U.S. Navy Journal of Underwater Acoustics Volume 61, No. 2 April 2011

MEMOIR OF THE LONG RANGE ACOUSTIC PROPAGATION PROGRAM (LRAPP)

Louis P. Solomon
Bethesda, MD 20817

(Received December 9, 2009)

Today, an understanding of acoustic programs of the ocean can be learned from any one of a number of textbooks, but in the relatively recent past much of today's knowledge is unknown. The Long Range Acoustic Propagation Program (LRAPP) was a major contributor to today's knowledge and was arguably responsible for some of the key technical developments that blunted the Soviet submarine threat during the Cold War. The strength of the program was twofold. First, its unique combination of military personnel and applied scientists from universities, Navy and university laboratories, and government contractors, and second, its management by OP-095 (Manager, AntiSubmarine Warfare), an organization focused exclusively on the ASW mission to be accomplished. OP-095 was a rare example of true "out of the box" managerial thinking in that era. The LRAPP team (less than 200 people over 25 years) developed models for acoustic propagation and ambient noise prediction from first principles. Subsidiary models on worldwide shipping distributions, and measurements of radiated noise of submarines and surface ships allowed ambient noise predictions of levels as a function of depth. These models, and others, were all validated in a large number of extensive ocean exercises (96) with data collection that included direct measurement of sound speed, detailed measurements of the bathymetric profile, and basin shipping distributions, in addition to temperature and salinity data as a function of depth. The measurement and accurate prediction of directional ambient noise as a function of depth was a novel concept at the time. This characterization led to advances in array processing that resulted in significant improvements in array performance in real-world operations. This combination of validated scientific research and its translation and acceptance by the operational Navy provided the successful ASW program that the United States needed during the Cold War.

I. THE THREAT

The advent of the nuclear submarine was a formidable new threat to the Free World. It was much faster and quieter than earlier submarines, was seemingly undetectable, and carried substantial and continuously improving weapons. Two types of submarines were developed, the attack submarine and the missile submarine. [1]

The diesel-electric-powered attack submarine was designed to attack merchant ships, surface warships, and enemy submarines. It had a long history of successes in both World Wars I and II. The supply lifeline between the United States and England was almost severed by German diesel submarines during both of those wars. The Japanese merchant traffic within the Greater East Asian Co-Prosperity Sphere was almost completely destroyed by American diesel submarines operating in the Western Pacific during World War II. The later development of the nuclear submarine made the attack submarine even more deadly than its predecessors. The Soviet Union, with the largest submarine force in the world, clearly had in its hands a potential major threat to Free World commerce.

Table of Contents

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **APR 2011**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Memoir of the Long Range Acoustic Propagation Program (U)**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Ocean Research and Development Activity (NORDA)**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADC081439. U.S. Navy Journal of Underwater Acoustics. Volume 61, Numbers 1-3, 2011.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**32**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The missile-carrying submarine was designed to position itself in selected ocean areas and, upon receipt of the appropriate command, launch its missiles quickly against a previously designated target. Initially, the missiles were not armed with nuclear warheads and could only travel short distances (approximately 100 miles). Within a short time, however, advances in technology allowed the missiles to strike the target at much longer ranges and to carry nuclear warheads. The mission of nuclear ballistic missiles was to destroy large areas, major installations, and cities.

The Cold War and Antisubmarine Warfare

The Cold War (1964–1989) has substantial precedent in written history. Tensions between nations have existed for thousands of years, and actual combat between nations has lasted for substantially longer periods than the Cold War between the United States and the Soviet Union.

During modern history, however, there have been few protracted periods in which the nations of the world have divided themselves into armed camps for such a long time. Furthermore, because of the skill and persistence of the scientific community, modern weapons were, and still are, capable of eliminating life as we know it on our entire planet.

During the 1964-1989 period of extended tension, the United States as the leader of the Free World, and the Soviet Union, as the leader of the Communist World, faced each other with antagonism and fury that were barely contained. However, the Soviet Union disintegrated in 1989. The Cold War was declared officially over; the United States and the Free World had won.

But did a specific country win the Cold War? Can a specific organization be singled out as having won the Cold War? A case could be made that the Manhattan Project, which developed the atomic bomb, was the one project that resulted in the success of the Allies in defeating Japan during World War II. (Germany had already surrendered by the time the A-bomb was used.)

It may be said that winning the Cold War was materially assisted by the Long Range Acoustic Propagation Program (LRAPP), even though the LRAPP program was virtually unknown to almost everyone, including almost the entire U.S. Navy.

III. ADVENT OF THE COLD WAR

The advent of the Cold War brought the possibility of the United States being attacked on its own shores, launched by submarines that carried missiles. The U.S. Government believed that it was imperative to establish defenses that would warn of the presence of Soviet submarines near the United States homeland, and to develop methods to sink them if necessary.

The success of the aircraft carriers during the war in the Pacific showed that the U.S. had the ability to project power anywhere on the face of the planet. Their existence and the power that they could project made them obvious targets for submarine-launched torpedoes and missiles. The antisubmarine warfare (ASW) problem became two separate problems: (1) confronting Soviet missile-carrying submarines off the coasts of the United States, and (2) protecting U.S. aircraft carriers and other Navy ships that operate throughout the world's oceans from attack by submarines. (Appendix A contains a listing of acronyms and abbreviations.)

Fortunate Events

By the 1960s, Soviet nuclear submarines had appeared on the scene. They not only had turbo-generators that produced electricity at 50 Hz, but they also were very noisy. Their engineering was adequate but did not focus on the myriad details that quieting demands. In effect, the Soviets made submarines that worked, but were easily detectable. This flaw gave the Sound Surveillance System (SOSUS) an expanded mission and life extension. U.S. submarines were much quieter, but they also were susceptible to detection, albeit less frequently.

A naval strategy emerged that depended on maintaining an advantageous difference for U.S. submarines as quieting technology was pitted against improvements in detection of complex acoustic signatures. The relatively easy detection of all nuclear submarines in the early days (early 1960s) gave way to an increasingly intricate evolution of systems and techniques in the seventies.

Throughout this era, the submarine component of the U.S. Navy instituted procedures to assure that only Soviet boats were reported to the ASW community as being detectable. The U.S. Navy remained concerned about ASW. As a direct result, in 1964 a new organization, the Director of Antisubmarine Warfare Programs—designated OP-095—was formed as part of the staff of the Chief of Naval Operations (CNO). Its first commander was VADM Charles B. Martell, U.S. Navy. OP-095's mission was to focus on, and solve, the ASW problem.

As always in a bureaucracy, there was a question about the reporting chain. The question was whether OP-095 should report to the Assistant Secretary of the Navy for Research and Development ASN(R&D) or to the Chief of Naval Operations (CNO), the military head of the Navy. After some deliberation, VADM Martell made it clear that OP-095 would report to the CNO, and would also have direct access to ASN(R&D). That decision was extremely important. As OP-095, he was the czar of ASW for both the technical and operations functions of the ASW program of the U.S. Navy. Reporting directly to CNO, he had both the responsibilities and the power for setting ASW requirements for the CNO. However, the financial resources to fund the program and its technical developments depended on support from the ASN(R&D).

In a single stroke, VADM Martell controlled the operational requirements, the technical and materiel assets, and the financial chains of command of the U.S. Navy for ASW. Furthermore, he clearly recognized from the beginning that the ASW problem could be solved only by thoroughly integrating its technical and operational functions. He was in an excellent position to control the naval part of that partnership. The problem, then, was how the technical community would respond to the challenge, and how it could best be integrated into the program.

At the same time another event occurred: Dr. Arthur E. Maxwell, formerly provost at the Woods Hole Oceanographic Institution, resigned from his position as head of the Ocean Sciences Group (Code 408 on the organization chart) at ONR. The Chief of Naval Research (CNR) required that this position be filled without delay. Dr. J. Brackett Hersey, also formerly part of the staff at Woods Hole, was selected for the position as Code 408. The placement of Dr. Hersey as Code 408 was extremely fortunate since he had excellent relations with the academic scientific community, and rapidly earned the trust of senior naval officials. He was knowledgeable in both policy and scientific matters and capable in dealing with both scientific and military personnel.

III. FUNDAMENTAL CONCEPTS

When the U.S. Navy decided that it needed OP-095 to focus on ASW, this move was more than extraordinary within the OPNAV organization—it was unique. All organizations within OPNAV had historically been organized along platform lines, i.e., submarines, surface ships, and aircraft. The naval officers had their specialties as submariners, or surface ship officers, or aviators. These officers were focused on the issues associated with their platforms. Before the formation of OP-095, no organization within OPNAV focused on the function of ASW as a complete system.

The concept of appointing a czar for ASW was orthogonal to standard thinking. Using the jargon of today, it was "out-of-the-box" thinking. The selection of VADM Martell as the first OP-095 proved to be extraordinarily successful.

Contracting Problems

VADM Martell and Dr. Robert A. Frosch, who was ASN(R&D) at that time, organized and sponsored LRAPP in 1967 and assigned the responsibility for the program within the Office of Naval Research (ONR). At that time, ONR controlled Basic Research (6.1) funds almost exclusively. Limited Exploratory Development (6.2) funds were also available to ONR, but not Advanced Development (6.3) funds. The placement of LRAPP, with its associated 6.3 funds, in the ONR administration was unique at that time. The LRAPP funds were directed from ASN(R&D) into ONR. The people within ONR were not familiar with the people and procedures using funds that support advanced development. Contract administrators were more accustomed to operating with the 6.1 and 6.2 cultures and their types of projects. The objectives and projects of the 6.3 community were sufficiently different from 6.1 and 6.2 programs that it caused some initial difficulties within the ONR contracting community. These difficulties were eventually resolved, but it was a struggle for all involved.

At that time, the recipients of 6.1 funding were almost exclusively universities and some government laboratories. All organizations that received 6.1 funding performed basic science research and never felt a sense of urgency to deliver their products. Their work served as the scientific foundations for naval technical systems and programs that would be executed perhaps 20 years in the future. They previously had no role in trying to stand shoulder-to-shoulder with the operational Navy.

The primary recipients of 6.2 funding were not the universities but were Navy laboratories; a few industrial organizations also used 6.2 funds as part of their research programs. These organizations were not accustomed to working with the operational Navy, but they were a little closer to doing so than the basic researchers. The 6.2 culture, however, also felt no sense of urgency in dealing with the existing ASW threat and that, too, was correct; it was not their job to solve immediate operational problems with exploratory development funding.

The recipients of 6.3 funding were basically members of the Navy laboratory system and industrial contractors. These organizations were much closer to the operational Navy. Frequently, some of their advanced development systems were used on a "not-to-interfere" basis in Fleet exercises. After all, the Navy was interested in ensuring that the systems in the advanced development stage could perform the task for which they had been designed, and the systems being tried would eventually have to operate accurately in the real world. This culture was alien to the 6.1 research and development (R&D) communities that were the primary organizations reporting to and supported by ONR. Clearly, the introduction of LRAPP into the ONR community would induce certain administrative strains.

Although VADM Martell and Dr. Frosch had established LRAPP as the only 6.3 program in ONR, it was VADM Edward Waller's (who served as OP-095 after VADM Martell and VADM Shear) opinion that this unusual arrangement was the only way that LRAPP could have survived and prospered. VADM Waller understood that LRAPP, as an R&D program, would have been at the mercy of the other Advanced Development programs within the Navy's System Commands (SYSCOMs). As the only 6.3 program in ONR, there was no possibility for any reprogramming of funds from other ONR programs. Remember, it is nearly impossible to change money categories, i.e., 6.2 Exploratory Development money cannot be used for 6.3 Advanced Development programs. The reverse is also true. Therefore, other programs in ONR, which were 6.1 and 6.2, could not use LRAPP money to conduct related scientific studies.

ONR was unique within the Navy. It was a research office that reported directly to the Secretary of the Navy and was primarily under the guidance of the Assistant Secretary of the Navy for R&D (ASN R&D). Thus it differed from a platform-focused System Command. ONR had wide-ranging interests in scientific research in all disciplines. Because of this uniqueness, there was considerable concern within ONR that LRAPP, as a 6.3 program, was outside the bounds of the ONR mission, which was to conduct research in science and technology of potential future value to the Navy and the Marine Corps. VADM Waller, however, felt that LRAPP, with its advanced scientific developments, was doing exactly that—supporting development of tools focused on the ASW problem that would support future Fleet operations.

The Fleet Supports Science

Another unique characteristic of LRAPP was the integration of scientific explorations with Fleet exercises. VADM Waller, in a personal interview, clearly remembers that he never heard any complaints about LRAPP explorations from the Fleet. The Fleet commanders were grateful for any help that LRAPP could provide.

The LRAPP philosophy under Dr. Hersey (the first program manager) was well balanced and well integrated. It was clear from the beginning that (1) the real focus of support to the operating Fleet would have to be the extended use of computer models; (2) these models would have to be developed by the scientific community and validated with the results of oceanographic exercises; and (3) these models would have to be computed and the results delivered to the operating Fleet in a timely manner. These three requirements essentially defined the operations of LRAPP for its entire life.

The computer models were developed by individuals from universities, Navy laboratories, and industry. The oceanographic data, which were both difficult and expensive to obtain, would require assets (ships and associated support equipment) from both the university oceanographic fleet and the Navy laboratory fleet of research platforms, as well as support from actual operational Navy ships. The Navy ships normally were extremely difficult to obtain. The oceanographic data collection efforts would be supported by people from the seagoing measurement community, primarily from universities and Navy laboratories, with some industry participation. Reduction of the massive amounts of data would be done by specialists in such efforts. These specialists came from diverse places, but generally from Navy laboratories and industry.

The Fleet computer models operated 24 hours a day, using naval communication capabilities that reached all the corners of the world. This Fleet support operation would be totally under the control of the U.S. Navy, and there was a place for this to happen – Fleet Numerical Weather Central (FNWC), under the command of CAPT Paul Wolff.

IV. LRAPP EXERCISES

Immediately following his appointment as the program manager of LRAPP, Dr. Hersey sponsored four exercises. One exercise, the Pacific Acoustic Research Kaneohe/Alaska (PARKA), collected some excellent data. In fact, PARKA was one of the most carefully collected and complete oceanographic data set ever taken, even to this day. The other three exercises failed to collect useful data. Generally, failures mean the death of a program. But, in this case, lessons learned from these failures transformed the LRAPP administration and focus to one that eventually led to success in every part of the program.

PARKA Experiment

Literally hundreds of people were associated with the PARKA series of experiments. There were three experiments as part of the PARKA series. The care and devotion of the participants in gathering the data from this major oceanographic measurement series set a standard for at-sea experiments that is still followed today. The acoustic database for the PARKA series of experiments remains unique among oceanographic databases because of its exacting detail and accuracy.

The first major measurement experiment took place in the Northeast Pacific. PARKA was run over 1700 nautical miles (nmi) from Hawaii to the Aleutians to validate the acoustic models. The chief scientist was Dr. Rudy Nichols from AT&T.

Seven at-sea units were scattered throughout the operating area to gather acoustic data. The only way to integrate the measurement results was through rigid adherence to a time schedule. After the experiment, the data reduction and analysis could be coordinated only by knowing the location of each unit at the specific time the data were taken. Throughout the experiment, many of the units at sea never came close to each other.

The PARKA program had three components: PARKA I, IIA, and IIB. All measurements were taken along designated lines of bearing from Hawaii to the continental shelf of North America.

Environmental measurements included all measurements relevant to underwater acoustics. The standard oceanographic measurements, temperature and salinity as a function of depth, were collected. These data were supplemented by directly measuring the speed of sound as a function of depth. The bottom profile, i.e., the bathymetry, was also measured in detail.

Acoustic measurements consisted of placing hydrophones in a vertical string and measuring the amplitude of the arriving signals. The sources of the signals were explosive charges dropped from a ship (later airplanes). These explosives are called sound underwater signal (SUS) charges. The drop time of the SUS charges was measured and noted with great precision. The arrival times for a given range had been precalculated so that with a reasonable degree of certainty, the arrival time for the SUS-generated acoustic wave could be correlated with when and where it was dropped.

As a simple example of why this information is so important, consider the travel time for an acoustic signal. Sound travels at approximately 5,500 feet per second (ft/sec) in water. Since one nautical mile (nmi) is 6,000 ft, it takes an acoustic signal approximately 1 sec to travel 1 nmi. When a SUS charge is detonated at a range of 300 nmi, the signal takes approximately 300 sec (or 5 minutes (min.)) to arrive at the receiving hydrophone.

To complicate matters, sound does not travel in straight lines; it follows curved paths that are dictated by the speed of sound in the ocean at each point along the propagation path. Because the paths are not straight and the speed of sound varies with depth (as well as with range), the arrival of the SUS signal is not a single precise arrival. Rather, the arrival of the acoustic signal sounds like a rumble, similar to thunder. This sound indicates that while all the signals started at the same time, different paths and thus different parts of the acoustic signal arrive at different times. Therefore, great care must be taken to associate the arriving spread-out acoustic signals with a particular SUS event. This task was not easy, but with tremendous care on the part of all participants, it was done.

Knowledge of the signal strength of the arriving acoustic signal and knowledge of the signal strength at the SUS explosion (or actually 1 meter (m) away from the explosion point) allows the transmission loss to be measured. If a sufficiently accurate acoustic model is used, the transmission loss can be correctly calculated. Comparing the measured transmission loss and the calculated transmission loss allows the accuracy of the computer model to be evaluated. Since the computer model requires environmental inputs (both the sound speed field and the bathymetry must be known), this process of model evaluation is difficult, time-consuming, and dependent on myriad details.

Two additional measurements must be made: ambient noise, and detailed information about the operation of the measurement system itself. During PARKA, since all the hydrophones were recorded, the ambient noise (the acoustic signal measured while no SUS shot were arriving) was recorded as well. The ambient noise measured during the

PARKA experiment was not considered of great importance since the development of ambient noise models was still in the conceptualization stage. There were no ambient noise models that could predict ambient noise, therefore no mathematical predictions were available to compare to the measured data. The computing requirements for making ambient noise calculations were simply too great for the state of computing equipment at that time.

The measurement systems were simply omnidirectional hydrophones. While there were many of them, they were not considered as components of a distributed array. However, because of the detailed knowledge of the hydrophone distribution, and their individual performance, it would be possible to make virtual arrays mathematically and to make predictions on how such arrays, if they existed, would perform.

V. LRAPP RESTRUCTURING

In the late 1960s, a "SEA SPIDER" measurement system was unsuccessfully deployed in the northeast Pacific. A second try similarly was unsuccessful. In the fall of 1970, remnants of SEA SPIDER were used in a horizontal array dubbed TESTBED that was deployed off Bermuda and terminated at the Navy sound fixing and ranging (SOFAR) station. Its failure to produce usable acoustic signals contributed to the decision of Dr. Hersey to make changes in personnel and the way the program was run. He hired Dr. Roy David Gaul as the new program manager. Dr. Gaul had a completely different management style from Dr. Hersey. He was well organized and believed that the program should be run with tight management controls.

Dr. Gaul was an extremely competent scientist and engineer. He understood that much of what was being attempted was high risk and thus subject to failure. He never held team members responsible for failure of physics, but he held the entire team accountable for performing at their peak capability and for keeping him and his staff informed about progress and difficulties at all times.

Each contract, whether with an industrial organization, a Navy laboratory, or a university, had a precise and detailed statement of work (SOW). As part of this SOW, the deliverables were specified in great detail. In addition, a carefully thought-out schedule was associated with the performance of the SOW. The entire mood of the program was changed from one of academic interest and scientific inquiry to one of delivery of fundamental advanced development systems, based on solid science, that would work — and work on time.

Finally, Dr. Gaul insisted on a firmly interlocked team approach to the entire problem. Personality conflicts were simply not allowed. Everyone did their job, on time, and with satisfactory results. There was neither room nor time for lack of coordination. Approximately 10% of the team participants were dismissed every year for the first several years until it became clear to all that they must work together.

EASTLANT Experiment

At that time, this experiment was unique. VADM Harold Shear (OP-095) and CAPT Vern Anderson, PME-124 at that time (PME –program manager, Naval Electronic Systems Command (NAVELEX)); 124 was the NAVALEX organization at that time) agreed to provide the towed arrays and their surface ships that were necessary to measure the directionality of the noise.

Dr. Gordon Raisbeck and Dr. Budd Williams, civilian scientists, invented the measurement technique to ascertain the directionality of the noise field using two towed arrays. The towed arrays then available were the Interim Towed Array Surveillance System (ITASS) arrays. They would be pulled at very low speeds (3-4 knots (kts)) in very specific patterns. The patterns were octagonal, and each side was long. The use of this type of pattern approximated a circle. Additional patterns with 12 equal sides were also used.

One leg took approximately 1 to 1.5 hours to complete. About 3–4 days were spent at each site. Only the amplitude of the noise was measured, not the phase. This measurement procedure provided sufficient data to answer the noise directionality question. This at-sea experiment, which lasted for two weeks, was under the control of Dr. Gaul, a civilian, something that was completely outside the experience of the operating Navy at that time, but it worked well.

The position of the Sixth Fleet was adamant: they would not give up use of the operational towed arrays in the Mediterranean to operate under scientists in the eastern Atlantic. It was the power of OP-095 and PME-124 that forced the issue. Not only were the ambient noise measurements made during the EASTLANT exercise, but environmental measurements that were necessary for the inputs to the models were also made. Shipping surveillance was conducted to learn the location of most of the merchant fleet operating in the eastern Atlantic at various times.

EASTLANT was a two-week experiment. The results showed an approximately 10 dB azimuthal variation in the directional noise, which could be directly correlated to the non-uniform, but relatively static, shipping distribution. The results were presented to VADM Shear. After considerable discussion, it was decided to permanently implant the SOSUS system in the eastern Atlantic at a cost of approximately $180 million. AT&T made the necessary equipment changes to allow enhanced analysis of the signals.

The philosophy of the SOSUS system was changed. The SOSUS system went from detecting signals in an assumed omnidirectional ambient noise field to detecting signals by taking into account the directionality of the measured ambient noise. This effort was quite substantial. The changes were based on predictions from the models and measurements made in EASTLANT. It was a significant accomplishment that the SOSUS system worked just as predicted. For the first time, Soviet submarines could be detected and tracked from the Greenland-Iceland-United Kingdom (GI-UK) Gap to the Straits of Gibraltar. This change to the SOSUS system and the associated analysis changed the entire operational procedure used by the U.S. Navy in dealing with the Soviet submarine force. It made the Soviet submarine force more vulnerable to attack.

As a direct result of this measurement exercise, the credibility of LRAPP was established with senior officers of the U.S. Navy. The LRAPP scientists had shown that they could provide something of value to the operating Navy. LRAPP was virtually assured of continuing support from both OPNAV and senior Navy civilian leaders. The substantial enhancement of the SOSUS system through the contribution of LRAPP was a notable achievement. But, in itself it did not solve the ASW problem. There was much more to accomplish, and LRAPP undertook the detailed problems with vigor and determination.

VI. LRAPP CONTINUING

LRAPP enjoyed spectacular success with the EASTLANT experiment. Dr. Gaul and members of the LRAPP leadership had faced the predisposition of the existing power structure and demonstrated that the ASW problem might be solvable if the environment was used correctly. Senior Navy officers within OPNAV now agreed that the scientists might be of use to them. The Navy civilian leadership was delighted with the success of the program and the suddenly enhanced value of a costly investment, the SOSUS system. Now it remained important to make the rest of the U.S. Navy associated with the ASW world believe that the scientific community could contribute something to the operational world.

Aftermath of EASTLANT

The EASTLANT exercise changed the paradigm on how detection and classification were made. In addition, the exercise established credibility of LRAPP with the Fleet. Previously, detection was attempted only at 50 Hz but in the

Mediterranean they began looking for 300 Hz lines. The ambient noise at 300 Hz is substantially less than noise at 50 Hz. Therefore, for a given signal strength, the signal-to-noise ratio (SNR) is higher for 300 Hz than it is for 50 Hz.

The Sixth Fleet had been using ITASS arrays towed by USS *Courtney* and USS *Hammerberg* for searching. They had been failures. They had virtually no contact time against enemy submarines. During the TASSRAP exercise in the Mediterranean Sea, two old and tired minesweepers, the USS *Alacrity* and the USS *Assurance,* took up the ASW searches using 300 Hz equipment. In three months, the two ships had more than 671 hours of verifiable contact time against Soviet submarines. Control of the two minesweepers was transferred from the Atlantic Command to the Sixth Fleet. They were then scheduled to return to the United States for retirement. This left no reliable asset in the Mediterranean theater to use against Soviet submarines. The Sixth Fleet did everything in their power to retain the old minesweepers and their ASW equipment, the towed array systems.

In the end, the *Alacrity* and the *Assurance* returned to United States home waters and were decommissioned and sold for scrap. The cost for refurbishing them as minesweepers was too great. But the Fleet operators had seen what could be done. Also, someone else recognized that the game had been substantially altered—the Soviets realized that they were in danger of being detected in the Mediterranean Sea. They left the area for a long period of time. After the success of TASSRAP, the LRAPP charter was upgraded to include Fleet support. LRAPP received additional funds from OP-095 to continue these types of support and demonstration exercises.

In the meantime, the exercise of the Large Aperture Marine Basic Data Array (LAMBDA) provided LRAPP with substantial environmental data. LAMBDA was a new towed array designed for the Advanced Research Projects Agency (ARPA), which eventually became the Defense Advanced Research Projects Agency (DARPA). This array, the brainchild of Dr. Henry Aurand, was much longer than earlier towed arrays. The greater length allowed it to be sensitive to very low frequencies, as well as to generate very narrow beams. This array was now being used in the Mediterranean for scientific measurements. An offshoot of LAMBDA was to arrive in the Mediterranean several years later and achieve astounding success.

While LRAPP was building equipment, going to sea, making measurements, and reducing and analyzing data, another part of the Navy closely aligned with LRAPP was also undergoing substantial growth and success – Fleet Numerical Weather Central (FNWC). In support of LRAPP, the modeling community began to deal directly with FNWC.

More about FNWC

FNWC's success depended on many things, but most certainly on the existence of mammoth computing power. The development of the digital computer and its effects have been told by many. In this particular instance, it was the advent of the IBM 704 that affected FNWC.

In 1954, the Naval Weather Service began to make daily weather predictions using the IBM 704. In 1956, the Naval Sea Systems Command (NAVSEA) issued a contract to a new company called Control Data Corporation (CDC), which was begun and developed by three former Navy officers, Dr. William Norris, Dr. Seymour Cray, and Dr. James Thornton. Their contract with ONR was to design and build the first all-transistor computer (later known as the 1604).

The first two computers were built and installed in the new FNWC facility in 1958. At that time, the entire staff consisted of CAPT Paul Wolff, two ensigns, three civilians, and six enlisted personnel. FNWC was the only place in the U.S. Navy where worldwide ASW predictions were made on a 24-hour-a-day basis. CAPT Wolff points out the reasons for their uniqueness:

- FNWC had the computers to do what was required;
- FNWC had databases for the Northern Hemisphere that included water temperature and salinity as a function of depth, the water depth in a six-mile grid, and the bottom reflectivity for low-frequency sound calculations; and
- FNWC had the organization, the communications equipment, and the motivation to support the Fleet on a timely basis.

Everything occurred because of a confluence of people and events, most of which were accidental and unique.

In 1967, FNWC was directed by CAPT Wolff, a world figure in meteorology. Two CDC 6400 computers were located at FNWC, as well as the CDC 1604, Serial No. 1. This machine used a 48-bit word and was the fastest machine in the world at the time of its delivery. While IBM had led the digital computing world for many years, CDC was specifically designing its machines for scientific work rather than for general computing purposes. The CDC 6400 was an excellent resource. It was used for the development and refinement of weather calculations. Remember, FNWC was an operational command, so computer predictions were made and transmitted to the Fleet on a regular basis.

At that time, ASW emphasis was on digital signal processing (DSP). To make advances in DSP, computer time was extremely important. Computers were not readily available then, nor were they easily accessible for experimentation and development. Two Fleet models had been developed. One was the Acoustic Range Prediction Systems (ASRAP) model developed by CDR Peter Tatro for patrol airplanes (VP). The other was the Ship Helicopter Acoustic Range Prediction System (SHARPS) model for ships and helicopters developed by LT Terry McCloskey. Predictions were provided to the Fleet daily. This direct operational model link to the Fleet was later exploited by LRAPP in both the model development and Fleet operations support.

Since there was not enough computer capacity at FNWC, the system has to be operated in a multiuser environment. Operating this way meant that when Fleet support was not going on, the storage space could be automatically reprogrammed and the computer could be used by model developers. This situation led to some very interesting discussions on priorities; nevertheless, the operation continued and progress was made.

In 1972, the Signal Processing Prediction System (SPPS) was operating. The SPPS was the precursor to the long-range system performance models. A contractor, Ocean Data Systems Incorporated (ODSI), was developing performance calculations to be done on the computer, and signal performance prediction was required. The environment was anisotropic, and the SPPS required careful investigation of the individual environmental elements.

The transmission loss model at that time was RP70, which was formerly the Wolff model in the 1969–1970 timeframe. It took approximately one hour per radial to do the calculations. At a minimum, there were eight radials (45-degree (deg) sectors) for its long-distance calculations (1,500 nmi). RP70 allowed range-dependent variation in both the sound speed profiles and the bathymetry, or water depth. RP70 was simply much too slow. Another model was required. This model was the Fast Acoustic Coherent Transmission (FACT), developed circa 1972. FACT was excellent for 200 nmi but could only use a single velocity profile and a flat bottom.

There were no noise prediction models then. The first model was called the FACT Ambient Noise Model (FANM), and its development was a one man-year effort. There were no signal processing, beam pattern, or shipping models. A shipping model, which is crucial as input to any ambient noise model, was developed by Dr. Louis Solomon and Dr. Allen Barnes of Planning Systems Incorporated (1973). It was called the Historical Temporal Shipping Model (HITS). Mr. Ken Osborne developed the architecture for the components of the models. The components were built individually and in parallel with each other.

It was decided to run the RP70 overnight for many different cases and then to relate the parameters that drove the RP70 to the convergence zone (CZ) predictions they supplied to the VP community. The result was the Acoustic Sensor Range Prediction (ASRAP) model.

Other transmission loss models began to be developed at FNWC. At that time, the Fleet either made direct path detections or first convergence zones detections, spaced about 30 nmi from the source. (The exact distance depends primarily on the characteristics of the sound speed profiles.) The Fleet could detect nothing between convergence zones, so there were many relatively close regions where no submarines were detected.

The next major effort was the development of the ASW prediction areas. The specific ASW prediction area was designated as being within those areas in which everything remained relatively constant. There were maps of the bathymetry, bottom loss, and major water mass boundaries. When these maps were overlaid, there were regions where everything remained relatively constant. Such a region became an ASW prediction area. FNWC was responsible to perform all the acoustic performance predictions for each ASW prediction area. This information was calculated and delivered to the Fleet. Three frequencies were used for the calculations. On one day, one frequency was calculated for all ASW prediction areas; on the next day, a second frequency; and on the next day, the third frequency. Then the process was repeated. The environment was sorted by latitude and longitude.

It was inevitable that Dr. Hersey and CAPT Wolff would collaborate and that CAPT Wolff would receive R&D money. Naval Weather Service funds were operational monies and could not be used for R&D efforts. Under various influences, CAPT Wolff became interested in underwater acoustics. Dr. Hersey, whose main interest was science, became involved in a real-time data network because of his relationship with CAPT Wolff. Dr. Hersey and his subordinates also got substantial running time on the world's biggest and fastest computers. CDC was an ardent supporter because FNWC was the first to purchase their large computers and let them be tested by CDC personnel in FNWC spaces. The three all had much to gain, and the U.S. Navy profited.

SOSUS was now beginning to provide considerable information about transiting Soviet submarines. The Navy needed predictions about the capability for any SOSUS site and for any beam, to detect the Soviet submarines at different ranges. The calculation of transmission loss required the environment as input. That environmental data set was as difficult and time-consuming to prepare as the model runs themselves.

After considerable argument and discussion about the needs of the users, it was decided to abandon detailed calculations. Approximation would be used whenever possible. This method of using approximations reduced the running time from one hour/radial to one minute/radial. The environmental data were put together from synoptic sound velocity profiles obtained from the Naval Oceanographic Office (NAVOCEANO).

The cost to run the calculations for each SOSUS site was about $50,000, mostly because of the improved modeling techniques developed under LRAPP sponsorship (in the late 1970s, the cost for calculations dropped from $50,000 to $1.50). This amount was for only eight radials and for 1,500 nmi from each site. Both the cost and the poor coverage were simply unacceptable. It was necessary to consider radials to be at 5-deg increments, giving a total of 72 radials. Clearly, a different approach would have to be used. In addition, the need to switch to a climatological database that was in 5-deg sectors became apparent. The climatological database was then merged with the synoptic surface temperature. The result was an environmental database that changed on a daily, even diurnal basis.

Because of the computing power at that time, it was considered that transmission loss could not simply be a ray trace model. New models had to be developed. This meant that CAPT Wolff's model, RP70, and the basis for his beginning relationships with Dr. Hersey, had to be relegated to the museum. RP70 survived by making calculations for very short ranges. The results of PARKA, CHURCH ANCHOR, EASTLANT, and many other at-sea measurements gave substantial evidence that computer models could predict the behavior of ASW systems in general, and SOSUS bottom systems in particular. The models were used for new SOSUS site selections and new system designs and, in particular, they were applied to towed arrays.

LRAPP had a collection of people who worked on different elements of the computer programs. Mr. Charles (Chuck) Spofford invented the Antisubmarine Warfare Transmission Loss Model (ASTRAL). Dr. Ron Larsen of the Naval Ocean Systems Center (NOSC), San Diego, California, worked on the beamformer. The signal excess equation was calculated, and work was done on the elements of the equation; the signal excess calculation was known as the Automated Signal Excess Prediction System (ASEPS). Dr. Solomon and Dr. Barnes developed the Historical Temporal Shipping (HITS model). Mr. Spofford and others invented the Bottom Loss Up-Grade (BLUG) model. Each person was an expert in the individual components. Mr. Ken Osborne's group at Ocean Data Systems, Inc. (ODSI) did the integration.

Early LRAPP days saw constructive collaboration between the contractors and the Navy. The principal investigators were hand-selected. This early collaboration did not last forever, and corporate competition eventually came into play. The Competition in Contracting Act made it impossible to just pick the best performer for a job without full and open competition. It is Mr. Osborne's opinion that an effort such as LRAPP could not be done today, given the current contracting climate. Although LRAPP had significant internal cooperation, there was some hostility among some organizations and some individuals. However, many people were devoted to retaining the professionalism of the program. Initially, there was a significant "not invented here" factor, but that ultimately was overcome.

VII. MODEL DEVELOPMENT

As FNWC grew and supported the Fleet, which included providing the performance predictions for all the ASW systems throughout the world's oceans, a group devoted to the development of acoustic models directly focused on the needs of LRAPP evolved: the Acoustic Environmental Support Detachment (AESD), a detachment of ONR located at the Naval Research Laboratory (NRL). Its first officer in charge was CDR Peter Tatro of ONR, who had originally worked for CAPT Wolff and with Dr. Aurand in the early days of LRAPP, and then founded and led AESD.

Computer models are the favored tools of scientists and engineers. Since the original and early work associated with a model requires very little money, almost everyone develops computer models for their own projects. This abundance of models leads to substantial difficulties between different models and modelers, who have a tendency to compete for fame and fortune in the same area. The issue becomes serious when different models, focused on the same problem and driven by the same inputs, provide different predictions.

Thus, it became necessary to have model "bakeoffs," which were sponsored by AESD. The issue was that models had to generate the same outputs for the same inputs. These bakeoffs were meetings where anybody could come and present their model results to the assembled community. The catch was that all the models presented were given the same set of input data – then the outputs of the different models were compared with each other as well as with measurements. This process, while at times embarrassing for those models (and modelers) that made predictions that didn't compare well with data or with other models, was necessary. The process was done with reasonable diplomacy and tact but proceeded regardless of the occasional embarrassments and obvious model failures. The only thing that really counted was the ability of the computer models to have independent agreement with the measurements.

There were other issues also; speed and model size were two measures. Since the ultimate user of the models and their predictions provided by FNWC was the operating Fleet, the correct predictions were very important. But, the computer models had to run sufficiently fast and also had to be capable of being run on existing computers of that time.

The Navy uses many systems. Their optimum performance depends on consistent and correct predictions from Navy Standard models. Dr. Hersey was the modeling coordinator of the U.S. Navy for oceanographic models. He was responsible for developing and certifying Navy Oceanographic Standard models. Existing systems used the computer models developed by the Navy laboratories. Unfortunately, systems using different but ostensibly similar computer models frequently provided different predictions for the same problem. For example, two high-speed, short-range transmission loss models (FACT and RAYMODE) used a single velocity profile and a flat bottom. While both computer models were based on the same physical assumptions and used the same forms of available input data, they sometimes provided different, incompatible predictions. Which model was correct? How would the operators at sea know which answer to choose if they had two different answers? The Fleet, whose members needed to use the model predictions, simply threw up their hands in disgust at the model differences. It was absolutely imperative that computer models used by the Fleet provided the same answers for the same input data. Eventually, this led to the concept of competition between two or more similar models. This competition led to the selection of only one model, which became certified as the Navy Standard Model, to be used for a specific set of circumstances. This model provided only one answer, and this was the answer used by the Fleet.

FACT eventually became the interim Navy Standard Model for transmission loss. Later, the Parabolic Equation model (PE), developed by Dr. Fred Tappert, became the Navy Standard model for transmission loss at surveillance frequencies. The PE model evolved from its original form that was developed and used as a model to predict radar performance. Initially, PE could not handle upslope calculations. However, as it was further developed, that problem was solved. PE used a triangular scheme developed by Dr. John Hanna for interpolating velocity profiles that worked very well.

An interesting issue grew within the surveillance community. Substantial conflicts arose between the Navy laboratories and Bell Laboratories. Within the Navy, each laboratory was funded by the parent Systems Command (SYSCOM). At that time, Naval Air Development Center (NADC) was funded by Naval Air Systems Command (NAVAIR); Naval Undersea Systems Center (NUSC) was funded by NAVSEA; and Naval Ocean System Center (NOSC) was funded by NAVELEX. These laboratories received 6.2 money. AT&T worked on surveillance, but there was no SYSCOM for surveillance.

With the continued success of SOSUS, Navy laboratories began to be interested in supporting SOSUS, which really had been developed by AT&T. As part of OPNAV, OP-095 was worried because there was no real technical organization that could or would challenge AT&T. However, LRAPP provided that opportunity for real scientific competition. Although competition between the working scientists and engineers was relatively pleasant and cordial, real tension developed between the leaders of these organizations. The primary reason was the financial support provided by the SOSUS system, OP-095, and PME-124.

All SOSUS data were received from Western Electric. Both Western Electric and Bell Laboratories were wholly owned subsidiaries of AT&T. It was decided that future SOSUS system detection arrays would be placed in the sound channel, as well as on the bottom. That meant that it was necessary to find seamounts (underwater mountains) that rose from the sea floor into the sound channel. Finding such places involved reviewing the bathymetry to find seamounts that intruded into the sound channel. Just before the sound arrived at the hydrophone array, it interacted with the bottom, or in this case, the side of the seamount. This effect caused a major effort to focus on sound interaction with the bottom. The data used for development of bottom interaction models came from the old worldwide survey for the SQS-26 active sonar. These data, painfully and expensively gathered in support of the SQS-26 system by Alpine

Geophysical over many years for NAVOCEANO, still existed. Mr. Spofford and others used those data to develop the Bottom Loss Up-Grade (BLUG) model that replaced the ancient curves (called the Bassett-Wolff bottom loss curves) developed by Mr. Charles Bassett and CAPT Paul Wolff.

AESD supported the SYSCOMs and delivered results of transmission loss and ambient noise calculations. One other major effort of AESD, in addition to supporting the development of different types of models, was the preparation of common data sets necessary for use in Requests for Proposal (RFP). Big companies that design and manufacture hardware systems for use by the military always attempt to demonstrate their systems in the best possible light. However, it is the responsibility of the government and its representatives to make sure that these expensive systems will operate as advertised in a variety of environmental and operational scenarios.

For that reason, when RFPs were issued by the government and sent to the industrial community, data sets were prepared and provided to each interested contractor. They were required to show how their system would perform under each of the environmental and operational scenarios. This information would allow comparisons between the capabilities of the competing systems. This approach, so standard today, was met with considerable reluctance by the industrial community. They were accustomed to present their systems in a favorable light and leave it to the Navy to decide how the systems would work in not so favorable conditions. When this procedure was implemented the first time in support of the Moored Surveillance System (MSS), at least one contractor objected strenuously, raising the objection to the Secretary of the Navy. After listening to the arguments in an emotionally charged meeting where AESD was represented by CDR Tatro, the Secretary wisely decided to support the process. It was a precursor for the procedure that is followed to this day.

Most people focus on the at-sea experiments, which were the most expensive part of the LRAPP effort. These experiments get the most publicity and can be extremely exciting as well as interesting. But they take data in one general area, at one time. These data cannot be changed to be applicable for another time and place; however, these data can be used to validate and verify the predictive capability of the computer model.

Computer models have the power to live past the experiment. A system can also be built using only models. Not only do the models subject the system to substantial tests in different areas under different environmental conditions, but they also are critical in ascertaining how the actual physical systems should be deployed. Finally, models allow the results of either experiments or operations to be interpreted and explained. Thus, in the final analysis, it was a suite of computer models that was the ultimate product of LRAPP.

VIII. ADDITIONAL LRAPP EXERCISES

The most obvious activity of LRAPP was the unceasing planning, implementation, analysis, and reporting of field exercises. These exercises were not unique in the annals of the U.S. Navy, but the way they were conducted was unusual. Historically, most naval field exercises were run by universities or Navy laboratories and were generally supported by basic research (6.1) or exploratory development (6.2) funds. As such, they had little interaction with Fleet units. They were generally conducted without a sense of urgency. Experiments were planned, measurements made, and results eventually analyzed and finally reported in professional journals. The results were not readily available to senior government and naval officials, nor were their implications easily understood.

The LRAPP field exercises were radically different. They were supported by advanced development (6.3) funds and had close interactions with Fleet units. They were designed to produce results that had possible national repercussions, and their visibility to senior naval and government officials was high. In the course of LRAPP, approximately 96 exercises took place over the life of the program. This number of exercises has no precedent in naval/scientific investigations. (The number is approximate because some exercises had different phases and were sometimes counted as separate exercises, and sometimes as part of the same exercise. At least one exercise, BEARING STAKE, was not paid for with LRAPP funds. It was directed by Dr. Robert Gardner using all LRAPP personnel and support contractors. BEARING STAKE belongs with the LRAPP list of exercises for all intents and purposes.

Each exercise took approximately 18 months from conception to conclusion of the actual event. To some extent, this period of time was the direct result of Dr. Gaul's leadership. He insisted that the exercise be planned in meticulous detail. Not only was this important, it was also mandatory. Dr. Gaul had an unusual procedure that was generally not followed by any other manager associated with at sea experiments: he divided the funds into two separate parts, roughly equal in size. One part was for the actual expenses associated with the exercise. The other part was for the data analysis and reporting.

Other managers generally did not use this demanding procedure. The previous result frequently was that most if not all of the funds that their programs received for ocean exercises were spent on the exercise itself. Regardless of the quality of data, frequently no funds remained to perform the analysis. Dr. Gaul believed and was strongly supported by many members of the scientific community that unanalyzed data and data unreported in a timely fashion were equivalent to having no data.

The process of running field experiments first required specification of the objectives of the experiment. What needed to be measured? What equipment would be used? Where would the exercise take place? What platforms (ships and airplanes) would be required for support? Once these questions were answered and agreed to by the senior naval officers, the detailed planning would begin.

It is useful to comment on the scale of these experiments. As an example, consider the CHURCH ANCHOR exercise. It was run in 1973 in the Northeast Pacific. It was roughly bounded by the west coast of the United States, the International Date Line, Hawaii, and Alaska. This area comprises approximately one fourth of the Pacific Ocean. Most of the measurements were made along the experiment baseline, which was 143°30′ W longitude for a distance of approximately 2,000 nmi. This geography meant that many ships that took part in the experiment never saw one another. They left for participation in the exercise from different ports at different times, performed their assigned tasks at sea at different positions according to a rigid time schedule, and left the exercise for their individual destinations once their jobs were complete. The airplanes used in the exercise took-off from military air bases throughout the North Pacific region at different times, flew different tracks, and returned to their designated bases at the end of their missions.

The complexity of this effort was directed by the chief scientist or the technical director; these were senior people assigned to exercises for monitoring or coordinating day-to-day at-sea operations. There was communication among all of the exercise elements using radio and military messages.

Time was the common element that allowed the integration of the data after the exercise was completed. All activities were governed by Greenwich Mean Time (GMT) or, using the military designation, Zulu time. Accurate time coordination was mandatory. Ships in one part of the Pacific did their assigned tasks at the same time other ships in different locations did theirs. Each individual platform had a senior scientist on board who regularly informed the technical director of his or her activities, difficulties, etc. If there was a problem, sometimes it was up to the technical director to make changes in the exercise schedule. Such changes were initiated only under the most compelling conditions. There were several ships, many aircraft, and dozens of people whose sole point of contact was the technical director and his support staff.

At the end of the experiment a meeting was held by most, if not all, of the participants at a convenient place (usually near an international airport). This meeting, called the Hot Wash-Up, allowed all data to be transferred to the control of the technical director and his analysis support staff. All pertinent information was discussed, and the general and specific details of the individual platforms were given to all attendees. These meetings, while informal and usually punctuated by "sea stories" of the happenings during the exercise, were crucial. Each senior scientist gave a preliminary report on the quality of measured data, and it was immediately clear to all whether the experiment was a success or failure.

In the 96 experiments run by LRAPP over 25 years, there was never a major failure (although some consider SEA SPIDER and TEST BED to be major failures). The participants were forced by Dr. Gaul to have plans, contingency plans, and even further contingency plans to make sure that data would be obtained and that the objectives of the experiment could be met. The cost of such experiments, depending on the size of the exercise, was generally measured in millions of dollars. A failure of a critical element, measurement device, or platform would mean that the entire experiment produced no data. The money would have been spent, and there would be no results. The responsibility for assuring success in obtaining the data was felt by the entire scientific community. It was frequently stated that they were working for the United States taxpayers and success in obtaining data was a personal responsibility.

Dr. Gaul insisted that the modeling community step up and be counted. While the glamour, whatever there is, generally resides with the people who go to sea, take the measurements, and have wonderful stories to tell after they return, the real fundamental results that LRAPP delivered to operating Fleet assets were predictive models. At any given moment, Fleet ASW personnel have only certain information available. This information translates into knowledge of the environment (summer or winter, which ocean, stormy or clear, etc.) and some intelligence information (e.g., "a submarine left Soviet home waters and historically followed some general path to its operating area").

In addition, only certain types of equipment were part of each ship's operating inventory. ASW personnel needed computer models that would use all existing data to predict their best tactics, given the constraints of equipment, geography, and local operating conditions, to provide the highest probability of detecting and then tracking the Soviet submarines. Therefore, Dr. Gaul insisted on using the "Mason jar" approach. When an exercise was finally planned, i.e., it was decided what was going to be measured, at which frequencies, at which depths, etc., etc., etc., the modeling community had to generate predictions for each and every measurement. These predictions would be made before the experiment was begun. The results were placed in a sealed Mason jar and then compared with actual measurements when the exercise was over. The data were analyzed and put in a format that would allow comparison to predictions.

The modeling community was reluctant to do this, but Dr. Gaul prevailed. The knowledge that comparisons would be made between actual measurements and model predictions produced several interesting results. First, the measurement people knew that their results were going to be considered as fundamental truth. This knowledge increased their concern with accuracy, multiple measurements, contingencies, and many other techniques that would provide a database that was as precise as possible.

Second, the modelers really focused on the results of their models. When the predictions of measured results were presented in a semipublic forum (highly classified, but involved members of LRAPP were there) and found to be substantially different from the measurements, it became necessary for the modelers to explain why there were differences. It could be most unpleasant time, and modelers simply did not like it. As a result, considerable care and effort were used to increase the capabilities of the models.

Third, the modelers came to realize that not only was predictive accuracy required, but also the calculations must be available in very short periods of time. The Fleet has hundreds of operating units, and they operate worldwide for 24 hours a day, 7 days a week. At this period of computer development, all the calculations were to be performed at FNWC and the results transmitted to the operating units of the Fleets on a daily, and frequently hourly, schedule. Thus, the modelers need to develop fast and accurate models.

Because of the short time between the end of the experiment and the Hot Wash-Up, there was limited time for preliminary major results to be considered, analyzed, and discussed. These results, preliminary and incomplete as they were, were the basis for presentations to senior naval and civilian command authorities. This process of making these presentations was generally referred to as the Road Show. Dr. Gaul and those who had actually done the work (generally the exercise technical director, the chief scientist, and the appropriate senior scientists) presented the results at numerous meetings.

Of particular importance were the presentations to ASW elements of the Fleet. In many cases, LRAPP was heavily involved with Fleet units during the course of the experiment and worked on problems of direct and immediate concern to them. Scientific results of the experiments were placed in the context of operations. LRAPP may have been the only program that regularly worked with Fleet units and made their results known to them in the period immediately after the conclusion of the experiment. This created a very strong bond between the Fleet units and LRAPP.

LRAPP management solved this problem in several ways. The first was to have naval officers as part of their staff. It was quite instructive to see commanders and lieutenant commanders accompany Dr. Gaul and senior scientists when they went for meetings with the major Fleet commanders. Hierarchies exist in all organizations, and perhaps more in the military than in nonmilitary organizations. Within the Navy culture, lieutenant commanders do not usually talk directly to admirals in command of major Fleets, and usually do not attend working meetings with them. Yet LRAPP scientists marched in and part of their staff may have been a lieutenant commander or commander.

In fact, the relationship between LRAPP and pertinent naval commands prospered because of this. Dr. Gaul and the senior civilians would discuss details of the experiment, and a general agreement would be reached between the scientific and naval leaders. Dr. Gaul would then indicate that the lieutenant commander would be his point of contact for all matters relating to interactions with the Navy. The admiral would then feel at ease because he knew that a naval officer would interact with all the elements of his command, observe the proper protocols, send the proper messages, and understand the requirements of Navy operations. And it worked. All the naval officers associated with LRAPP recognized their highly unusual positions and considered it to be an unusual trust. Each of them earned the respect of their naval superiors, and each was promoted regularly. The operating units of the Fleet, both at sea and ashore, were extremely responsive to requests from the LRAPP naval officer for two reasons:

- One, they were naval officers and clearly knew what they were doing and knew how to ask for things in the Navy way.
- Two, it was clear that this particular naval officer, while perhaps only a lieutenant commander, had direct access to the Fleet commander. This access was highly unusual, but it was understood by all that this was the only way to assure the highest probability of mission success.

LRAPP assured its success with the Navy in one other way. The LRAPP community in general recognized that they would be on intimate terms with operating Fleet units. LRAPP would use the ship's equipment as well as their own, and they also would use the Navy communications system. Thus LRAPP would become part of the Navy in an odd way. Every member of LRAPP came to the conclusion that they would make themselves acceptable to the Navy at all levels. So, everyone did things "the Navy way." In addition to doing things the Navy way, LRAPP also showed naval personnel what they were doing and how their results were specifically focused on the problem of finding Soviet submarines. After initial skepticism (in every exercise), LRAPP personnel found that the naval personnel respected them and treated them as colleagues with special capabilities that could help them in their day-to-day mission: defeating the Soviet submarine force.

IX. FIELD EXERCISES

The 96 field exercises were arranged roughly into two separate groups: scientific and operational. The scientific exercises, by far, predominated.

LRAPP people went to all the oceans in the Northern Hemisphere and the Indian Ocean (BEARING STAKE). Figure 1 shows the location of the worldwide LRAPP exercises; Fig. 2 is a detailed chart for the Mediterranean. Table 1 corresponds to the location of the exercises. Each exercise had specific and detailed objectives. As a rule, these objectives involved the measurement of certain ocean characteristics: temperature, salinity, and sound speed at various points as a function of depth from the sea surface to the bottom, and bottom measurements. It also entailed measurement of transmission loss and ambient noise, as well as the components of ambient noise such as merchant ship locations.

EASTLANT

EASTLANT might be considered to be the most important exercise that LRAPP conducted. The situation of the U.S. Navy and AT&T having different recommendations about the implantation of SOSUS arrays in the eastern Atlantic was resolved, but certain facts bear repeating here.

The Navy was desperate for indications and warnings (I&W) of Soviet submarine activity in the open ocean. The ASW problem, always difficult and thought perhaps impossible to solve, was even worse without I&W because it was the first element in the prosecution of an enemy submarine.

AT&T, or at least one part of AT&T, believed that ambient noise levels were very high, making the SNR so low that the range for possible detection of submarines would be too small to provide any I&W intelligence of value. Dr. Hersey and Dr. Gaul, supported by members of the LRAPP community, insisted that the ambient noise in the part of the frequency spectrum of primary interest (lower frequencies around 50 Hz) was directional. That one piece of information, if true, would radically affect the methods that would be used to search for submarines.

VADM Shear had already delayed the implantation of the SOSUS arrays for one year. He could not wait any longer. Either he would cancel the implantation, or he would let Dr. Gaul and his scientists see if a solution could be found. It was good fortune for the nation, ASW, and LRAPP that VADM Shear decided to let Dr. Gaul try to prove his theories.

The results clearly demonstrated, even with the relatively crude equipment of the moment (ITASS arrays towed by destroyer escorts), that the ambient noise was directional, showing some 10–15 dB variation with different azimuths. This result proved to OPNAV and to the ASW military and civilian leadership that civilian scientists focused on ASW and working hand-in-glove with the Fleet might be able to provide the scientific tools that the operational Navy was lacking. In essence, not only did EASTLANT provide an answer that saved the basis for SOSUS system enhancements, but it also established LRAPP's credibility, which was never lost for the rest of the life of LRAPP.

X. ARCTIC OPERATIONS

By the early 1980s, Soviet strategic submarine operations began to change from forward deployments off the coasts of the United States and in the Caribbean, to patrols that did not leave the waters near their submarine bases on the Kola Peninsula and the Seas of Okhotsk and Japan. The United States responded to these developments by promulgating a plan called the Maritime Strategy. This plan called for an immediate, large-scale naval response to

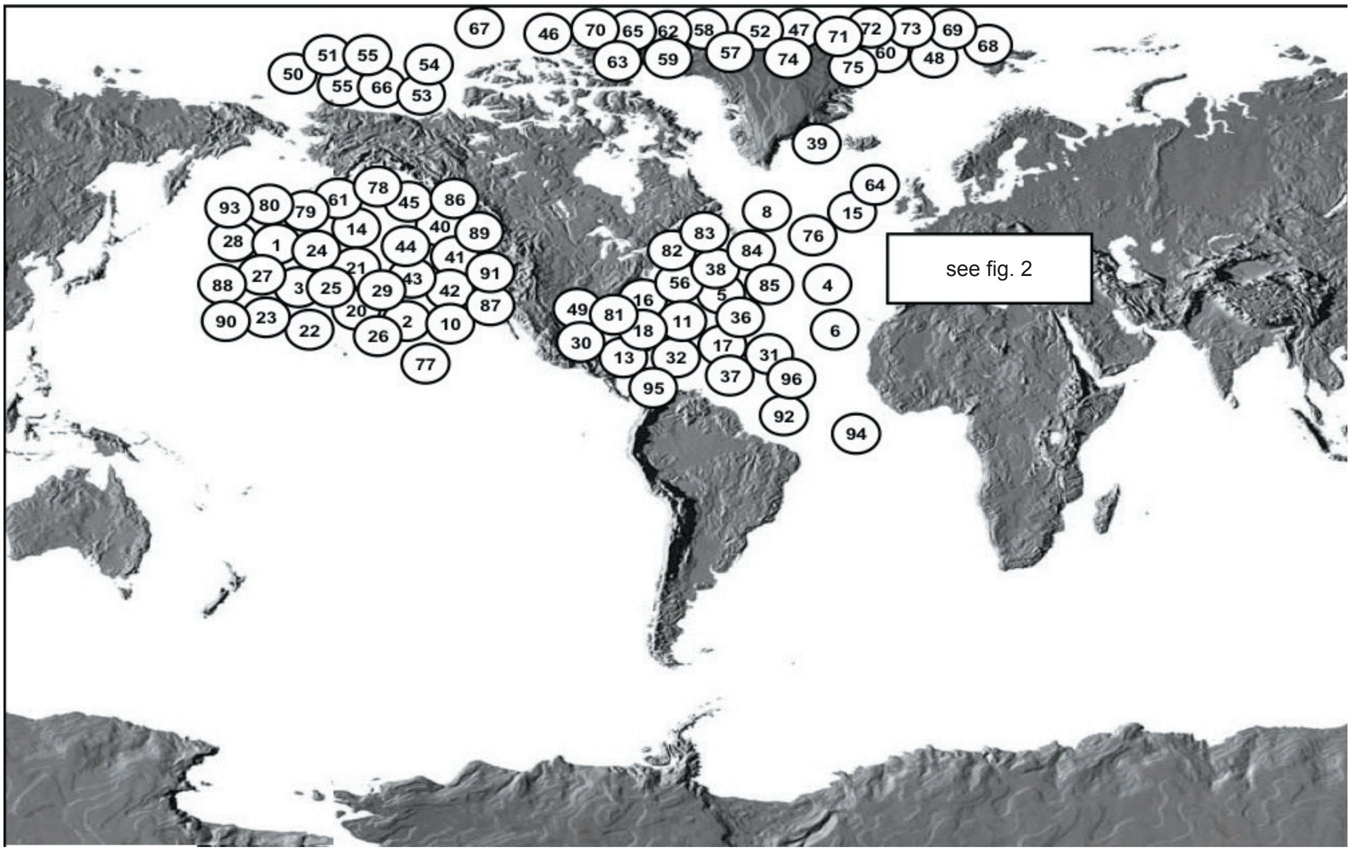

Fig. 1 — LRAPP exercises worldwide

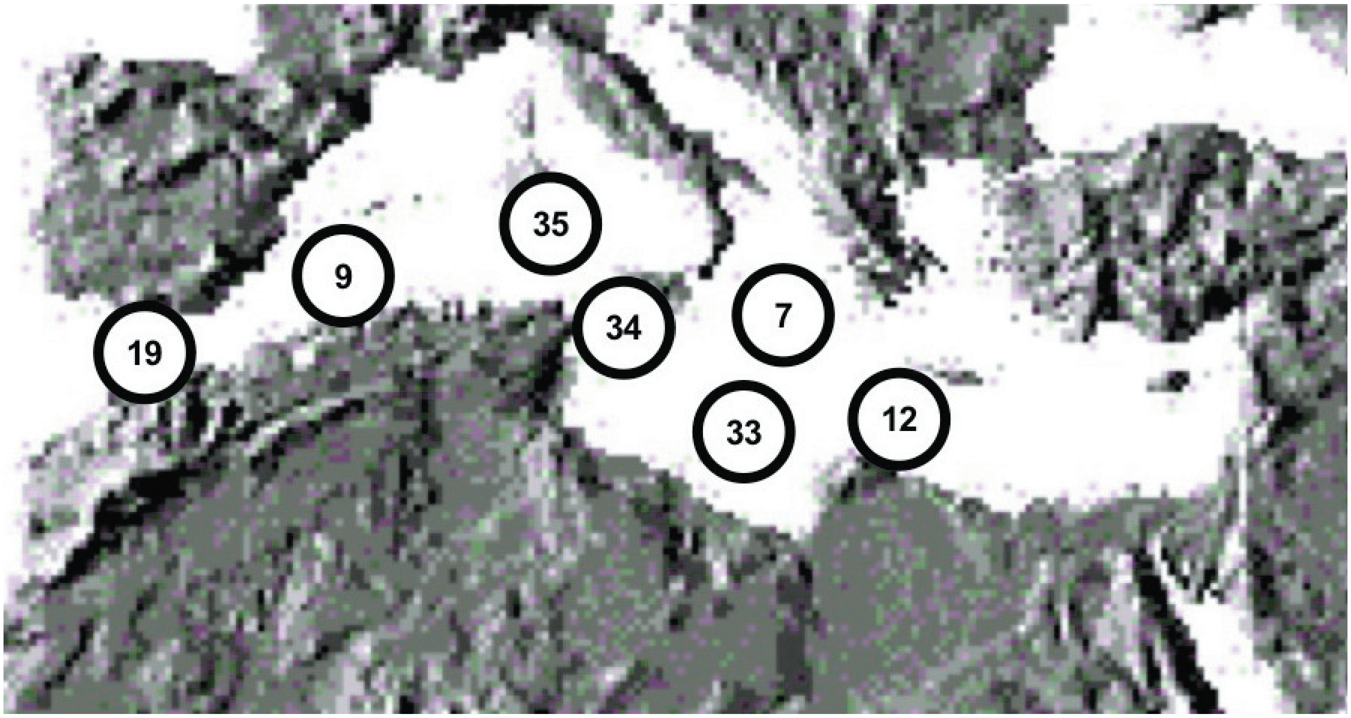

Fig. 2 — LRAPP exercises Mediterranean Sea

Table 1 - Geographic Key to LRAPP and Related Exercises

No.	Experiment	Date	Geographic Area	Remarks
1	PARKA I	Aug–Sep 68	N of Hawaii	Incl. Sea Spider attempt Rudy Nichols/CS; Gerry Fisher/Proj. Coordinator
2	PARKA IIA	Sep–Dec 69	NE of Hawaii	Incl. Sea Spider attempt Rudy Nichols/CS; Gene Flesher/OTC
3	PARKA IIB	Mar 70	N of Hawaii	Fred Speiss/CS
4	NEAT I	70?	NE Atlantic	Ralph Goodman
5	TEST BED	Dec 70	Bermuda	Ray Hasse
6	NEAT II	71?	NE Atlantic	Ralph Goodman
7	IOMEDEX	Nov 71	Ionian Basin	
8	NORLANT-72	Jul–Sep 72	E of Labrador	Bob Martin/CS
9	Alboran Sea	Aug–Sep 72	Alboran Basin	
10	EASTPAC Sea Test	Oct 72	Off San Diego	
11	Bermuda Coherence Test (unnamed)	Oct 72	Bermuda	
12	TASSRAP	Fall 72	Mediterranean	
13	Church Gabbro	Nov–Dec 72	Caribbean Sea (Cayman Basin)	
14	Church Anchor	Aug–Sep 73	NE of Hawaii	Bud Fadness
15	Square Deal	Aug 73	NE Atlantic	
16	Blake Test	? 73		
17	MSS Baseline	Oct 73	Virgin Islands	
18	CAPER	Jul 74	Pacific	
19	MASWAP	Aug 74	Mediterranean	Terry McCloskey
20	Kent Beacon	? 75	Pacific	Primarily Fleet exercise
21	Church Opal	Sep–Oct 75	N of Hawaii	
22	Fixed-Mobile Exercise	? 76	Pacific	
23	CHURCH STROKE I	Jun–Jul 77	NE of Hawaii	
24	CHURCH STROKE II Cruise 1	Aug 77	Pacific	
25	CHURCH STROKE III. Cruise 2	Sep 77	Pacific	
26	CHURCH STROKE II, Cruise 3	Oct 77	Pacific	
27	CHURCH STROKE II, Cruise 4	Nov 77	Pacific	
28	CHURCH STROKE II, Cruise 5	Nov–Dec 77	Pacific	
29	CHURCH STROKE III (Cruise I)	1979?		
30	Gulf of Mexico Cruise	1979		
31	PILOT MEASUREMENTS	1979		
32	RDSS/AVT (Rapidly Deployable Surveillance System)	1979		
33	Big Dipper	Jun–Aug 80	Ionian Basin	
34	SEINE NET I	1980	Strait of Sicily/ W. Ionian Basin	
35	SEINE NET II	1980	Strait of Sicily/ W. Ionian Basin	
36	WESTLANT 80	Oct 80	NW Atlantic	
37	BERMEX 81	1981	Atlantic	
38	WESTLANT 81	1981	NW Atlantic	
39	OUTPOST CREOLE	Summer 82	NE Atlantic	
40	OUTPOST RESOLUTION	Spring 82	West of Washington State, Juan De Fuca Ridge (JDF)	USNS *DeSteiguer*
41	OUTPOST CREOLE II	Fall 82	West of JDF	
42	OUTPOST ENCORE	1983	NE Pacific (JDF)	
43	OUTPOST REPRISE I	1983	NE Pacific (JDF)	
44	OUTPOST ENCORE II	1984	NE Pacific (JDF)	
45	OUTPOST REPRISE II	1984	NE Pacific (JDF)	

No.	Experiment	Date	Geographic Area	Remarks
46	ICEX-85 THRU ICEX-92	1985	Central Arctic & Marginal Ice Zone	
47	OUTPOST AREA 85	1985	N of Greenland	
48	OUTPOST AREA 85	1985	Central Arctic	
49	PROJECT GEMINI	1885	S of Galveston TX	
50	ICEX I-86 Ice Camps Red and Rose	1986	Chukchi Sea	Ed Gough, PI
51	ICEX-86	1986		
52	ICEPOST HERITAGE 86 Ice Camps Mandy, Ruby II, Astrid	1986		
53	OUTPOST HERITAGE	1986	Central Arctic	
54	OUTPOST HERITAGE WEST	1986	N of Barrow AK	Dan Ramsdale, PI
56	BROADBAND 87 Broadband Dist. Sys.	1987	Bermuda	Bruce Steinberg, PI
57	ICEX-87	1987		
58	ICESHELF-88 Ice Camp Jerry	1988	Lincoln Sea	Dan Ramsdale, PI
59	ICEX-88			
60	MIZEX-88	1988	Greenland Strait	Paul Bucca, PI
61	CRITICAL SEA TEST II	1989	N. Pacific Gyre	
62	ICESHELF-89	1989	Lincoln Sea	Ice Camp Shirley/Spinnaker
63	ICEX-89	1989		
64	CRITICAL SEA TEST IV	1990	E of Scotland/UK	
65	ICESHELF-90 Ice Camp Panama	1990	Lincoln Sea	Dan Ramsdale, PI
66	ICEX 90	1990	N of Barrow AK	
67	ICEX-90	1990		
68	OUTPOST AREA 90	1990	North Pole	
69	AREA 91 Ice Camps Opal, Crystal, Ruby	1991		
70	ICESHELF-91 Ice Camps Fogg and Sudds/Spinnaker	1991	Lincoln Sea	
71	ICEX91	1991		
72	Icex-92	1992		
73	OUTPOST AREA 92 Ice Camp Gator	1992		
74	OUTPOST AREA 93	1993	N of Greenland	
75	OUTPOST AREA 94	1994		
76	BLAKE TEST		Atlantic	
77	BOTTOM INTERACTION		SE Pacific	
78	CHURCH OPAL		NE Pacific	
79	CHURCH STROKE I		NE Pacific	
80	CHURCH STROKE II		N Pacific	
81	CHURCH STROKE III		Caribbean	
82	CRITICAL SEA TEST I			
83	CRITICAL SEA TEST III			
84	CRITICAL SEA TEST V			
85	EASTLANT			
86	FIXED FIXED		NE Pacific (JDF)	
87	FIXED-FIXED I Exercise			
88	KENT BEACON		NE Pacific	
89	MARCOT 2-85		NE Pacific (JDF)	
90	NATIVE 90			
91	OUTPOST CREOLE I		W of JDF	
92	OUTPOST GRANDE		S Atlantic	
93	PACIFIC SURVEYS		N Pacific	
94	SOUTHLANT		SW Atlantic	
95	WESTERN GULF TEST		Gulf of Mexico	
96	WESTLANT		NW Atlantic	

Soviet aggression in Europe that would take the war to "forward areas," the euphemism for waters near the Soviet Union where their warships, including submarines, operate.

Since Soviet strategic submarines then operated in "bastions" ("safe" areas within missile range of U.S. targets), the Maritime Strategy required that the United States be able to "penetrate the bastions" by conducting a strategic ASW campaign in the bastion areas. This strategy established the requirement for conducting large-scale ASW in polar conditions, including near the edge of the polar ice pack, the so-called marginal ice zone, and under the ice in the deep water of the Arctic Basin.

The areas near and under the ice are environments different from those where submarine and antisubmarine operations were usually conducted in the early 1980s. Most notable is the constant presence of floating sea ice, often completely covering the ocean surface for many square miles. The presence of sea ice complicates ASW in many ways, especially by denying free movement to surface ships and by denying access to the water to most air-deployed sensors and weapons. The ice cover thus provides added protection to the submarine from ASW forces.

Program Objectives

In response to the requirement for an essentially new warfighting capability, CNO's Arctic Initiative was promulgated as formal policy when Navy Instruction OPNAVINST S3470.6 was issued in March 1983. The 14 elements of the CNO Arctic Initiative included a number of initiatives of value to the ASW programs.

The Oceanographer of the Navy, then OP-952, responded to the CNO's initiative with a new Arctic Initiative in the Program Objectives Memorandum (POM) 85 cycle. This program set out to establish the environmental performance baseline and to improve performance for torpedo, SSN, surveillance, and air ASW capabilities in the Arctic. As part of this effort the ASW Environmental Acoustic Support (AEAS) program developed and issued a specific plan of action entitled "AEAS Arctic Environmental Program, POM85 Initiative, Plan of Action and Milestones." The primary goal of the program was to provide sufficient understanding and realistic environmental databases to allow the selection of logical alternatives in sensor design, signal processing, and system configuration for Arctic operations. To reach this goal, measurements, modeling, and analysis objectives were established.

Measurement objectives included design and participation in field exercises to collect data needed to fill data voids. These voids included environmental and acoustic data at almost all locations in the Arctic. Acoustic data were needed to address the effects of the Arctic environment on ASW systems performance, including seasonal ambient noise levels and directionality, propagation loss, signal arrival structure, and signal coherence. A large part of the measurements program included the design and acquisition of instrumentation to collect both environmental and acoustic data.

The modeling objective was to provide an ice-capable modeling system with acoustic propagation models and Arctic environmental databases. Accurate acoustic modeling was needed for interpreting measurements products and for predicting performance of current and future ASW systems.

The analysis objective was to provide ASW guidance and site/system assessment products to the surveillance, submarine, and air ASW communities, as well as to the R&D community. The approach was to obtain these products by combining the systems and threat characteristics with the results of the transmission loss and ambient noise measurements where available, using modeled propagation and databases to address locations, frequencies, and depths for which measurements were not available.

The AEAS program sponsored the development of equipment, the collection of data, and the analysis of data to provide the Navy guidance on how to operate in the Arctic and the modeling capability to assess the performance of its platforms in that hostile environment.

XI. DATA ANALYSIS AND EQUIPMENT

The equipment used by LRAPP can be divided into two separate categories: (1) equipment developed without LRAPP funds (but used by LRAPP and improvements paid for by LRAPP) and (2) equipment developed with LRAPP funds.

Some of the equipment was only for making scientific measurements; other equipment was focused on trying new techniques that might be transferable to the military. The measurements, of course, were focused on the terms of the sonar equation. LRAPP had to measure transmission loss, sound speed as a function of depth, ambient noise (both omnidirectional and directional, also as a function of depth) and bottom loss. Some of the information was used as inputs to the models also developed under LRAPP, and some was used for comparison with the model predictions.

Data analysis is closely linked to equipment. Although the skills are focused in different areas of expertise, they are so closely aligned that it is beneficial to consider them together. The data analysis community looks on the experiment definition, preparation, and actual performance with considerable interest, but without much activity. However, when the experiment is complete and the massive amounts of data are then handed from the "experimentalists" to the data analyzers, their work begins in earnest. These efforts require that the data be organized, reduced, reorganized, and then finally analyzed. This work was done primarily under the direction of Applied Research Laboratory: University of Texas (ARL:UT). Although many organizations provided support in special areas, the one organization primarily responsible to LRAPP for that function was ARL:UT.

Data Analysis

In the beginning of the LRAPP experience, the data analysis function was spread among many organizations. Substantial progress was made only when Dr. Gaul recognized that data analysis - as well as all of its associated functions - demanded the same level of preparation and coordination that the at-sea exercises required. The key point was in recognizing that the experimentalists and the data analysts had to work together, and that was the only way to assure success.

The data analysis process was performed by ARL:UT, whose many members contributed to the process. They had a long history of supporting the U.S. Navy in the area of underwater acoustics, with a focus on high-frequency sonars. They were convinced to support LRAPP by Dr. Gaul. When they entered, they proved to be a mainstay in many areas, with particular emphasis on data analysis and its attendant functions. Perhaps an equally important role played by ARL:UT was in comparing the final data sets to the model outputs from the modeling community. ARL:UT had skills in the experimental arena, but their capability in the modeling area was especially notable.

The experimentalists had always developed their equipment and put their data into a format that was convenient for them. This practice caused a situation in which many measurements were obtained using similar data types but were done by different organizations and archived in different formats. Any organization attempting to integrate the data into a consistent format had major difficulties. Most of the data were "raw," i.e., not reduced into standard data formats.

This became a standard problem that ARL:UT always solved but only with considerable effort. Finally, the problem became so serious to LRAPP that the experimentalists and the data analysts were called in and forced to resolve their differences in how the data were formatted and recorded.

The problem disappeared once the experimentalists made some modest changes to meet the requirements of the analyzers, and once computer programs were developed that made the raw data capable of being reformatted so that it could be rapidly reduced and then analyzed. Not only did the problem disappear, but also the time required for data reduction and analysis was substantially reduced. Although it never became trivial to organize, reduce, reorganize, and then to analyze massive amounts of data from at-sea experiments with many different participating organizations, the close interaction between the experimentalists and the data analyzers made the process almost pedestrian.

XII. TOWED ARRAYS

Towed arrays became the trademark of the LRAPP efforts, and several towed arrays were used by LRAPP during its existence. The ITASS arrays and the Towed Array Surveillance System Reliable Acoustic Path (TASSRAP) arrays, however, were built before LRAPP was formed. They were built in ONR and the Navy laboratories. The man who had the vision was Dr. Marvin Lasky, who is probably entitled to be designated the “father of towed arrays” in the U.S. Navy. Some arrays continued to be built by the Navy within the system commands, and DARPA built an array called the Large Acoustic Marine Basic Data Array (LAMBDA).

In the Navy the long towed arrays attached to a surface ship made the ships look as if they had tails. Thus, towed arrays in the Navy were known as “tails.” Towed arrays were built for use in areas where fixed arrays were not feasible and because they were able to eliminate noise from arriving at the sensor from all directions through beamforming.

The original beamformers were physical devices with large cylinders and magnetic delay lines that had connection points to the signal processing over its entire surface. However, as electronics became more sophisticated, some complex and sophisticated beamformers were based entirely on electronics.

One problem still remained: the distance between the elements was still fixed for a particular frequency. In underwater acoustics, the “elements” were omnidirectional hydrophones. However, someone came up with the idea of “nesting” arrays. In other words, build arrays for three frequencies (or as many as desired, but three was generally the number used). The idea was to construct directional sensor systems with broadband omnidirectional devices as their elements. To achieve this, the omnidirectional elements were placed in a line with fixed, but different, intervals. Sensors with different characteristics and different sensitivities could be achieved through the selection of the appropriate elements. Some elements were used for one array only; some elements were used for two arrays and, finally, at least one—the center element—was used as an omnidirectional element for all the arrays. This configuration solved the problem of using different frequencies.

Now, towed arrays were conceptually able to look simultaneously in many directions at once (and with computer controls these directions were variable and could be selected at will) and were designed for different frequencies. The issue of constructing the electronics necessary to perform this magic remained. However, this was accomplished, along with the use of very narrow filters to look at some frequencies of particular operational importance, as well as developing the ability to store the data.

The original data collection devices were analog tape recorders. These devices were extended and developed until digital recorders capable of recording enormous quantities of data arrived. The development of these devices came from the requirements of LRAPP and other programs where recording data for long periods of time was required.

XIII. LAMBDA

The original LAMBDA was developed and built by DARPA. LRAPP used it in one or two experiments. The man who was most responsible for the development of the original LAMBDA and its successors was Dr. Henry Aurand of NOSC. Dr. Aurand was one of the original workers with Dr. Hersey at the inception of LRAPP. To find Soviet submarines, it was clear that it would be necessary to have very narrow beams (approximately 1 deg or less). This need for such narrow beams required the towed arrays to become of remarkable length. The original ITASS arrays were approximately 600 ft long; the final LAMBDA array was more than 3 nmi long!

Some additional problems were associated with towed arrays that required considerable skill and imagination to overcome. Towing an array that exceeded three miles in length (that included not only the array itself, but also the ancillary vibration-isolation modules, power cables, etc.) was not difficult for the ships that were used. These ships were oil rig resupply boats, commonly called "mud boats," which are extremely seaworthy vessels used in the seismic array industry. They were developed, supported, and relied upon by the offshore oil industry. In fact, long towed arrays were used in the offshore oil industry before they were used in the U.S. Navy. The Navy insisted that the offshore oil industry was ahead of them technologically, although the offshore oil industry always came to the Navy to see what advances they had made. Both communities were making advances almost simultaneously, but had different objectives.

The difficulty in towing long arrays is that the towing ships must proceed slowly. The average speed of advance (SOA) was about 3 kts. Operating at such a slow SOA was entirely foreign to U.S. Navy combatant vessel commanders so the Navy was pleased to use civilian ships to perform this mission.

Another technical problem also challenged the LRAPP community: these long towed arrays deformed. As they were pulled through the water at different depths, the arrays began to develop bends – waves in the array caused by its own motion. These wave motions were side to side and up and down. The beamformers were built on the assumption that the arrays were straight and horizontal. This difference between the theoretical array attitude and its actual attitude would cause errors in the look directions and the beamwidth and would become time-dependent. This problem could be easily solved if the positions of each sensor were known in three-dimensional space as a function of time.

It turned out that the problem was relatively easy to solve. Perfection is always the goal but it is never achieved. If very short bursts of acoustic energy from a noise source could be received by every sensor, the time delays in the signal arrival would allow the position of all the sensors to be determined. The method used was to fire mortars from the ship, lobbing mortar shells into the ocean, having them explode at some known depth, and then after repeating this in a short time (a few seconds apart) by firing additional mortar shells at similar time intervals. The positions of each array sensor could be thereby be determined. These positions then could be entered into the computations, and the deformations would be automatically taken into account.

Towed array-generated beams were so narrow that all noise could be mathematically rejected from every direction except in the direction of the beam itself. So, if a submarine was the only object in the beam being considered, it was possible to detect the submarine, even at great distances. In fact, the beams were so narrow that we were able to "look between the ships," where the ships were the surface merchant vessels that were the primary generators of the noise detected by the arrays in that particular frequency band. The other part of that problem was that the submarine was in the beam only a relatively short time so it was necessary to look at many beams (hundreds) very rapidly and very frequently. Computers solved that problem.

XIV. COMPUTER MODELS

The development and use of computer models was a major focus of LRAPP; the other was at-sea exercises. The two worked together in a symbiotic relationship. In general, both could – and do – exist without each other. But when the two are meshed in a common focus, their individual value increases dramatically.

Models are attractive to the scientific community for several reasons. First, they are relatively easy to build and are also inexpensive. Many scientists and engineers can build a computer model. Because of this, many technical people are either upgrading an existing computer model or have built their own computer model. This practice has its good and bad points. On the one hand, it is good because of the substantial interaction between people with similar models. By interacting, they can compare their models. On the other hand, people tend to want to continue to use their own models and denigrate models developed by others.

Models are also attractive to the operational Navy for two major reasons: system design and performance prediction. In underwater acoustics, these take on an added role since the ocean has unique effects on sound. The first reason that models are so important is that they assist with the design of equipment. When the SQS-26 was designed, the total effect of the ocean was not appreciated, and a worldwide and expensive effort needed to be undertaken to develop a database on the ocean bottom. Many sonar signal waveforms were distorted by the bottom in ways the sonar design engineers did not understand. A worldwide sound-speed database also needed to be developed because sonar detection ranges varied from season to season and region to region. The second reason that models are so important is that the Navy cannot measure every ocean parameter that is needed to predict sonar system performance. Sonar performance models are needed.

If there is a major concern of the operational world anywhere in the technical community – not just limited to naval applications – it is configuration control. If several people or organizations have ostensibly the same computer model and if they use the same database to serve as the input data, then the results should be identical. However, this is almost never the case.

This state of control is mandatory for industrial production of physical parts. It is also necessary for computer models when they have reached the operational state. That, however, was not LRAPP's role; rather, development of the models in the R&D sense was part of the LRAPP function.

Computer models have two major tests that they must undergo: one is verification, the other is validation. These tests are both complex and sophisticated processes in the model world; in concept, they are both fairly simple. Verification is the process where the actual internal operations of the models are considered. Does the data flow from one part of the model according to the rules set by the developer? Is each component of the model doing what it is supposed to do? While these questions appear to be simple, in practice it becomes difficult with larger models. In a model that is small, such internal data flow is easy to ascertain and check; in models that may number 500,000 lines of code, such a process is almost impossible. Once a model is verified (that is, it is actually calculating what it should), it can go on to the next process: validation.

Validation is the process whereby the model outputs – or predictions – given a specific set of input data, are compared to "truth." The issue of truth is almost philosophical, but in this particular area, it is defined to be measured data.

The process of validation is when the predicted results from the modeler are compared to the measured results from the experimentalist, and they agree closer than by random chance. The point to understand here is that the predicted model results will be compared to real data and, if the differences between the predicted ranges and the measured ranges are acceptable to the eventual user of the model, then the model is said to be validated.

LRAPP management never forgot that the eventual product would be models that could be used by the Fleet. Several types of models were developed under LRAPP sponsorship, and used by LRAPP in the design of their experiments. These models were planned to be run by major facilities, such as FNWC and now, even onboard ship and aircraft during actual operations. This perception meant that conditions were placed on the models. For example, in the beginning of LRAPP, RP70, a transmission loss model, worked well but it was painfully slow. In fact, it was a research model and could not meet the time requirements for delivery of predictions to the operating fleet units.

FACT met those time constraints, but it was designed for use in an environment where there was only one sound speed profile and the bottom was horizontal. This particular condition was (more or less) met in large areas of the Northeast Pacific (the area of the CHURCH ANCHOR experiment) if propagation was east and west or at a relatively constant latitude. If propagation was north and south, however, the sound speed profile changed with latitude. Thus, the actual environmental conditions for north–south propagation violated the assumptions built into the FACT model. It was clear that the FACT model was not correctly dealing with the actual environmental conditions. Therefore, it was also clear that the predictions of transmission loss would be different from the actual measurements. Inevitably, the question was always: is the FACT model good enough? Only comparison to measured data would provide that answer.

The acoustic models built and used by the LRAPP community essentially tried to predict the values of the terms of the sonar equation, transmission loss and ambient noise. Transmission loss is based upon the geometric positions of the source and receiver, and the conditions at the local environment. The environment consisted of the sound speed field and the losses and spreading of acoustic energy from the ocean surface and bottom.

In the development of the transmission loss models, substantial effort was put into the development of databases, especially bottom characteristics. The models developed for that particular problem were compared to the SQS-26 bottom bounce sonar database generated for the NAVOCEANO by Alpine Geophysical. This worldwide effort began long before LRAPP was established. The data were taken at 3.5 kHz (the frequency at which the SQS-26 operates). Since the LRAPP frequencies of interest were in the general area of 25–300 Hz, some remarkable steps were necessary to work with the large database.

The calculation of ambient noise is almost the same as transmission loss. Transmission loss must be calculated as part ambient noise. In this particular case, however, all the sources are merchant ships, and they are located on the sea surface; however, they are not distributed uniformly over that surface. Approximately 40,000 merchant ships are in existence and about 16,000 of them are at sea on any given day (these numbers were gathered in 1973 for the HITS database). Their locations in each ocean are dependent on the season of the year. Because approximately 3,000 ships are located in the northern Pacific, the calculation of ambient noise anywhere in the northern Pacific must include both the source level and the transmission loss from the merchant ships on the sea surface to the receiver.

It was gratifying when this calculation was done using only the ship distributions measured in CHURCH ANCHOR. The results showed that the measured omnidirectional ambient noise and the predicted ambient noise were different by only 0.5 dB.

Once the transmission loss and the ambient noise models were in hand, the real problem could be considered. For a given body of water and a given environmental scenario (season), where should the receiver (almost always a towed array for LRAPP, but other passive sonars for the operating Navy) be placed to optimize the probability of detecting a submarine? The placement was not only at which depth but also at which direction the array should be aligned.

XV. PROOF IN THE FIELD

In any program, a time comes when the final product of many people must be tested to see if the primary objective of the program was successfully met. This is testing for validity of outputs and to see if all the efforts made over a number of years and after money has been allocated and spent are finally worthwhile in the ultimate test: does the system do what it is supposed to do? This time came for LRAPP in the summer of 1980 in the Mediterranean Sea.

The Sine Qua Non of the LRAPP Effort

This effort was tested in the Mediterranean in the summer of 1980. RADM R. Bell (later VADM Bell) was then in charge of the part of the Sixth Fleet responsible for U.S. submarines. VADM William Small was CDR Sixth Fleet (COMSIXFLT). He ordered RADM Bell to know where all the submarines were, all the time. Note that this was not just U.S. submarines, but all the submarines of all the nations, both our allies and our adversaries.

The principal concern for the submariners during exercises and operations was waterspace management. Although the Mediterranean Sea is very large compared to a submarine, and the chances of one submarine running into another was remote, it was still possible. However, at certain positions (for example, the Straits of Sicily) the waters become narrow and the possibility of an underwater collision, although still not high, increases substantially. VADM Small was concerned about ASW, and he had given RADM Bell an order that was quite difficult to carry out because successful implementation of ASW required integration of all U.S. Navy ships and aircraft devoted to ASW. The glue that held all of these assets together and forged them into a successful operational force was intelligence and coordination.

Commander Task Force 66 (CTF-66) became the leader for ASW coordination for the Sixth Fleet. In general, all platforms were used in the ASW operations, but they did not have common goals, tactics, or guidance in their daily operations. RADM Bell, through his chief of staff, CAPT Terry McCloskey (previously with early LRAPP as LCDR), and using a new Joint Operational Control Center in Naples, Italy, forced coordination of all the ASW forces, including surface ship towed arrays from CTF-66. This clear, well-defined operation was remarkably successful.

RADM Bell pointed out that one fights as one trains. We knew that we were superior to the Soviets in ships, aircraft, and submarines and their crews, but all needed additional ASW training. Nevertheless, the Soviets had good submarines. Mid-frequency acoustics (300 Hz) had not been used regularly before this time. Neglect of frequencies above the 50 Hz passive frequency contributed to our poor or moderate success in detecting Soviet submarines. At this time one new tool was added to RADM Bell's operational assets: the Mid-Frequency Array (MFA), which was specifically designed to operate at 300 Hz. The MFA was built by NOSC, and LRAPP supplied part of the funding.

RADM Bell, strongly supported by CAPT McCloskey, believed that when all the assets were used in a coordinated manner, it was possible to solve the ASW problem in real time, for long periods of time. All the assets available to the U.S. Navy were used: submarines, surface ships, VP aircraft, SOSUS, and the MFA.

The use of the MFA was a major event in the Mediterranean. The naval personnel were very happy to have this tool, even if it was run by civilian scientists. Naval communications personnel onboard the towed-array ships were responsible for all communications. The scientists onboard the ships operated within Navy operational constraints and provided excellent information. The physics and the science were correct. Because of the LRAPP experiments and practice with the equipment, it was well known where to put the MFA. The MFA allowed continuous detection and contact of all submarines in each of the Mediterranean basins in which it was deployed.

XVI. RECONSTITUTION AND DEATH

By 1981, things were going well. Although Dr. Gaul had left, his place was taken in turn by several very capable men. Evidence of the ability of towed arrays to detect and track submarines was proven. Fleet units had used them as part of their operations in several areas and found that ASW could be accomplished effectively. SOSUS, the towed arrays, and the ASW ships and aircraft of the operational fleet could detect, track, classify, and maintain a killing solution for long periods of time. The battle of ASW between the U.S. Navy and the Soviet Union submarines was essentially decided. Through persistence and the integration of technical and operational assets, the devotion of small numbers of military personnel and civilian scientists and engineers had won the day. Everything worked, and the team could serve as the prototype for standard military ASW operations.

Although relatively fierce political battles were still being fought, this was a standard problem. Everyone involved knew that as long as ASW remained at the top of the priority list, things would never be too bad. ASW had been at or near the top of the priority list for more than 20 years and showed no sign of slipping from its position.

XVII. THE SURVEILLANCE TOWED ARRAY SENSOR SYSTEM

The Surveillance Towed Array Sensor System (SURTASS), which had competed with the MFA with some vigor (since it was felt that it could suffer some programmatic changes), had triumphed. They were in the system for continued development, production, and purchase. The ships were being designed to tow them.

Then in 1985, the Soviet Union began to collapse. From the U.S. Navy's point of view, the Soviet submarines went from being a very serious threat, which was the responsibility of the Navy to counter and control, to being a possible minor annoyance. In a very short period of time, ASW slipped from its high priority to just another problem to deal with. This slippage was reflected in the reorganization of OPNAV. The organization responsible for ASW, OP-095, was renamed and became known as Director for Naval Warfare, and was renumbered to become OP-08. Further changes followed in the next few years.

All the information that had been gathered by LRAPP was still highly relevant and would be used if the nation needed those data in the future. But ASW was no longer of great importance. Since LRAPP always claimed that the knowledge of the environment was extremely important and played a major role in the design, development, and use of systems, the program continued. Now issues arose that had only partially been listened to. The Navy declared that mine warfare and the Arctic were also very important. LRAPP, as an advanced development program, began to focus on those areas but there was no great interest or support from the Navy.

LRAPP remained in ONR. With time and the budget battles within the Navy, however, changes were made in the programmatic structure. LRAPP had been designated Program Element 63785N since its conception and birth. Now, that number was struck from the list, and LRAPP was funded from another program element as part of a more general task. When a program loses its program element designation, it means that it has died.

It should be said that many of the veterans from the ASW days are still associated with ONR and LRAPP, although it is now called by another name. The same skills are still used and applied by men and women to solve the operational and technical problems encountered by the operating forces. The death of this program proved that its goal was achieved and intense activity was no longer needed. In addition, the extraordinary dedication of the men and women of LRAPP and the U.S. Navy, as well as their willingness to work together, contributed strongly to LRAPP's amazing successes.

XVIII. SUMMARY

The Long Range Acoustic Propagation Program (LRAPP) was organized to defeat the dangerous, missile-carrying, nuclear-powered Soviet submarines that roamed freely off both coasts of the United States, requiring urgent action to prevent the Soviet Union from assuming a commanding role in naval and diplomatic offensive maneuvers. LRAPP was formed during the Cold War; when the Cold War ended, the program slowly faded away. It was, however, part of the U.S. Navy's important programs from 1964 to 1989. The knowledge gained from LRAP and its unique management, technical, and at-sea operations resulted in meaningful guidance that could be helpful to future programs that require solving technical and operational problems of national importance. Some items of interest observed during and after LRAPP, in no particular order of importance, are:

1. LRAPP was a program of long duration (25 years) that cost little relative to benefits realized. Total cost was about $250 million.

2. Members of LRAP were assembled for a major integration of Navy operating forces, government laboratories, ONR scientists and engineers, academic institutions, and industrial contractors – all organized into a single team.

3. The team was never very large – probably less than 500 scientists, engineers, and Navy personnel.

4. The primary emphasis of the LRAPP organization was on a complete analysis of the sonar equation, term by term.

5. One goal of the program was to develop computer models that could predict propagation loss and ambient noise based on measured environmental information. The accuracy of these models was dependent on periodic modifications to the models based on their actual use and results obtained. Fleet operations demanded faster and less detailed models than those needed for designing highly sophisticated equipment for future U.S. Navy operational use.

6. The fundamental inputs to the computer models were measured environmental data.

7. All the models used and developed by LRAPP for scientific and Fleet operations were subject to verification and validation, using the measured input and output data from field exercises. Data were obtained throughout the life of the program, at the highest possible scientific levels, in all ocean areas of naval operations.

8. The application of basic science research to operational problems led to major contributions to the ASW mission of the U.S. Navy: to detect, localize, classify, and provide an "opportunity to kill" operational submarines of the Soviet submarine threat.

9. Multiple components of the Navy worked well together: Weather Service, Fleet Numerical Weather Central, R&D organizations, the staff of the Chief of Naval Operations (OPNAV), and the operating Fleet of the U.S. Navy.

10. U.S. Navy management components: program managers, contract administrators, legal officers, security offices, and OPNAV administrators were part of the LRAPP team. They worked well together to reach the common goal: neutralization of the Soviet submarine threat. Despite occasional rivalries, there are experts in all fields who will work with others to accomplish a goal of importance.

11. ONR, with a stable of experts in all of the scientific disciplines involved, took the lead in solving technical problems.

12. An effective security system was put in place, binding all who had a "need to know" into a tightly controlled, self-monitored, self-enforced system that provided maximum protection to all aspects of the program, without leaks or unauthorized disclosures.

These 12 items were an integral part of LRAPP operations. Can such a program exist again under the current government requirements? Perhaps not, but a variant could certainly be produced if attention is paid to the vital elements observed that were important parts of LRAPP operations.

XIX. ACKNOWLEDGMENTS

This article was carefully checked and edited by Linda Jenkins and RADM M. Dick Van Orden, USN (ret). They helped immeasurably in the preparation and final version of this paper. However, any errors of fact are entirely those of the author.

XX. REFERENCE

L.P. Solomon, *Transparent Oceans: The Defeat of the Soviet Submarine Force* (Pearl River Publishing, Bethesda, MD 2003).

Louis P. Solomon has had a varied career, covering multiple disciplines, both in government and in the private sector. He received his PhD in Engineering from UCLA in 1965, specializing in Fluid Mechanics, Applied Mathematics, and Electromagnetic Theory. Dr. Solomon worked for the Department of the Navy for nine years as an SES. As the Associate Director of Naval Ocean Research and Development Activity (NORDA) for Program Management he was responsible for the LRAPP program. Subsequently, he worked with the DoD National Security Education Program (NSEP) in placing within the federal government more than 3,000 NSEP award recipients (graduate and undergraduates in all academic fields), who lived and studied throughout the world and learned less commonly taught languages and cultures. Dr. Solomon also served as a subject matter expert in developing The Language Corps for DoD as a national entity to support government agencies in times of national emergencies. Dr. Solomon is founder and chief executive of several firms: LPS Collaborative Group (a technical and management consulting firm), Pearl River Publishing (a book publishing firm), and Life Echoes (a Family Legacy Book Publishing Service). He also writes historical novels.

Table of Contents

This Page

Intentionally

Left Blank

Table of Contents