. The profiler was delivered from Florida, assembled and tested in four diverse areas; sand deposits not previously imaged were identified. This development extends technology applied at NUSC and for NRL Benthic Boundary Layer program. Sea Engineering seems to be developing a "breakthrough" technological tool for commercial application in the Pacific. In May 1996, the Geological Survey of the United States Department of the Interior contracted with Sea Engineering to survey sediment deposits in Kailua Bay, O'ahu using the profiler. The survey's chief scientist acknowledged the Sea Engineering system as providing excellent records to support deposit volume, composition, and history estimates.

- **Science & Technology International, Inc. formerly SETS Technology. Honolulu, Hawaii -** *Hyperspectral Remote Sensing (AAHIS) for Maritime Applications: Phase II* **- Contract No. 38101 for $647,974 in FY94.**

In this project, SETS Technology, now known as Science & Technology International (STI), developed the first hyperspectral sensor system with the required signal-to-noise ratio (SNR) and spatial and spectral resolution adequate for advanced maritime applications. During the first phase of the project, a flight-tested, visible/near-infrared (430 to 840 nm) hyperspectral imaging system was optimized for use in maritime applications—advanced airborne hyperspectral imaging system (AAHIS). The AAHIS system offers the ability to do high-speed, wide-area surveillance from an airborne platform.

Under CEROS FY93, STI adapted its proprietary signal-processing scheme into a prototype airborne hyperspectral imaging system for near-shore surveillance and mapping for marine applications. The FY94 effort focused on improving the resolution of the advanced airborne hyperspectral imaging system (AAHIS), and demonstrated the system's capabilities. STI increased the search rate, resolution, and accuracy of the AAHIS system and demonstrated specific applications. STI increased spatial resolution five-fold, incorporated image stabilization into the AAHIS flyaway package, provided on-board real-time spectral image processing, and integrated differential GPS with a geographic information system.

The AAHIS flight navigation system was completed, and high resolution AAHIS data were collected from Kaneohe Bay. A mirror stabilization system for AAHIS was developed by SETS to meet project schedules and deadlines. SETS has "captured" a technology from SAIC and developed it within a specific maritime, littoral niche. DoD demonstration of AAHIS technology application being coordinated through the Navy Technology Insertion Program (NTIP). Based on the work sponsored by CEROS, STI has secured over $10 million in funding from other federal sources to continue development of AAHIS-related projects.

- **Science & Technology International, Inc. formerly SETS Technology. Honolulu, Hawaii -** *Grazing Angle Imaging Lidar (GAIL) for Organic Mine Countermeasure* **- Contract No. 41357 for $698,277 in FY96.**

SETS Technology, Inc., now known as Science & Technology International (STI) developed and demonstrated a prototype "grazing angle" (4 to 6 degrees below horizontal) imaging LIDAR system for detecting and discriminating objects in shallow water. This prototype mine countermeasure system is based on the LIDAR return of pulsed LASER light at near incident grazing angles to the sea surface.

As part of the CEROS-sponsored effort, STI performed a mission analysis and concept definition study for grazing angle LIDAR systems. STI contends that a system such as GAIL could function as an "organic" (that is, own ship) mine countermeasure system for escort ships in a battle group, on landing craft, or as part of a point defense system ashore or afloat.

In addition to the system concept definition study STI, assembled a "breadboard" system, tested the system at NELHA, and developed a top-level system description for an operational GAIL MCM system. The resulting system model identifies the landing craft mounted system as the leading candidate for a "real world" GAIL application.

During tests at NELHA, the breadboard GAIL system demonstrated single pulse detection of mine-like targets in clear ocean water to depths of 65 feet. STI reports that greater detection depths would be possible with more elaborate real-time signal processing for the signals. For the tests, the prototype system used a frequency-doubled flashlamp pumped Nd:YAG laser from Big Sky Laser with maximum output energy at 532 nm wavelength of 125 microjoules per pulse. The laser operated at a pulse repetition frequency between 10 and 30 Hz. STI developed and installed a unique "haul down" mooring system to test the GAIL prototype at NELHA. STI conducted the proof-of-concept testing at NELHA efficiently and in full compliance with FAA, Coast Guard, and environmental regulations.

The STI effort showed that the GAIL system concept is practical and that the preliminary system model is valid. Results are sufficient to support development of a prototype sensor system. However, STI also recommends further testing to refine the system concept for operational utility.

- **Science & Technology International, Inc. formerly SETS Technologies. Honolulu, HI -** *Dual Mode Fluorescence Imaging for Maritime Applications* **- Contract Nos. 39496 and 41365 for $894,976 and $996,428 in FY95 and FY96.**

SETS Technology, now known as Science & Technology International (STI), proposed to develop and demonstrate a dual mode, multi-spectral fluorescence imaging system (DFI) for through-the-surface and subsurface maritime applications. The DFI system would be the first to use both ultraviolet and visible wavelengths in a dual mode (reflectance and fluorescence) imaging system. The goal of the DFI is to provide quantitative, nondestructive remote discrimination and characterization of marine and littoral zone phenomena. Targeted missions include assessing coral reef health, mapping and dectecting benthic pollutants, tracking contaminant streams, mapping plankton, mapping fish, and mine and unexploded ordinance detection/discrimination. The phase I work included: (1) design and assemble the DFI system; (2) collect through-the-surface and subsurface multispectral reflectance and fluorescence data from a variety of targets; (3) develop spectral discrimination algorithms; (4) develop spectral detection and characterization algorithms; and (5) validate the DFI model in Pearl Harbor and Kaneohe Bay. STI configured the DFI system to perform both laser-generated DFI and passive hyperspectral imaging from the same "pushbroom" configuration. A supplemental agreement extended the effort to provide for demonstration of system in coral reef assessment project, and an additional $100k was provided by CEROS to support demonstration (total project funding = $895k).

The phase II work plan included several system upgrades, and the integration and field-testing of the system on a helicopter. During the contract, the aircraft was changed from a helicopter to a Piper Navajo small airplane, but field testing of the full system was blocked by lack of FAA approval for the instrument housing. Ground-based tests of the active, fluorescence device were conducted at Barber's Point Naval Air Station. The passive, hyperspectral device was flown over Pearl Harbor on a Panavia aircraft. The active data was somewhat inconclusive, and the passive data was successful.

- **Synthetic Technologies, Inc. Honolulu, Hawaii -** *Bioactive Marine Isonitrile Compounds from Hawaiian Sponges as Models for Synthetic Nontoxic Antifoulant and Antibiotic Agents* **- Contract Nos. 39616 and 41777 for $155,055 and $326,553 in FY95 and FY96.**

This exploratory work is based upon (1) the observations that some sessile marine organisms remain significantly free of biologically based fouling and (2) the speculation that such organisms possess chemical defenses against fouling organisms.

Synthetic Technology Corporation developed and tested synthetic isonitrile compounds based on the natural metabolite *isocyanopupukeanane*, **isolated from the marine sponge** *Ciocalypta* **sp., for effective, nontoxic, antifouling activity against common ship fouling organisms typical of the Pearl Harbor marine community. These and closely related compounds were also tested as antibiotics, particularly as inhibitors of microbial biofilm, which is suspected to play a role in biologically signaling suitability for settlement of larvae of significant marine invertebrate fouling organisms. The active compounds were incorporated into marine paint using several techniques and field tested in the ocean for antifouling activity using** *Hydrodies elegans* **(a calcareous tube worm) as a representative ecological receptor.**

Synthetic Technology Corporation has demonstrated that several naturally occurring compounds have potentially significant antifouling properties. However, most successful results are from laboratory bioassay studies and the compounds' antifouling potential has yet to be reproduced in ocean trials of paint formulations. The challenge remains to carry the compounds' antifouling capability into a practical formulation that efficiently delivers the active ingredient to the host organisms over an extended period of time.

- **TerraSystems, Inc. Honolulu, Hawaii -** *Development of an Underwater Video Camera for Optical Contrast and Range Enhancement Using Spectral Stretching* **- Contact No. 41358 for $247,323 in FY96.**

The objective of this project was to develop a working prototype of an underwater video camera with enhanced optical contrast, enhanced range performance, and real-time color video display for the diver (and surface monitor) using a technique termed "Spectral Stretching." A prototype was developed (the UCSS: Underwater Camera Using Spectral Stretching) and tested in a variety of underwater environments: shallow, deep (70 feet), clear, and turbid.

Research into the radiative transfer properties show that improved visibility and contrast to the human eye is possible if the nearly monochromatic (green) light at depth is split into narrow bands and re-imaged on a video screen as red, green, and blue. A specially designed liquid crystal tunable filter (LCTF) and image intensified camera were enclosed in a watertight submersible housing and driven by computer control at video rates. The sequential images taken through each filter state of LCTF (at 30 Hz) were recombined as RGB for display.

Tests in shallow turbid water off Waimanalo show increased contrast performance relative to the eye and video camera. Tests in deep water off Hawai'i Kai show increased color contrast (compositional discrimination) over the eye, video camera, and color film.

The UCSS approach has potential applications in all underwater activities where optical range and contrast enhancement is important. The applications for the DoD and the private sector include environmental monitoring (e.g. coral reef species discrimination and health), inspection of underwater pipelines, communication lines, oil and gas well heads, pilings, moorings and piles, and surveys for unexploded ordnance or mines.

Recommendations for follow-on work include additional testing in more diverse environments, the development of an underwater computer (module) for miniaturization, the testing of different camera systems such as large dynamic range intensified CCD systems, and higher throughput LCTF. The spectral imaging techniques developed here can be applied to other underwater mapping and optical systems.

- **Thermal Energy Storage, Inc. San Diego, California -** *Development and Testing of a Clathrate Desalination Research Facility* **- Contract No.41367 for $250,000 in FY96.**

Desalination is the process of producing potable water from seawater. The clathrate desalination plant is based on two fundamental principles: (1) when seawater freezes, salt is excluded from the ice crystal so freshwater may be obtained from the ice, and (2) clathrates are a class of chemicals that can crystallize or "freeze" water at temperatures well above the normal water freezing point. This project sought to design, build, operate, and test a high pressure crystallization facility and a water purification and clathrate recovery system at the Natural Energy Laboratory of Hawaii Authority (NELHA) as an adjunct to an existing desalination pilot plant. Preliminary research by Thermal Energy Storage, Inc. (TESI) indicated that fresh water by clathrate desalination can be produced at a cost of $0.53/$m^3$ ($2.00/1000 gal.).

Makai Ocean Engineering, Inc. designed and constructed the high-pressure clathrate/water crystallizer at NELHA. The clathrate forming chemical is HCFC R141b (dichloromonofluoroethane (CCL_2FCH_3). The crystallizer houses the seawater phase change and separation to freshwater ice and excluded salt slurry. Makai learned that water from the 3000' depth at NELHA provided a sufficiently low temperature for natural clathrate formation. Tests showed that clathrates were formed spontaneously, and that the high pressure had little affect on the freezing temperature.

Thermal Energy Storage, Inc. designed and assembled the water purification, clathrate recovery system and integrated it with the pilot plant. TESI operated the Clathrate Desalination Pilot Plant intermittently over a period of several months. The system did not perform to design specifications and relatively small quantities of clathrate ice were produced. The water produced had a salinity of about 500 ppm total dissolved solids, the EPA's potability limit. The results validated the concept of a clathrate desalination plant.

All of the elements of the plant functioned as intended except for one subsystem, the wash column, which was to collect and wash brine from the surface of the clathrate crystals. Engineering and testing work done since completion of the CEROS funded work indicates that the drain area of the wash column must be increased substantially to make the system operational.

- **Varian Medical Systems, Inc. Mountain View, California -** *Laser Heterodyne Imaging For Shallow Water Surveillance* **- Contract No. 39615 for $299,674 in FY95.**

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FINAL TECHNICAL REPORT

Varian Associates, Inc. developed a proof-of-concept imaging system for object identification in very turbid waters (visibility range 50-80 cm). The Varian system obtained images with millimeter resolution at a range of over 10 attenuation lengths. The Varian prototype system exceeded the range and resolution capabilities of all existing optical systems for imaging in highly turbid waters.

To achieve the technological breakthrough demonstrated with the prototype laser imaging system, Varian used long wavelength (683nm) illumination, coherence gating, and heterodyne detection. The resulting system produced exceptional resolution and images in highly turbid waters during laboratory tests and demonstrations. The tests were run on a specially built underwater optical bench at the Varian facility in specially mixed water that duplicated the optical properties of highly turbid seawater in the littoral zone.

Under CEROS sponsorship, Varian created a novel laser heterodyne system and achieved unprecedented image resolution in very turbid seawater. Under CEROS FY97, Varian improved the unique heterodyne imaging system for object detection in littoral waters.

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