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TEN YEARS OF APL OCEANOGRAPHY IN THE *JOHNS HOPKINS APL TECHNICAL DIGEST*

During the 1980s, APL staff reported frequently on the "where, what, how, and why" of oceanography through articles published in the *Johns Hopkins APL Technical Digest*. The work described in those articles is discussed in relation to the Laboratory's mission, and some predictions are made for the 1990s.

INTRODUCTION

Laboratory staff members are constantly involved in oceanography. Someone is always either on the sea (on surface ships or moored platforms), in the sea (in submarines or diving suits), over the sea (in aircraft or using satellites), modeling the sea (through theory, laboratory experiment, or numerical simulation), or planning one of these activities. The work is reported in many ways: in peer-reviewed journals, in classified reports, at professional meetings, at briefings to sponsors, in internal APL documents, and in the *Johns Hopkins APL Technical Digest*.

About 80 articles related to oceanography have appeared in the *Digest* since publication of the first issue in 1980. Most of those articles can be found in four theme issues that were devoted to oceanography,[1-4] one issue that focused on Geosat,[5] and another that discussed synthetic aperture radar.[6]

The Laboratory rarely undertakes seagoing projects in isolation; we collaborate with most U.S. Navy laboratories, many private contractors, various governmental agencies, academic experts, and even other countries. Some oceanographic work at APL has not been reported in the *Digest*, whereas some of the published articles have been written by colleagues at other institutions. Thus, to focus on the APL contribution and specifically on the *Digest*, this article draws only on *Digest* articles written by APL staff. This review is meant to be comprehensive, but not exhaustive. To find all the articles, the reader is referred to the contents pages of the special theme issues mentioned in the preceding paragraph as well as all other issues, and to the annual listing of ocean science and technology papers that appears each year in the fall issue of the *Digest*.

The broad range of results of all the investigations cited in this article cannot be summarized briefly. Therefore, a topical guide to the references is presented in Tables 1 to 3 so that one can find the results quickly. Table 1 lists references by location (see the section entitled "Where" and Fig. 1 for a map), Table 2 lists references by phenomenon (see the section entitled "What"), and Table 3 lists references by method (see the section entitled "How"). The reference numbers in the tables refer to the reference list at the end of this article. A perusal of the tables shows that *Digest* articles tend to address regional problems rather than global ones, and they also tend to exclude problems related to climatic trends.

Table 1. Geographical listing of oceanography articles written by APL staff for the *Digest*.

Location	Reference No.
Agulhas Current (Africa)	7, 8
Andaman Sea (Indonesia)	9
Atlantic	10–12
Caribbean	13, 14
Chesapeake Bay	15–17
Coastal United States	18–21
Coast of Chile	8, 11, 22, 23
East Iceland Polar Front	24
Gulf of Mexico	24, 25
Loch Linnhe (Scotland)	26
Pacific Ocean	19, 27
Sargasso Sea	28–33
Sognefjord (Norway)	34, 35
Strait of Gibraltar	36
Sulu Sea (Indonesia)	37

WHERE

During the 1980s, APL staff traveled far and wide over the world's oceans. Investigators visited many regions repeatedly and used different instrumentation to investigate various phenomena for several programs and sponsors. A map of the areas featured in *Digest* articles is shown in Figure 1, and some of the corresponding articles are listed by location in Table 1.

Table 2. Oceanographic phenomena reported by APL staff in the *Digest*.

Phenomenon	Reference No.
Acoustics	
Scattering	27, 38
Signal processing	20
Biology, chemistry, and mixing	
Chesapeake Bay experiments	15–17
Drag reduction	39
Electromagnetism	
Propagation	40
Scattering	12, 41
Energy	
Ocean thermal energy conversion	42–44
Ice	45
Mesoscale oceanography	24, 28, 46, 47
Microstructure	
Observations	13, 33
Salt fingers	44
Ocean currents	
Currents/waves	7
Vertical shear	48
Optics	16, 25
Small-scale dispersion	29
Vortex flow	
Laboratory experiments	49
Numerical simulation	50
Waves	
Agulhas	7, 8
General theory	51, 52
Hurricane	8
Internal	11, 14, 30, 34–36
Prediction	53
Solitons	9, 37
Spectra	23
Surface wind	18
Swell	30, 54, 55
Wind	
Via altimeter	10
Via scatterometer and synthetic aperture radar	32

Table 3. Methods used in oceanographic research reported by APL staff in the *Digest*.

Method	Reference No.
Computer simulations	
Systems	56
Vortex	50
In situ instrumentation	
Acoustics	27
Airborne expendable bathythermograph	46
Current meters	17
Echo sounder	17
Electromagnetic	40
Expendable current profiler	48
Fluorometer/dye	29
Thermistor chain	13, 17, 30, 33
Underwater video	16
Laboratory experiments	
Drag reduction	39
Ice	45
Ocean thermal energy	44
Salt fingers	44
Turbulence	44
Vortex	49
Waves	44
Remote sensing	
Airborne radiometer	31
Geosat/altimetry	5, 24, 28, 47, 57, 58
Overview	21
Scatterometer	32
Shuttle imaging radar	8, 23
Synthetic aperture radar	6, 11, 12, 22, 26, 34, 35, 41, 59–62
Theory	
Acoustic scattering	38
Synthetic aperture radar/electromagnetic scattering	12, 41
Wave propagation	51, 52
Waves/currents	7
Waves/fine structure	14

WHAT

Various oceanographic phenomena have been investigated at APL and described in the *Digest*. The range of phenomena that have been addressed will be presented in this section, even though all the results of the studies are too numerous to discuss.

The first oceanographic article to appear in the *Digest* described the mapping of mesoscale features by using airborne expendable bathythermographs.[46] This survey method continues to be important, even though many alternative methods are now available.

Laboratory staff members have studied various types of ocean waves and have frequently reported their findings in the *Digest*. Topics of articles have included sur-

Figure 1. Regions of the ocean studied by APL investigators and discussed in the *Digest*.

face wind waves[18] (and the wind that drives them[10,32]), swell,[30,54,55] hurricane waves,[8] internal waves,[11,14,30] and solitons.[9,37] In addition, articles have addressed the spectral properties of waves[23] and their interactions with currents,[7,8] as well as wave theory[51,52] and wave predictions.[53]

Although acoustical properties are of paramount importance to the Navy, only a small portion of APL work in this area has been reported in the *Digest*.[20,27,38] The published work only hints at the scope of the effort.

In the early 1980s when the search for safer forms of energy was a higher national priority, APL was involved in the study of ocean thermal energy conversion. The results of those efforts can be found in various *Digest* articles.[42-44]

The Laboratory has been a strong force in the measurement of ocean microstructure[13,33,44] and small-scale dispersion,[29] and several articles discuss these phenomena as well.

Digest articles also describe the vertical shear of ocean currents,[48] the interaction of currents and waves,[7] and electromagnetic[12,40,41] and optical[16,25] properties of the oceans.

At times, the study of oceanographic phenomena requires a look at fundamental fluid dynamical problems. The subjects of vortex flow,[49,50] drag reduction,[39] and melting ice[45] were described from this viewpoint in several articles.

To be a responsible neighbor in its community, an oceanographic institution must know its local water. Despite severe funding constraints, APL has maintained a small Chesapeake Bay project for many years.[63] *Digest* articles have focused on the Bay in general,[16] as well as the specific APL program[15,17] (in cooperation with the University), which involves studies of biology, fluid dynamics, and chemistry.

Table 2 summarizes the topics discussed in this section and provides the corresponding references as well.

HOW

Various platforms have been used in the oceanographic studies featured in the *Digest*, including satellites, airplanes, surface ships, submarines, moored buoys, and towers. Investigators at APL have studied the sea from these platforms by using a variety of sensors, including towed, lowered, free-floating, dropped, moored, and remote types. Many of the sensors were designed, developed, and deployed by APL.

In situ instrumentation built or deployed by APL has often been featured in the *Digest* (Figs. 2 to 7). The towed thermistor chain was one of APL's achievements in this regard.[13,17,30,33] At the end of the 1970s, the usefulness of the chain in measuring small-scale ocean turbulence was demonstrated, and its technology was enhanced considerably during its deployments of the 1980s. This development can be seen by comparing Figures 2 and 3. Figure 2 shows an early version of the chain outfitted with an external fluorometer and conductivity sensor, and Figure 3 shows a later version where these sensors as well as a dual dye-dispensing system were miniaturized into the chain.

Another *in situ* instrument used is the vertically lowered conductivity-temperature-depth system,[13] which was outfitted to include an APL fluorometer, as shown in Figure 4. Standard expendable current profilers have been used to measure velocity shears,[48] and later in the 1980s, acoustic Doppler profilers were used to measure velocities.[17] Special APL instrumentation developed for measuring extremely low frequency electromagnetic fields[40] is shown in Figure 5. Measurements of acoustic propagation loss were reported from a large instrument used in a two-ship configuration,[27] as depicted in

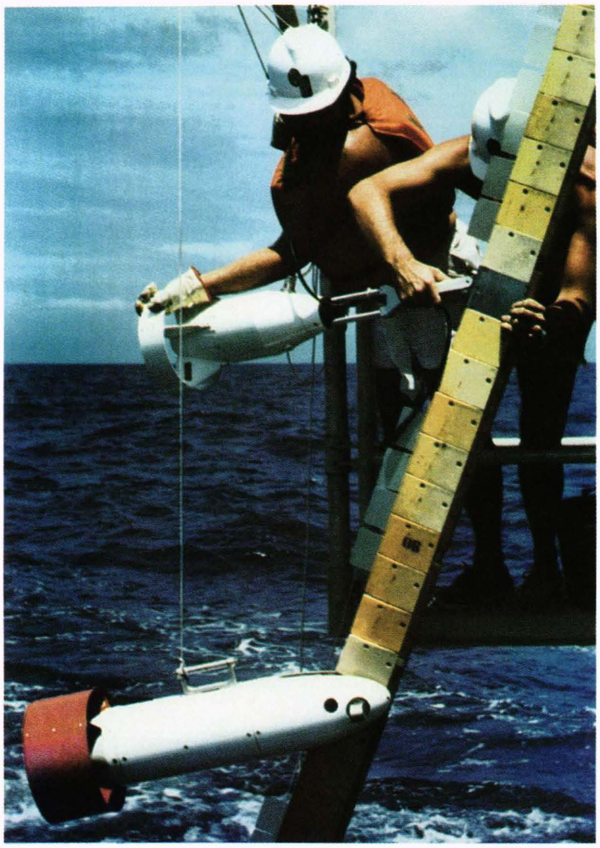


Figure 2. Sensors being deployed on a towed chain. The upper sensor is a fluorometer; the lower is one of the conductivity sensors.

Figure 6. Researchers at APL have even studied the sea by using an underwater video camera,[16] as pictured in Figure 7.

The Laboratory has been very active in remote sensing (Figs. 8 and 9).[21] The *Digest* issue on the Geosat satellite[5] contained articles on its design,[57,58] operation, and radar altimeter measurements (Fig. 8). The oceanographic applications included observations of sea-surface height,[24,28,47] wind,[10] waves, and ice. A synthetic aperture radar, which has been deployed from the space shuttle,[22] forms detailed images of the sea surface and can measure wave spectra.[11,12,59–62] Results obtained with this instrument were reported in the *Digest* issue on synthetic aperture radar.[6] An airborne radiometer (Fig. 9), which measures sea-surface temperature,[31] is deployed from the same P3 aircraft that is used to drop airborne expendable bathythermographs.

Laboratory oceanographic studies usually attempt a clear demonstration or measurement of fluid flow (Figs. 10 to 12). In this regard, *Digest* articles have addressed vortex wake[49] (Fig. 10), convection at a model ice edge[45] (Fig. 11), and the bending of salt fingers by a propagating internal wave[44] (Fig. 12).

Experimental and observational techniques range from the modern approach using computer simulations to the oldest of techniques, namely, the theoretical model. Studies reported in the *Digest* have used a variety of methods for modeling physical processes (e.g., vortex flow[50]) and for understanding instrument systems (e.g., the interaction of radar with surface waves[12]).

Table 3 summarizes the instrumentation discussed in this section and provides the corresponding references.

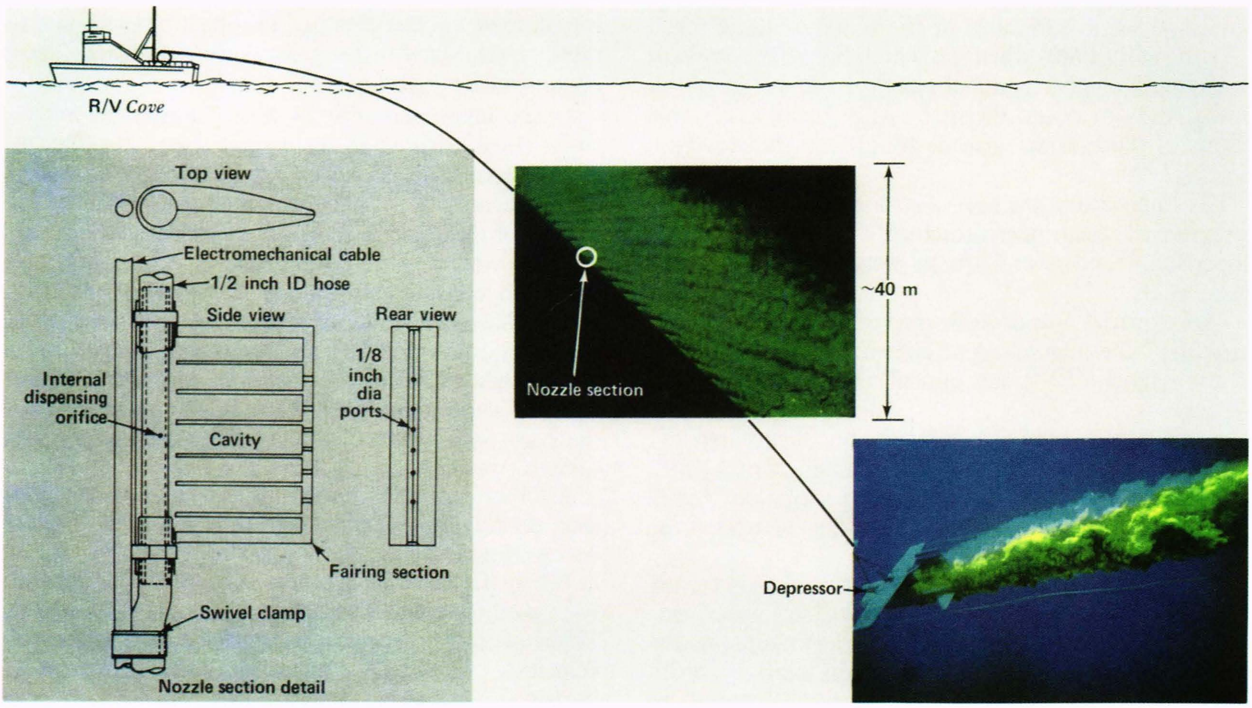


Figure 3. Surface towed dye system. The insets are underwater photographs showing two alternative modes of operation. In the upper picture, dye is being emitted continuously from a series of 91 nozzle sections to form an initially vertical sheet of dye roughly 40 m high. Also shown is an expanded view of one of the nozzle sections. In the lower picture, dye is being pumped from the depressor, allowing the study of turbulent wake effects on the dye concentration field.

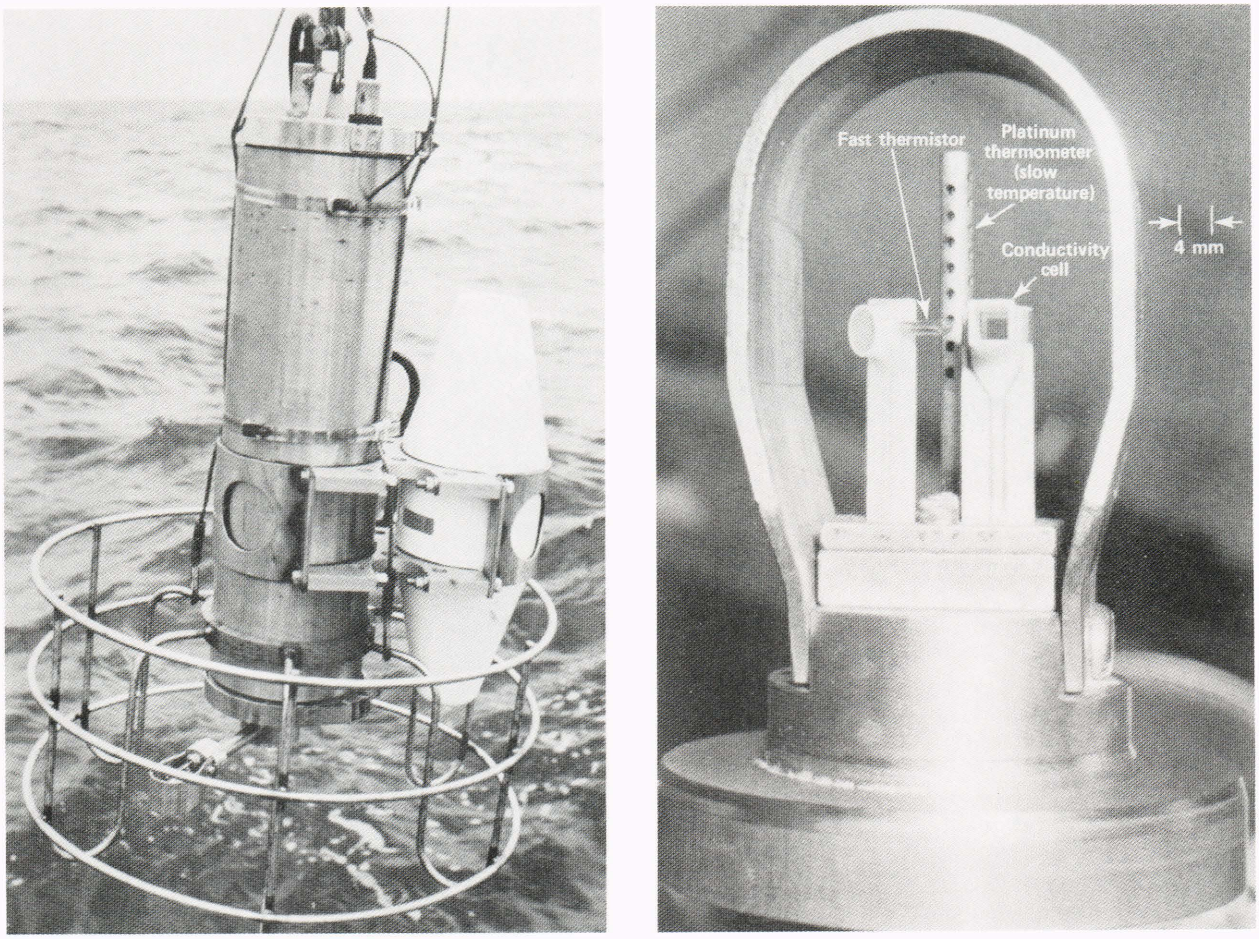


Figure 4. Conductivity-temperature-depth fluorometer system used for vertical profiling. The underwater unit is shown on the left, and an enlarged view of the sensor arm is shown on the right.

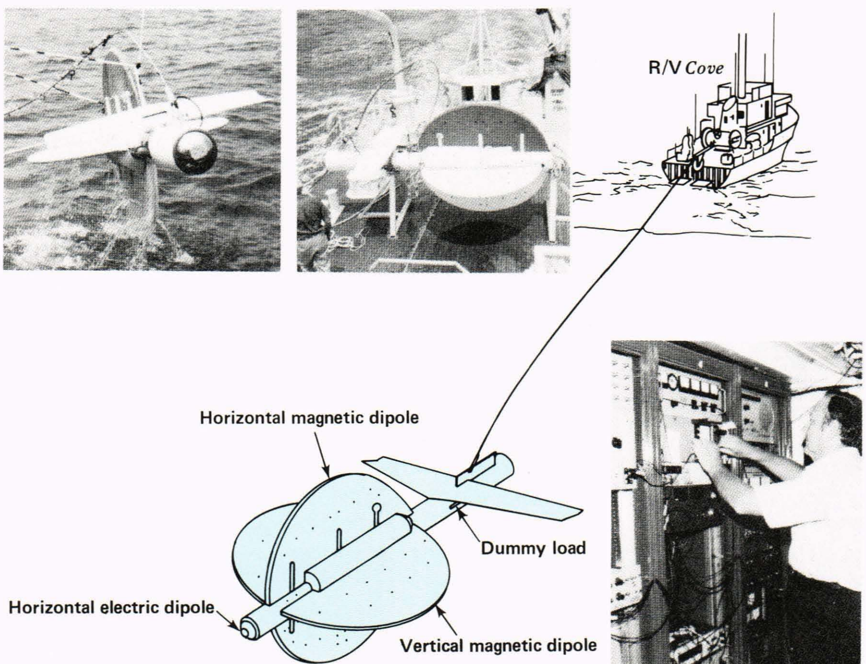


Figure 5. Underwater calibrated source platform towed in a stabilized fashion by the nonmagnetic R/V *Cove*. Shown are the three dipoles that furnish calibrated extremely low frequency signals for propagation studies.

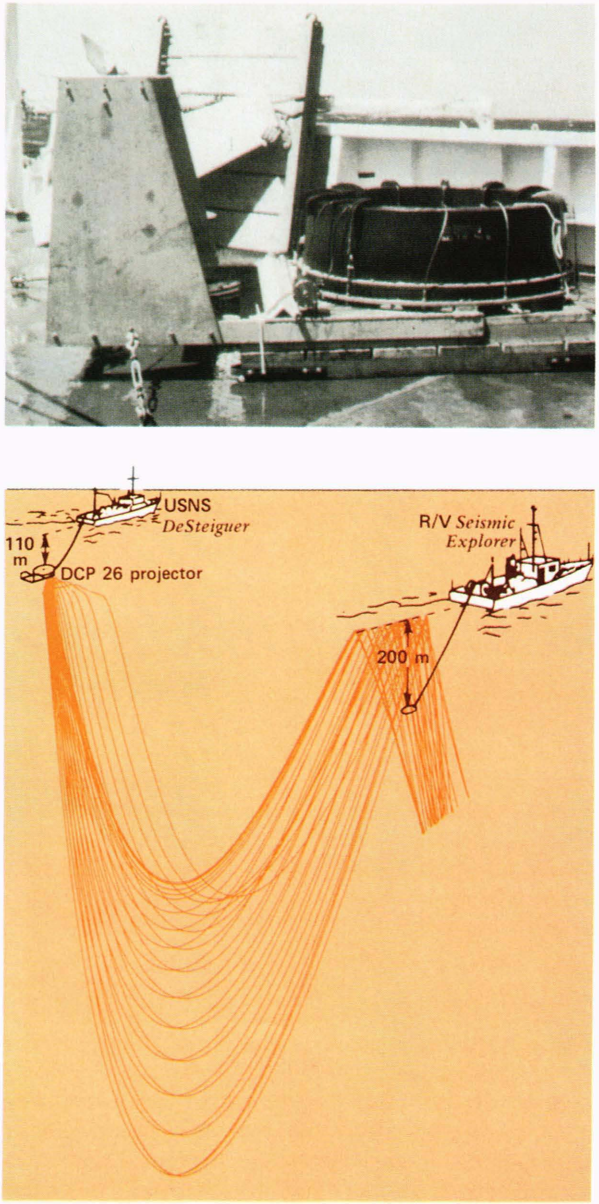


Figure 6. Measurement of acoustic propagation loss. The acoustic projector used to generate the comb of eight sine waves and the linear frequency-modulated signal is shown at the top. The projector is quite large and weighs about 2600 lb. An artist's conception of an opening run to measure transmission loss is shown at the bottom.

Figure 7. Aboard R/V *Ridgely Warfield* during an oxygen depletion study, crewmen prepare a waterproof bio-optical video system for lowering over the side. The chamber on the left houses a parallel light source that projects shadowgraph images of small sea-life passing through the gap. The video camera is housed in the large chamber.

WHY

Nearly 10 years ago, Carl Bostrom, Director of the Laboratory, wrote an article for the *Digest* entitled "The APL Mission: Challenge for the 1980s."[64] In the article, he quoted the Laboratory's mission statement, which was adopted by the JHU Board of Trustees in 1968 (italics denote the 1988 additions to the statement):

> The general purpose of The Johns Hopkins University can be stated as public service through education, research, and the application of knowledge to human affairs. As part of the University, the Applied Physics Laboratory shares this purpose through the application of advanced science and technology to the enhancement of the security of the United States of America, and through basic research *and participation in the educational programs of the academic divisions of the University* to which its *staff and* facilities can make an especially favorable contribution.[64]

In his interpretation of the mission statement, Bostrom noted that the Laboratory should work "to produce innovative, effective, efficient, and timely solutions to problems" in carrying out its mission.[64]

How did we do in meeting this challenge for the 1980s? The part of the challenge summarized in Bostrom's article was related to the enhancement of the ocean security of the United States. Most of the work described was connected to the major thrust of the Laboratory's work, that is, support of the Navy. Applying and advancing science and technology for purposes of national security are impressive undertakings, and the Laboratory has been successful in its ongoing effort to do the best possible job for the nation and to fulfill its mission.

FUTURE

Although APL is focused on the ocean security of the United States (i.e., primarily helping the Navy), the is-

Figure 8. Geosat radar altimeter spacecraft.

sue of national security seems to be broadening beyond its usual interpretation as military strength. More and more frequently, we hear about economic security; we also read about some of the nation's ocean-going military being used to fight a drug war, not a political war. Although the Laboratory's mission may not change in the 1990s, the problems surrounding the mission are broadening, and their urgency is increasing. The time is perhaps coming very soon when we will have to think about and work on environmental security as well. Because the Navy, the nation, and the rest of the world are using the oceans more frequently and exploiting its finer details and resources, environmental management of the oceans is becoming a growing aspect of national security. If advanced science and technology can be used at APL to produce innovative, effective, efficient, and timely solutions to problems and to enhance national security, then perhaps APL can serve the nation further as these new environmental problems confront us.

All indications are that APL's role with the University, the Navy, and the nation will continue in the next decade. We can expect to be surprised again, 10 years from now, by how much we have learned and how much technology has advanced. The 1990s will undoubtedly continue to dazzle us with the applications and power of smaller and less expensive computers, and APL will continue to apply the power of such technological developments to advancing national security and research. We look forward to reading about new developments in the *Digest*!

REFERENCES

1 "Ocean Science," *Johns Hopkins APL Tech. Dig.* **3**, No. 1 (1982).
2 "Ocean Science—I," *Johns Hopkins APL Tech. Dig.* **6**, No. 3 (1985).
3 "Ocean Science—II," *Johns Hopkins APL Tech. Dig.* **6**, No. 4 (1985).
4 "APL Ocean Sciences—1989," *Johns Hopkins APL Tech. Dig.* **10**, No. 4 (1989).
5 "The Navy Geosat Mission," *Johns Hopkins APL Tech. Dig.* **8**, No. 2 (1987).
6 "Measuring Ocean Waves from Space," *Johns Hopkins APL Tech. Dig.* **8**, No. 1 (1987).
7 Irvine, D. E., "Extreme Waves in the Agulhas—A Case Study in Wave-Current Interaction," *Johns Hopkins APL Tech. Dig.* **8**, 100–106 (1987).
8 Tilley, D. G., "SIR-B Ocean-Wave Enhancement with Fast Fourier Transform Techniques," *Johns Hopkins APL Tech. Dig.* **8**, 87–93 (1987).
9 Apel, J. R., Thompson, D. R., Tilley, D. G., and Van Dyke, P., "Hydrodynamics and Radar Signatures of Internal Solitons in the Andaman Sea," *Johns Hopkins APL Tech. Dig.* **6**, 330–337 (1985).
10 Dobson, E., Monaldo, F., Goldhirsh, J., and Wilkerson, J., "Validation of Geosat Altimeter-Derived Wind Speeds and Significant Wave Heights Using Buoy Data," *Johns Hopkins APL Tech. Dig.* **8**, 222–233 (1987).
11 Gasparovic, R. F., Apel, J. R., Brandt, A., and Kasischke, E. S., "Synthetic Aperture Radar Imaging of Internal Waves," *Johns Hopkins APL Tech. Dig.* **6**, 338–345 (1985).
12 Thompson, D. R., "Intensity Modulations in Synthetic Aperture Radar Images of Ocean Surface Currents and the Wave/Current Interaction Process," *Johns Hopkins APL Tech. Dig.* **6**, 346–353 (1985).
13 Mack, S. A., Wenstrand, D. C., Calman, J., and Burkhardt, R. C., "Characteristics of Thermal Microstructure in the Ocean," *Johns Hopkins APL Tech. Dig.* **3**, 28–35 (1982).

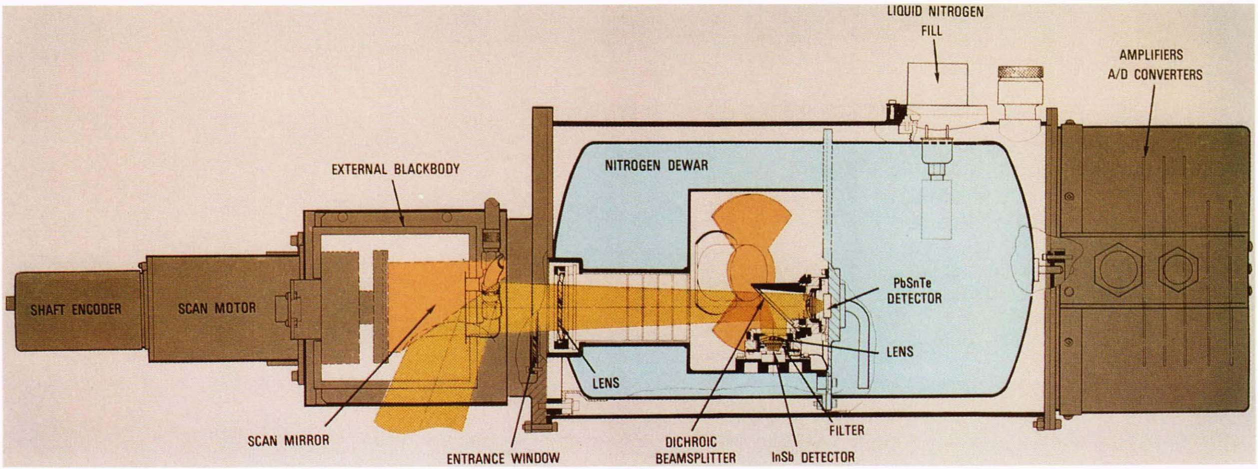


Figure 9. Side view of an APL radiometer. The instrument is mounted in a pod located above the radome of a P3 aircraft.

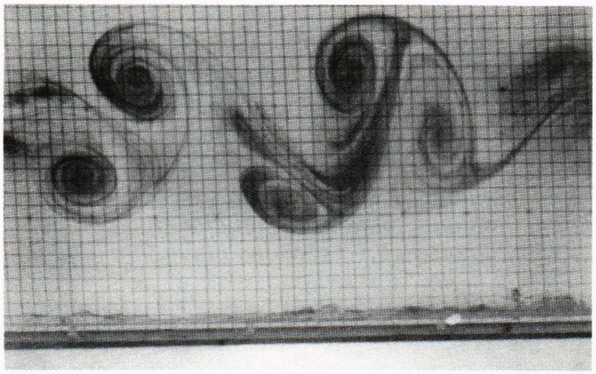


Figure 10. Vortex structure in the wake of a sphere towed through thermally stratified water. The vortex trail is shown in the horizontal plane 285 s after the passage of the sphere. The grid in the background is 1 × 1 in.

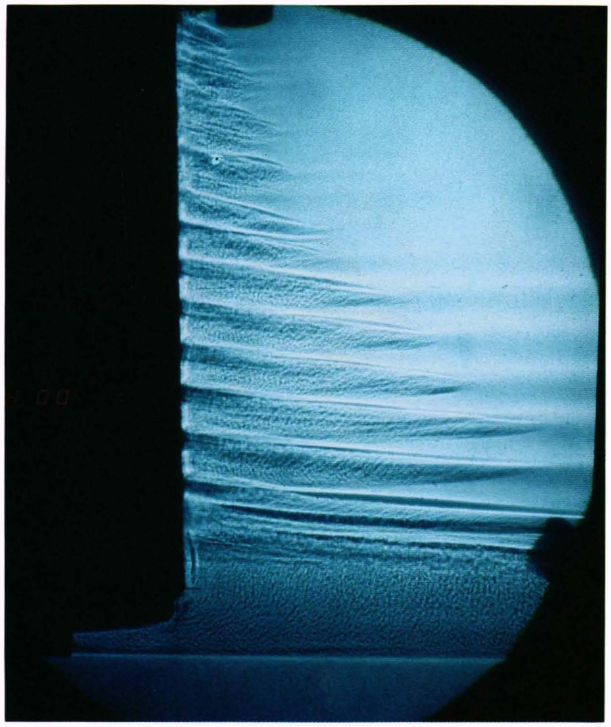


Figure 11. Shadowgraph of the flow near a model ice edge showing the strong horizontal boundary current going out from the edge and the convective layers along the vertical wall (time is 7 min after hot water had started to fill the reservoir).

[14] Roth, M. W., "The Separation of Oceanic Temperature Finestructure and Internal Motion," *Johns Hopkins APL Tech. Dig.* **3**, 19–27 (1982).

[15] Burton, D. T., "Aquatic Ecology at the Applied Physics Laboratory," *Johns Hopkins APL Tech. Dig.* **4**, 127–132 (1983).

[16] McCloskey, W. J., "Chesapeake Bay Research Institutions: A Bay-Wide Presence," *Johns Hopkins APL Tech. Dig.* **6**, 369–384 (1985).

[17] Sarabun, C. C., Brandt, A., Tyler, M. A., and Smith, G. D., "Biological Transport, Internal Waves, and Mixing in the Chesapeake Bay," *Johns Hopkins APL Tech. Dig.* **6**, 227–236 (1985).

[18] Irani, G. B., and Gotwols, B. L., "WAVDYN: Measurements of the Independence of Ocean Wind Waves," *Johns Hopkins APL Tech. Dig.* **3**, 49–58 (1982).

[19] Irvine, D. E., "Waves Across the Ocean," *Johns Hopkins APL Tech. Dig.* **6**, 313–319 (1985).

[20] South, H. M., "Digital Recording and Signal Processing Systems for Hydrophone Arrays," *Johns Hopkins APL Tech. Dig.* **4**, 212–218 (1984).

[21] McGoldrick, L. F., "Remote Sensing for Oceanography: An Overview," *Johns Hopkins APL Tech. Dig.* **6**, 284–292 (1985).

[22] Monaldo, F. M., "Measurements of Directional Wave Spectra by the Shuttle Synthetic Aperture Radar," *Johns Hopkins APL Tech. Dig.* **6**, 354–360 (1985).

[23] Monaldo, F. M., "A Practical Methodology for Estimating Wave Spectra from the SIR-B," *Johns Hopkins APL Tech. Dig.* **8**, 82–86 (1987).

[24] Calman, J., and Manzi, L. P., "Real-Time Satellite Altimetry," *Johns Hopkins APL Tech. Dig.* **10**, 380–385 (1989).

[25] Gotwols, B. L., and Irani, G. B., "Optical Measurement of the Phase Velocity of Ocean Waves During the 1978 Wave Dynamics Experiment," *Johns Hopkins APL Tech. Dig.* **2**, 56–62 (1981).

[26] Gasparovic, R. F., Thompson, D. R., and Apel, J. R., "Synthetic Aperture Radar Imaging of Ship-Generated Internal Waves," *Johns Hopkins APL Tech. Dig.* **10**, 326–331 (1989).

[27] Boyles, C. A., and Joice, G. W., "Comparison of Three Acoustic Transmission Loss Models with Experimental Data," *Johns Hopkins APL Tech. Dig.* **3**, 67–76 (1982).

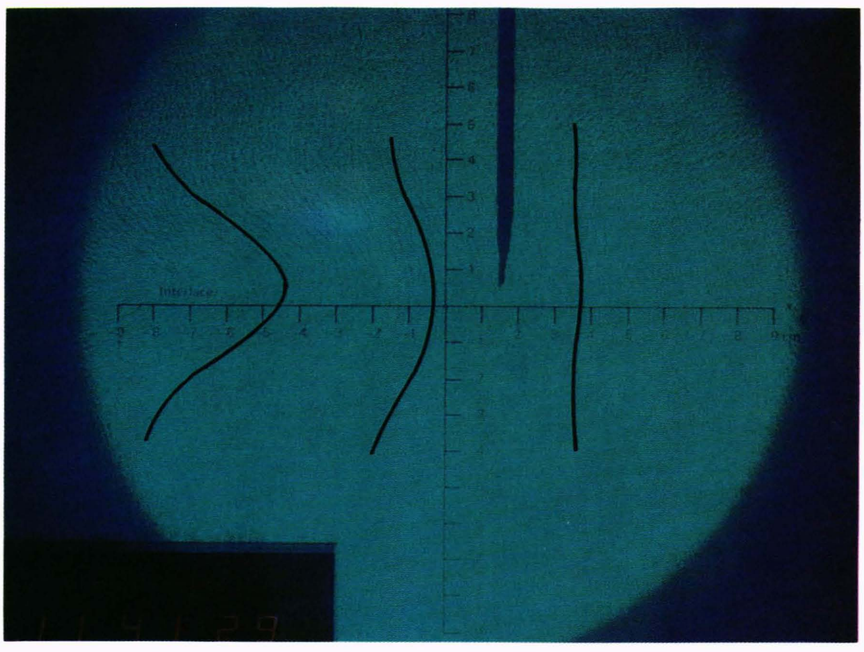
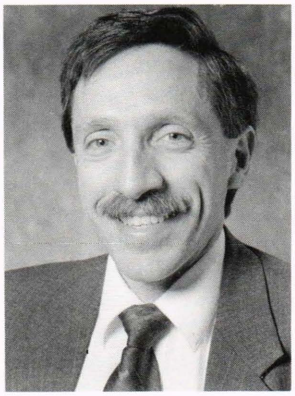


Figure 12. Straining of salt fingers by a left-to-right propagating internal wave. The photograph is a shadowgraph obtained in a double-diffusive experiment. Diffusive salt fingers are the small-scale, 1-mm-wide, curved striations, which were originally vertical.

[28] Calman, J., "Introduction to Sea-Surface Topography from Satellite Altimetry," *Johns Hopkins APL Tech. Dig.* **8**, 206–211 (1987).
[29] Crawford, L. J., Vasholz, D. P., Giles, J. W., Jr., and Gundersdorf, C. J., "Evolution of a Vertically Distributed Passive Scalar in the Seasonal Thermocline," *Johns Hopkins APL Tech. Dig.* **3**, 36–41 (1982).
[30] Dubbel, D. C., "The Reduction in Finestructure Contamination of Internal Wave Estimates from a Towed Thermistor Chain," *Johns Hopkins APL Tech. Dig.* **6**, 186–193 (1985).
[31] Gasparovic, R. F., Peacock, K., and Tubbs, L. D., "Airborne Radiometric Measurements of Sea Surface Temperature," *Johns Hopkins APL Tech. Dig.* **3**, 4–11 (1982).
[32] Gerling, T. W., "Remote Sensing of the Ocean-Surface Wind Field with a Scatterometer and a Synthetic Aperture Radar," *Johns Hopkins APL Tech. Dig.* **6**, 320–329 (1985).
[33] Schoeberlein, H. C., "A Statistical Analysis of Patches of Oceanic Small-Scale Activity," *Johns Hopkins APL Tech. Dig.* **6**, 194–202 (1985).
[34] Apel, J. R., and Gjessing, D. T., "Internal Wave Measurements in a Norwegian Fjord Using Multifrequency Radars," *Johns Hopkins APL Tech. Dig.* **10**, 295–306 (1989).
[35] Jensen, J. R., "Delta-k Radar Measurements of Internal Waves in the Sognefjord," *Johns Hopkins APL Tech. Dig.* **10**, 318–325 (1989).
[36] Watson, G., "Refraction Modeling of Internal Waves in a Two-Layer System, as Observed in the Strait of Gibraltar," *Johns Hopkins APL Tech. Dig.* **10**, 339–347 (1989).
[37] Apel, J. R., and Holbrook, J. R., "Internal Solitary Waves in the Sulu Sea," *Johns Hopkins APL Tech. Dig.* **4**, 267–275 (1983).
[38] Boyles, C. A., Dozier, L. B., and Joice, G. W., "Application of Coupled Mode Theory to Acoustic Scattering from a Rough Sea," *Johns Hopkins APL Tech. Dig.* **6**, 216–226 (1985).
[39] Taylor, T. D., and Hurdis, D. A., "Drag Reduction Studies by Compliant Surfaces and Surface-Active Substances," *Johns Hopkins APL Tech. Dig.* **5**, 56–58 (1984).
[40] Ko, H. W., Giannini, J. A., and Herchenroeder, P. J., "Oceanographic ELF Electromagnetic Investigations at APL," *Johns Hopkins APL Tech. Dig.* **3**, 59–66 (1982).
[41] Thompson, D. R., "Probing the Ocean Surface with Microwave Radar," *Johns Hopkins APL Tech. Dig.* **10**, 332–338 (1989).
[42] Avery, W. H., "Ocean Thermal Energy Conversion Contribution to the Energy Needs of the United States," *Johns Hopkins APL Tech. Dig.* **1**, 101–107 (1980).
[43] Avery, W. H., "Methanol from Ocean Thermal Energy," *Johns Hopkins APL Tech. Dig.* **5**, 159–166 (1984).
[44] Brandt, A., and Hurdis, D. A., "Simulation of Oceanographic Processes in the Hydrodynamics Research Laboratory," *Johns Hopkins APL Tech. Dig.* **3**, 42–48 (1982).
[45] Calman, J., "Convection at a Model Ice Edge," *Johns Hopkins APL Tech. Dig.* **6**, 211–215 (1985).
[46] Henrick, R. H., "Mesoscale Oceanographic Mapping," *Johns Hopkins APL Tech. Dig.* **1**, 49–51 (1980).
[47] Porter, D. L., Robinson, A. R., Glenn, S. M, and Dobson, E. B., "The Synthetic Geoid and the Estimation of Mesoscale Absolute Topography from Altimeter Data," *Johns Hopkins APL Tech. Dig.* **10**, 369–379 (1989).
[48] Smart, J. H., "Direct Measurement of Vertical Shear in the Open Ocean," *Johns Hopkins APL Tech. Dig.* **1**, 284–288 (1980).
[49] Pao, H. P., Lai, R. Y., and Schemm, C. E., "Vortex Trails in Stratified Fluids," *Johns Hopkins APL Tech. Dig.* **3**, 12–18 (1982).
[50] Hirsh, R. S., "A Numerical Simulation of Vortex Motion in a Stratified Environment and Comparison with Experiments," *Johns Hopkins APL Tech. Dig.* **6**, 203–210 (1985).
[51] Allen, K. R., and Joseph, R. I., "A Statistical Mechanical Explanation of the Garrett and Munk Model of Oceanic Internal Waves," *Johns Hopkins APL Tech. Dig.* **10**, 348–361 (1989).
[52] Apel, J. R., "A Linear Response Theory for Waves in a Geophysical Fluid," *Johns Hopkins APL Tech. Dig.* **7**, 42–57 (1986).
[53] Plant, W. J., "The Microwave Measurement of Ocean-Wave Directional Spectra," *Johns Hopkins APL Tech. Dig.* **8**, 55–59 (1987).
[54] Donelan, M. A., "The Effect of Swell on the Growth of Wind Waves," *Johns Hopkins APL Tech. Dig.* **8**, 18–23 (1987).
[55] Gonzales, F. I., Holt, B. M., and Tilley, D. G., "The Age and Source of Ocean Swell Observed in Hurricane Josephine," *Johns Hopkins APL Tech. Dig.* **8**, 94–99 (1987).
[56] Peletier, D. P., "The Application of a Distributed Computer Organization to Ocean Research," *Johns Hopkins APL Tech. Dig.* **4**, 270–273 (1983).
[57] Kilgus, C. C., MacArthur, J. L., and Brown, P. V. K, "Remote Sensing by Radar Altimetry," *Johns Hopkins APL Tech. Dig.* **5**, 341–345 (1984).
[58] MacArthur, J. L., Kilgus, C. C., Twigg, C. A., and Brown, P. V. K., "Evolution of the Satellite Radar Altimeter," *Johns Hopkins APL Tech. Dig.* **10**, 405–413 (1989).
[59] Beal, R. C., "The Potential of Spaceborne Synthetic Aperture Radar for Oceanography," *Johns Hopkins APL Tech. Dig.* **1**, 148–156 (1980).
[60] Beal, R. C., "Ocean Research with Synthetic Aperture Radar," *Johns Hopkins APL Tech. Dig.* **6**, 293–299 (1985).
[61] Black, H. D., "Satellites for Earth Surveying and Ocean Navigating," *Johns Hopkins APL Tech. Dig.* **2**, 3–13 (1981).
[62] McDonough, R. N., Raff, B. E., and Kerr, J. L., "Image Formation from Spaceborne Synthetic Aperture Radar Signals," *Johns Hopkins APL Tech. Dig.* **6**, 300–312 (1985).
[63] Gilreath, H. E., "APL's Independent Research and Development Thrust in Oceanography," *Johns Hopkins APL Tech. Dig.* **6**, 276–283 (1985).
[64] Bostrom, C. O., "The APL Mission: Challenge for the 1980s," *Johns Hopkins APL Tech. Dig.* **1**, 295–296 (1980).

ACKNOWLEDGMENT: I would like to thank Walter Berl for inviting me to write this article and for reviewing it. I would also like to thank the two other reviewers for their helpful comments.

THE AUTHOR



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