# APL's Research Organization: Then and Now

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## ABSTRACT

*Research has been key to the Laboratory's success since its very beginning. For the last 70 years, the focal point for research at APL has been its research center. During its long history, the research center has had several names and various incarnations driven by APL's changing needs as it has grown and evolved over the last seven decades. This article briefly traces the history of the central research organizations and then focuses on the Research and Exploratory Development Department (REDD), at the heart of the Laboratory's current research and development activities. REDD integrates strong engineering and prototype development activities with individuals focused on basic and applied research—yielding an innovative and creative organization capable of leading scientific and technological activities into the future.*


## INTRODUCTION

Since its founding during World War II, the Johns Hopkins University Applied Physics Laboratory (APL), as suggested by its name, has been dedicated to practically applying the principles of physics (and engineering) to solve complex problems of its sponsors, the nation, and society as a whole. From the beginning, APL recognized the need to conduct research into the fundamental physical and technological underpinnings of its systems development and applications business. Such continued research helped APL earn its reputation as a viable scientific and engineering development organization in the post-war era, as well as the continued sponsorship of Johns Hopkins University.[1]

These fundamental research investigations, extending the Lab's scientific and engineering knowledge, were formally organized into the Research Board in 1947, making the center and its antecedents the second-oldest enduring organizational entity at APL after the Director's Office, or Central Laboratory Office. The research center concept was developed by Ralph E. Gibson, Frank T. McClure, and Alexander Kossiakoff, and the organizational unit was established on April 1, 1947, by then-Director Lawrence R. Hafstad. (For more information on Gibson, Kossiakoff, and Hafstad, see the article on APL's previous directors, in this issue; for more information on McClure, see Ref. 2.) At its founding, the Research Center's basic objectives were threefold: (*i*) to carry out long-term basic research that would complement present and future APL tasks; (*ii*) to establish APL as a contributor to the nation's scientific and engineering research; and (*iii*) to enhance the staff's professional competency and growth through participation in fundamental research programs. Frank T. McClure was appointed in 1948 as the first full-time chairman of the

**Table 1.** Leaders of the Research Center and its other incarnations from its 1947 beginning to today

| Leader[a] | Title | Organization | Tenure |
|---|---|---|---|
| Ralph E. Gibson | Chairman | Research Board | 1947 |
| Frank T. McClure | Chairman | Research Center | 1948–1971 |
| Robert W. Hart | Chairman | Milton S. Eisenhower Research Center (MERC) | 1972–1982 |
| Theodore O. Poehler | Director | MERC | 1983–1989 |
| Donald J. Williams | Director | MERC | 1990–1996 |
| John C. Sommerer | Director | Milton S. Eisenhower Research and Technology Development Center (RTDC) | 1996–2007 |
| Bharat T. Doshi | Department Head | (New) MERC | 2007–2010 |
| James R. Schatz | Department Head | Research and Exploratory Development Department (REDD) | 2011–present |

[a] For more on Gibson, see the article on APL's directors by H. E. Worth, in this issue. For more on McClure, see Ref. 2. For more on the research center's leaders from 1972 until 2010, see the appendix. Schatz's biography appears at the end of this article.

Research Center, a position he held for almost 25 years. Table 1 lists the leaders of the Lab's research organization from 1947 to the present. During its 70 years, the research center has evolved, reorganized, and reinvented itself several times leading up to its current form, the Research and Exploratory Development Department (REDD). The creation of REDD and its current research and development activities are described in the Now section following a brief history of past research center organizations and their select accomplishments. (The accomplishments of the Research Center and its many instantiations over the decades are too numerous to adequately describe in a few pages. Fortunately, many of these accomplishments have been captured in detail in the pages of the *Johns Hopkins APL Technical Digest*. In particular, several issues of the *Digest* have been devoted entirely to the Lab's research arm.[3–6])

## THEN

As APL transitioned from working on the VT fuze to solving problems in missile and rocket guidance, the APL Research Center focused on research in related areas, such as supersonic and hypersonic aerodynamics, combustion, mass transport properties, flame spectroscopy, low-temperature physics, materials properties, and mass spectrometry of free radicals.

In the early years of the Research Center, several key accomplishments stand out. The first, the exploration of the upper atmosphere under the direction of James A. Van Allen,[7] occurred even before the center was officially organized. After learning that the military was planning to conduct a series of V-2 firings at White Sands, a small group of APL physicists, led by Van Allen, persuaded the Navy to fund making basic physical measurements of the upper atmosphere at altitudes well above those for any past measurements. Cosmic rays and the products of their atmospheric interaction, such as electrons and ions, were the focus of Van Allen's studies. Over the 4 years after the first successful launch on April 16, 1946, eight additional V-2 rockets launched with APL instruments aboard until the supply of V-2s was depleted.

When the team needed a new rocket to fully investigate the scientific problems in the upper atmosphere, APL, working in cooperation with the Aerojet Corporation and the Douglas Aircraft Corporation, designed and built the Aerobee rocket with strong support from the Navy. This simple, relatively small rocket (compared to the V-2) could carry a payload of 150 lb to an altitude of about 375,000 ft (71 mi).[1] An Aerobee rocket is shown in Fig. 1. Twenty rockets were produced under

**Figure 1.** First powered flight of an Aerobee rocket.

the Navy contract, with the first successful launch on May 3, 1948. On March 17, 1949, an Aerobee carrying APL instruments launched from the deck of USS *Norton Sound*. Van Allen's work led to new knowledge on ozone depletion, variations in Earth's magnetic field both with altitude and geomagnetic latitude, and cosmic rays. The work culminated a few years later, after Van Allen had moved to the University of Iowa (following APL's termination of the high-altitude research program), with his discovery of the layer of electrically charged particles trapped in Earth's magnetosphere, now known as the Van Allen belts.

A second early success was the postulation of the "big bang" concept of the origin of the universe by George A. Gamow (APL consultant), Ralph A. Alpher (graduate student), and Robert C. Herman (APL staff member). Even after 60 years, some of the concepts developed in this initial explanation of the big bang theory are still at the forefront of discussions of the origin of the universe.

After these early triumphs, the Research Center shifted its focus to increasing its direct support of the Laboratory's mission. While staff members could work on basic problems, the science and technology they pursued had to be directly linked with the Laboratory's system-level work. This approach resulted in many accomplishments in combustion research in support of APL's ramjet development efforts. Similarly, investigations into the cause of unstable, or resonant, burning led to the discovery that this behavior was the result of acoustic vibrational modes on the rocket motor gases causing an increased burning rate. Key experiments by Frank McClure and Robert Hart were instrumental in validating the theory and led to changes in solid rocket motor design.

As the Research Center evolved, APL leadership began to support work in novel areas and on interesting projects that were independent of the Laboratory's prescribed directions for research and development on sponsored tasks. Striking a balance between independent research into new areas and research support for the Lab's sponsored programs has always been a priority for APL's leadership, and the balance has swung back and forth during the Lab's history. The need for independent research was clearly evidenced by the dawn of the Space Age, spurring two Research Center scientists, William Guier and George Weiffenbach, to use Laboratory equipment to monitor signals from Sputnik (the first artificial satellite to orbit Earth).[8] From these signals, they found it was possible to precisely determine the satellite's orbit by analyzing the Doppler shift from a known position on Earth's surface. Frank McClure turned the problem around and found that if one precisely knew the satellite's orbit, one could then locate the observation point on Earth, and satellite navigation was born.

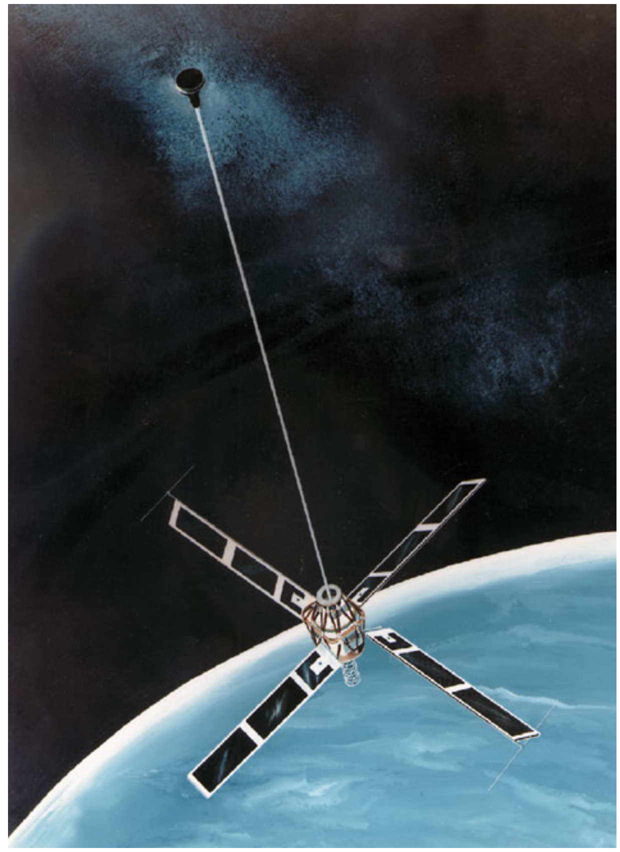

**Figure 2.** Artist illustration of the operational Transit satellite in orbit, dubbed Oscar (for the first letter, *O*, of *operational*). (Reprinted from Ref. 9.)

This concept was quickly funded by the Navy as a precise means of navigation for its ballistic missile submarines, improving the accuracy of missile strikes. The APL Space Department (now the Space Exploration Sector), under the oversight of Richard Kershner, was established to develop a working satellite navigation system. This system, which became known as Transit,[9] served the nation in low Earth orbit for about 30 years as the most accurate geolocation method in the world—only to be replaced by the Global Positioning System (GPS), in geosynchronous orbit, by mid-1990. An illustration of a Transit satellite is shown in Fig. 2.

Transit firmly illustrated the synergism between pure research and a development- or sponsor-driven program. The Transit program grew out of pure research and not only led to the development of an operational satellite navigation system but also generated new requirements for research. For example, the Transit program required APL to resume high-altitude research (see the discussion of Van Allen above) to determine the environment and problems that Transit satellites might encounter in low Earth orbit.

On September 19, 1979, Johns Hopkins President Steven Muller officially dedicated APL's Research Center to Milton Stover Eisenhower.

## BOX 1. SPOTLIGHT ON COLLABORATIVE BIOMEDICAL RESEARCH AT APL

APL leaders have long recognized that the Lab's advanced technology and system development expertise could be of significant benefit to the field of biomedicine. In 1965, with approval of university president Milton S. Eisenhower, a formal program in biomedical engineering was established in collaboration with the Hopkins medical institutions. The APL leaders of the effort were Dr. Frank McClure (chairman of the Research Center), Alvin Schulz (who later became the associate director of the Laboratory), and Joseph Massey (who later headed the Biomedical Program Office).[10,11] Richard Johns at the Johns Hopkins School of Medicine was the program's major champion on the medical side.

As the Collaborative Biomedical Program grew and involved many staff members from around the Laboratory, APL created a Biomedical Office in 1972. This office, headed by Joe Massey, was independent of the Research Center, although many of the Research Center personnel participated in the effort.

The Collaborative Biomedical Program had three major guiding principles:

1. The technology developed should address significant biomedical problems.
2. The researchers at APL and the School of Medicine should be committed to solving the problems (i.e., they should be personally involved).
3. Leadership at the highest levels of both APL and the School of Medicine should commit to supporting not only the task at hand but also follow-on objectives and the pursuit of funding.

The Collaborative Biomedical Program led to many advances in several fields, including ophthalmology, neurophysiology, oncology, and cardiology. In the field of ophthalmology, for example, the Hopkins Wilmer Eye Institute worked with APL laser engineers to use an argon laser to photo-coagulate blood vessels in the retinas of diabetic patients. These collaborations also led to an improvement in a fundus camera to view the choroidal vascularization behind the retina. With such accomplishments under their belts, APL scientists and engineers developed a relationship with the National Institute of Neurological Disease and Blindness, which resulted in grants that lasted for over 16 years. APL investigators used experimentation and modeling to better explain light scattering and transmission through the cornea and to establish a framework to assess eye radiation damage, which is extremely important in the modern warfighting environment with the increased use of lasers on the battlefield.

In neurophysiology, the collaborative APL–Johns Hopkins medical institutions work has resulted in many accomplishments, including the longest-standing neurosensory grant ever supported by the National Institutes for Health—26 years. These collaborations have involved studies of pain and brain edema and the localization characterization of epileptic events.[12]

APL has also had a long-standing relationship with the Hopkins Department of Radiology. In 1975, Dave Grant of the Space Department was appointed as director of radiation therapy physics, overseeing the application of APL's systems engineering approach to the development and use of several new radiation oncology systems. Later Dave became director of the Division of Clinical Engineering.

APL developed an Oncology Clinical Information System that was in use for many years at Johns Hopkins Hospital. In addition, APL has made many contributions to medical imaging as applied to mammograms and dynamic heart imaging. An APL-edited handbook captures many of the Lab's accomplishments in this arena.[13]

A more recent collaboration, this one with the Hopkins Department of Radiology, involved the development of an Advanced, Multiple-Projection, Dual-Energy X-Ray Absorptiometry (AMPDXA) system to measure bone loss.[14] This system, shown in Fig. 3, was originally developed under funding from the National Space Biomedical Research Institute to address astronauts' bone loss due to microgravity. The system laid the groundwork for improved bone loss measurements and analysis of humans on Earth—a major problem among our growing elderly population.

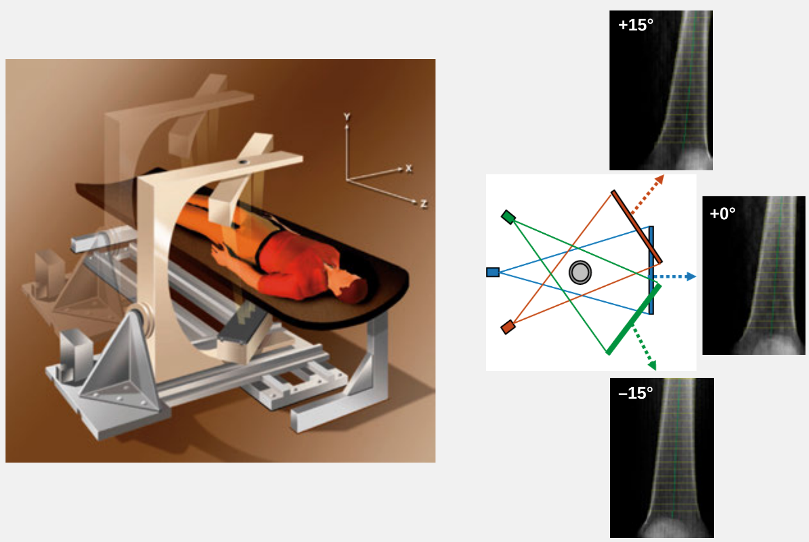


**Figure 3.** Left, Artist's illustration of a proposed commercial AMPDXA scanner requiring no rotation of the X-ray tube or head. The scanner uses three fixed X-ray sources with an adjustable line detector array for bone axes alignment. The mechanical simplicity of the device allows for ease of manufacture, thus facilitating commercialization. Right, AMPDXA multiple-projection (+15°, 0°, –15°) processed bone mineral density images of a human femur (reconstructed from individual slices of AMPDXA human test bed data). (Reproduced from Ref. 15.)

Eisenhower was the eighth president of Johns Hopkins University under whom many joint APL–Hopkins initiatives were established, including the APL Education Center (see the article by Charles and Morris, in this issue) and the Collaborative Biomedical Program (see Box 1, which describes this program in more detail).

With the rapid science and technology changes spawned by the integrated circuit revolution and related advances, the Milton S. Eisenhower Research Center (MERC) faced many challenges in conducting research relevant to APL while keeping abreast of the latest events in the scientific and technologic worlds. Since specific or applied research areas were (and still are) rapidly moving targets, staff members working in the center began focusing on fundamental disciplines that formed the underpinnings of any technical or applied program (just like their predecessors had done back in 1947 when the Research Center was formed). These disciplines included physics, chemistry, electronics, mathematics, computer science, engineering science, materials, atmospheric science, and biomedicine. Research into these fundamental sciences consumed large amounts of the Laboratory's independent research and development (IRAD) budget.

In 1983, APL management conducted a significant review to consider how the Research Center could best support APL and its sponsors. The review concluded with not only a verification of the Research Center's importance to APL but also a new funding model that required balanced support from three sources—external sponsors, internal departmental sponsors, and IRAD funds. Also at that time, the leader of the Research Center received a new title when the position changed from chairman to director (see Table 1).

APL management conducted a similar study in 1993 and decided to reduce IRAD support to the Research Center and to increase the center's emphasis on supporting the Laboratory's missions. This renewed focus on APL's missions was further strengthened by the establishment of the Milton S. Eisenhower Research and Technology Development Center (RTDC). RTDC combined the staff and facilities of the Research Center with the staff and facilities from the Aeronautics Department, including the Propulsion Research Laboratory (PRL). After its incorporation into the Research Center, the PRL was renamed the William H. Avery Advanced Technology Development Laboratory, and it brought with it a rich history of APL developments in aeronautics and missile technology, including the invention of supersonic combustion ramjet that became the operational engine for the Talos missile system, shown in Fig. 4. More importantly, it was the focal point for hypersonic research—a field in which APL has continued to make significant contributions to advance science and national defense.

Even amid the changes to the Research Center during the 1980s and 1990s, its personnel celebrated significant accomplishments in science and technology on programs of national importance—by supporting APL departments and their sponsors' needs or by directly working with governmental agencies and bureaus. Two particularly interesting and far-reaching Research Center programs during this period were the Securities Technology Institute,[17] operated for the Bureau of Engraving and Printing (BEP) to deter counterfeit money, and the Defense Advanced Research Projects Agency (DARPA) programs that used the APL-developed mini-mass spectrometry technology[18] to detect biochemical aerosol weapons attacks. Both these programs lasted several years, contributing to fundamental science and technology knowledge and providing useful information and products to their sponsors. Aspects of these programs are described briefly below.

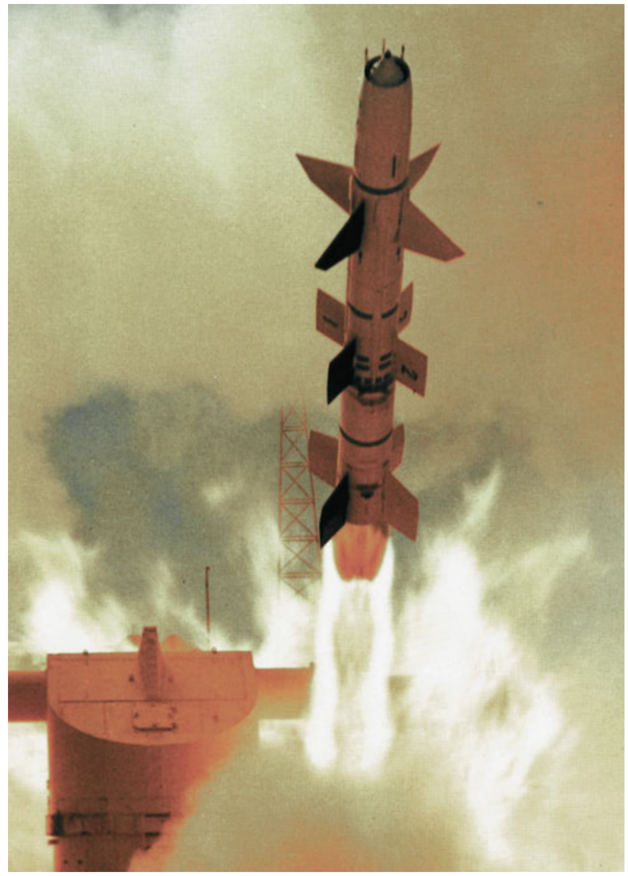

**Figure 4.** The Talos missile (circa 1958) incorporating the APL ramjet engine design capable of cruising at Mach 2.7 at an altitude of 70,000 feet. The Talos was first introduced into the Fleet in 1955 and remained in service until 1980. (Reprinted from Ref. 16.)

The Securities Technology Institute at APL aimed to increase the security of our nation's money supply and to deter counterfeiting. The program had two major goals: (*i*) to develop security features that make it difficult or nearly impossible to counterfeit our paper money and (*ii*) to monitor progress in reprographic technology that counterfeiters could exploit.

**BOX 2. SPOTLIGHT ON EARLY BIOMEDICAL DEVICES**

In cardiology, in addition to modeling and analyzing heart function and blood flow dynamics, APL made major advances in cardiac assist devices, including developing the implantable rechargeable pacemaker to address the short battery life of pacemakers of the late 1960s and early 1970s.[19] The rechargeable pacemaker is shown in Fig. 5. Over 5900 of these units were implanted in patients between 1973 and 1984. Following the pacemaker was the first Automatic Implantable Cardiac Defibrillator (AICD).[19] The AICD monitored the heart for arrhythmias, and when they became life threatening, it delivered electric shocks to the heart. By 1990, many hundreds of AICDs were being implanted each month.

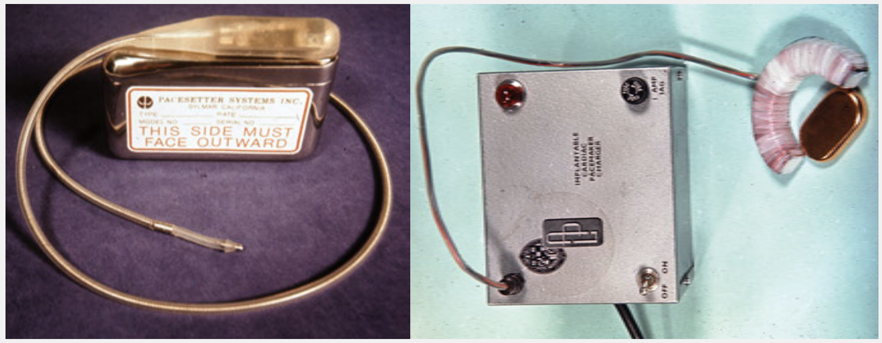


**Figure 5.** Rechargeable pacemaker (left) and charger (right).

These cardiology devices gave rise to a large array of APL-developed electronics and medical assist devices, including:

- The ingestible thermal pill, shown in Fig. 6, monitors body core temperature.[20] Originally developed for NASA to monitor the core temperature in astronauts, the pill telemeters its temperature as it passes through the gastrointestinal tract. The pill was commercialized and, in addition to helping astronauts and humans on Earth, has been used with livestock and in chemical process measurement.
- The nonreusable syringe was developed to help stem the spread of AIDS and other diseases attributed to the misuse of syringes.[21] Millions of these devices have been used by the World Health Organization.
- The Programmable Implantable Medication System (PIMS), shown in Fig. 7, was developed under the NASA Technology Utilization Program to demonstrate the dual use of space technology.[19] Basically described as an implantable "satellite," it delivers round-the-clock insulin for diabetic treatments. It contains sensors as well as computer, communication, and telemetry systems—all the major elements of a satellite—in a package shaped like a hockey puck.

The detailed design and prototyping for PIMS and the pacemaker were performed by many engineers and technicians in APL's Engineering, Design, and Fabrication operation, which is now part of REDD.

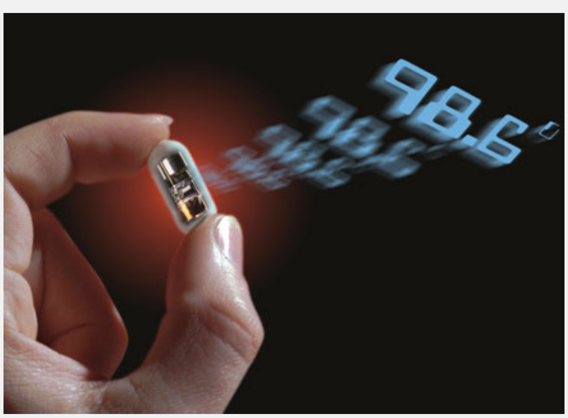


**Figure 6.** Ingestible pill.

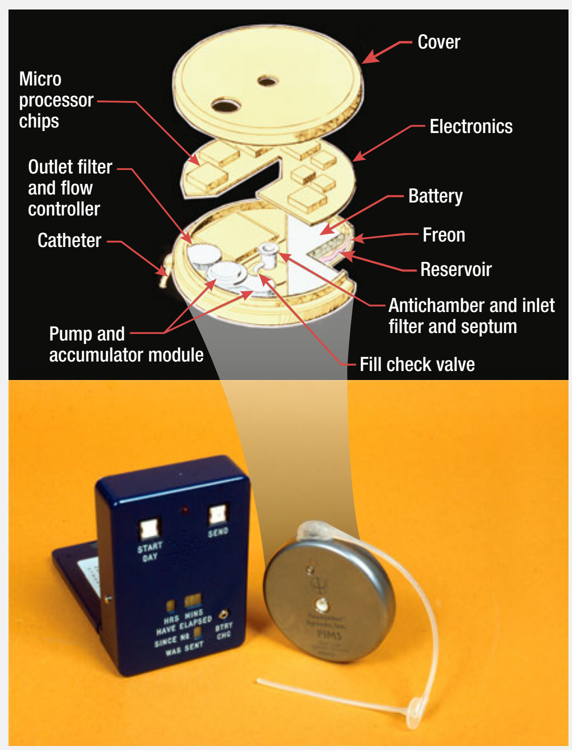


**Figure 7.** PIMS hardware (bottom) and cutaway diagram of the PIMS pump (top).


**Figure 8.** Noncontact probing of currency by using a laser or light beam focused on a phosphor-infused security thread in a paper note. (Reprinted from Ref. 17.)

The features developed are readable by humans, allowing the general public to identify counterfeit bills, and by machines, allowing rapid processing for cash transfer machines and for governmental inspection. The Securities Technology Institute combined APL scientific and technical expertise with the Laboratory's methodological strength in systems development, enabling the BEP to introduce new security measures and to plan for the future. APL's methods also had broad implications for other secure documents, such as passports, social security cards, and driver's licenses. Figure 8 illustrates how currency with embedded phosphors can be read by machines.

As part of the DARPA mass spectrometry programs, APL developed a small, portable time-of-flight (TOF) mass spectrometer for the field detection of chemical and biological substances. APL also developed sampling and ionization techniques for solids, liquids, and gases and conceptualized detection systems for deployment in military, environmental, law enforcement, and health care scenarios. A prototype miniature TOF mass spectrometer system is shown in Fig. 9. This small unit (approximately 2 ft in length) performs comparably to room-size commercial units. The DARPA mass spectrometer program formed the nucleus of what became the Lab's major thrust in homeland protection and also laid the foundation for many of the biological research programs that are now key to APL's future. (See the Now section for more details; Boxes 1–3 highlight biomedical achievements.)

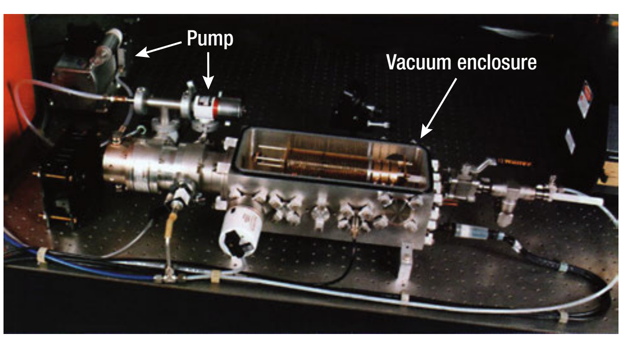


**Figure 9.** The miniature time-of-flight (Tiny-TOF) mass spectrometer illustrating the vacuum enclosure and the pumping arrangement. (Reprinted from Ref. 18.)

These are but two of the myriad research activities the Research Center carried out from the 1980s until the turn of the new millennium. As mentioned, during this period, foundations were laid for many of the current research thrusts that APL is pursuing today (see the Now section) as well as for many of the Lab's significant accomplishments over the last quarter-century. For example, the emphasis that Research Center scientists placed on materials, ranging from nanotechnology to high-temperature materials, has borne fruit during the last decade in support of programs involving hypersonic flight and high-temperature environments. Work on quantum computing[22] and quantum cryptography set the stage for today's efforts in those areas and led to significant accomplishments in this developing field. Research Center developments in robotics and autonomous systems led to significant accomplishments in unmanned vehicle development and deployment as well as national recognition with the Modular Prosthetic Limb (see Box 3). Development of machine learning and information retrieval techniques[23] provided the impetus necessary to open the Human Language Technology Center of Excellence at Hopkins. Work in robotics, autonomous systems, machine learning, and information retrieval methods all contributed to the creation of the Intelligent Systems Center (ISC) at APL.

With such diverse research efforts spanning many disciplines, at about the turn of the century and into the new millennium, it became clear that the Laboratory's organizational structure needed to center on common business that crossed departmental boundaries. Thus, APL leadership created business areas. As the business areas took shape, the Laboratory's organizational structure began to align with the business, and several new departments formed, including one focused on force projection from the air, sea, and under the sea. At about the same time, the high costs of maintaining the aging PRL led to the facility's closure; however, the capabilities persisted, with the scientists and engineers focused on aeronautics and propulsion research moving into other departments. Indeed, this incubation of capabilities is a hallmark of APL's research organization.

A new Milton S. Eisenhower Research Center (MERC) was formed in 2007 with a mission to serve, along with the National Security Analysis Department (NSAD), as the Laboratory's "headlights" for science and technology while still adhering to the financial principles of a business area and making significant contributions to APL's revenue stream. With its small size and limited laboratory facilities, APL's research organization struggled to satisfy all aspects of its charter, so as part of a significant APL reorganization effort in 2011, it was overhauled and named the Research and Exploratory Development Department (REDD)—a larger and more broadly based organization, described in the following section.

## NOW: A PERSPECTIVE FROM THE DEPARTMENT HEAD

When REDD came into being in July 2011, it included the former research element of APL, MERC. However, REDD's exploratory development charter was based on the perspective that designing and building prototype devices is an essential part of the Lab's mission. For this reason, REDD included both electrical and mechanical engineering design teams, along with APL's electrical, microelectronics, and mechanical fabrication facilities. In addition to these components, REDD also included the existing APL efforts on biomechanics and injury mitigation systems, extremely important areas focused on our nation's warfighters (see Box 3).

The first challenge REDD faced in the summer of 2011 was the urgent need to transform the disparate elements of the new department into a cohesive organization. All of REDD's group supervisors were asked to form a team that was charged with defining a new group structure for the department and assigning each of the 400 technical staff members to a group. An essential aspect of this process was that the supervisory positions for the resulting groups would be filled through a competitive selection process. In other words, the individuals charged with creating the structure for the new department were not assured of having leadership positions in this new structure. Setting aside this uncertainty, the team created a structure with 11 technical groups combined into a single branch.

At the time, a branch at APL usually consisted of three or four groups, but REDD leadership decided to start out with one large branch to emphasize achieving unity of purpose as a department. The most important goal for REDD was to build a vibrant culture in which scientists, engineering design experts, and fabrication specialists were all valued equally. REDD's strength was illustrated by its ability to imagine new technologies, solve fundamental theoretical problems, design engineering models, and build prototypes by taking advantage of the full range of resources available within the department.

During REDD's first 2 years, its objective was to support the Lab's sectors. This goal was reasonable in light of the Lab's recent reorganization into four sectors: Air and Missile Defense, Force Projection, Asymmetric Operations, and Space Exploration. Ensuring that this organizational model would be successful was naturally a top strategic priority. Along with providing technical talent for many sector projects, REDD management decided to devote a sizable portion of its IRAD funding to initiatives aligned with the sectors' strategic goals. Cross-organizational teams formed to identify important research projects for each sector; these projects had a 3- to 5-year time horizon and would be jointly staffed by researchers from REDD and subject-matter experts from the sectors. This model bore some valuable results, notably in the areas of cybersecurity tools, analytical tools, and space exploration concepts.

By 2014, the sustained performance of all four sectors gave rise to a shift in emphasis for REDD. The new charge is captured in the department's current vision

### BOX 3. SPOTLIGHT ON CONTEMPORARY BIOMEDICAL PROGRAMS

In addition to its work on the biomedical electronics described previously, APL has been involved in the development of devices and technologies to aid the disabled, including specialized wheelchairs, robotic manipulation to feed patients, and electronic communications devices for quadriplegics. It also established a strong biomechanics capability. Aimed originally at crash survivability for commercial vehicles, it has evolved into a robust injury prevention and blast trauma research and development program for the military.[24]

The blast trauma work, coupled with APL's long history of developing medical electronics and medical devices and its world-class systems engineering, led to the Revolutionizing Prosthetics system. This prosthetic system includes not only a robotic arm and hand assembly with unprecedented degrees of patient motion control but also a control mechanism that allows patients to control the limb with their minds and nerve impulses. This is truly an amazing accomplishment that will have lasting benefit for our injured military and civilian populations.[25] The prosthetic arm is shown in Fig. 10.

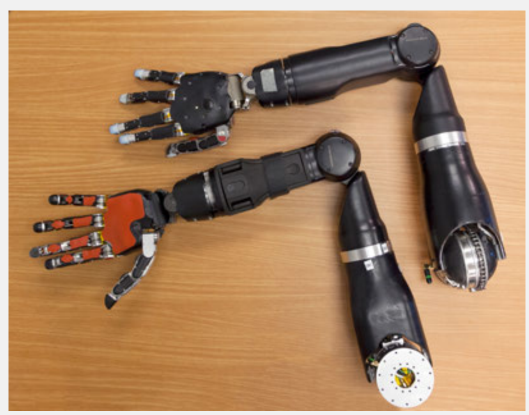

**Figure 10.** Modular Prosthetic Limb.

The Revolutionizing Prosthetics program, along with APL's work in injury prevention and blast trauma (stemming from its biomechanics efforts) as well as brain cognition and human behavior and complemented by the Lab's historic systems engineering approach, has paved the way for a major health care initiative at APL. The National Health Mission Area was formed in 2016 and is already making significant contributions to Hopkins medicine and military health care.

statement: "Accelerate transformative innovation and invent the future for APL." The emphasis is decidedly on blazing trails in new technology areas. The National Security Analysis Department is charged with a similar mission in the areas of analysis and policy studies.

To provide a framework for action under this new vision, REDD's group supervisors and program managers worked with the department's senior leadership team to identify a set of research focus areas for the department. They selected these areas by predicting the emerging technical disciplines that would be essential for APL's success 25 years into the future. From a practical point of view, the research focus areas serve as the overarching guide for strategic planning and provide the context for hiring decisions, allocating IRAD resources, and prioritizing capital investments. At the start of 2017, the research focus areas were as follows:

- Intelligent Systems, Robotics, and Autonomy
- Neuroscience
- Information Systems
- Systems and Synthetic Biology
- National Health
- Warfighter Protection
- New Materials and Manufacturing Science
- Power and Energy
- Alternative Computing Paradigms
- Trusted Computing and Electronics
- Sensing and Integrated Sensor Technologies

In addition to building a foundation of research and engineering activities within each research focus area, REDD also took the lead in exploring alternative organizational constructs and launching major new initiatives for the Laboratory. The four most important initiatives of this type were the Intelligent Systems Center (ISC), the Additive Manufacturing Center of Excellence (AMCOE), the National Health Mission Area, and the Discovery Program.

The ISC came about through a desire to foster creative collaborations and innovation among APL experts in robotics, autonomous systems, information sciences, and neuroscience. The cross-Laboratory vision was an essential aspect of the ISC from the start. In fact, the idea of a center of excellence was new for APL, and the ISC was an experiment in building a flexible workspace where multidisciplinary cross-organizational teams could come together, work on a project for a period of time, and make use of common facilities and software tools.

The ISC hosts key Lab projects, as well as Lab-wide challenges and hack-a-thons to accelerate the translation of recent breakthroughs in machine intelligence into new capabilities for APL sponsors. An early ISC project involved assembling a diverse collection of algorithms on autonomous systems into a unified autonomy tool kit (ATK) available to anyone at the Laboratory. During the summer of 2017, the ISC hosted a video game–themed challenge to introduce ATK to potential new developers at APL.

The ISC is housed in a building on APL's Montpelier Campus that was renovated and converted into an office facility with large open areas where robots could roam. In this way, the ISC also became an experiment in open offices, which turned out to be important for future building-design efforts.

AMCOE was the second REDD experiment with the concept of centers of excellence. Following the ISC's lead, AMCOE's general goal was to provide a cross-Laboratory resource for everything related to additive manufacturing, a transformational fabrication technology. When AMCOE was created, REDD already had a number of additive manufacturing machines for composite materials and had just acquired its first machine for processing metals. These machines were all in constant use on fabrication projects for APL sponsors. AMCOE centralized such fabrication services, but the center was also created to enable exploration of new materials and new methods for testing and evaluating the properties of objects built by additive manufacturing. The goals also included being a resource for DoD on the strategic use of additive manufacturing in a wide range of future operational scenarios.

Another significant accomplishment was the creation of the National Health Mission Area, a natural evolution for the Lab and for REDD. Over the years, APL had made a number of forays into health-related initiatives (see Boxes 1–3), especially in areas related to the military. When REDD was created, a successful effort on injury mitigation systems was already in progress, and this work continued to grow in size and importance during REDD's first 5 years as a department. The Lab made major capital investments in a vertical accelerator system that simulates an underbody blast to a vehicle and a blast simulator for studying traumatic brain injury and helmet designs. Also, from REDD's beginnings, its leaders made a concerted effort to expand the department's work in synthetic biology. A team of scientists built a research program centered on the study of viral evolution, protein folding, cell-free biology, bacteriophages, and the development of microfluidic analysis technology. The time was right to bring all of this work together in a program development effort focused on health.

During its first 5 years of existence, REDD had a single mission area, simply called the Research and Exploratory Development Mission Area. A program area for health was established within this mission area as an experimental first step, and one of its top priorities was to establish a strong partnership with Johns Hopkins Medicine. As it turned out, Johns Hopkins Medicine was enthusiastic about such a partnership. Based on the working relationship that quickly developed between the two organizations and the success of the Health Program Area, the APL Executive Council recommended in 2016 that a new National Health Mission Area be established. The National Health Mission Area is off to a great start, and we are optimistic that the work performed in this area will be valuable to both military and civilian populations in the years ahead.

Another major initiative that REDD took on in its early years was the creation of a rotational program for new college graduates entering APL. The Discovery Program allows new hires at APL to work in four different areas of the Laboratory in 6-month tours. After 2 years, program participants are free to bid for a permanent organizational home. The Discovery Program is now entering its third year and has enthusiastic support from across the Laboratory. Our hope is that each new generation of Discovery Program graduates will facilitate cross-organizational collaborations and drive innovation through cross-disciplinary teaming.

It is important to note that the ISC, AMCOE, the National Health Mission Area, and the Discovery Program are Laboratory initiatives that would not have been possible with the resources normally allocated to REDD. In each case, the APL Executive Council made a clear recommendation to proceed, allocated new resources for these efforts, and entrusted REDD to successfully execute the vision. This use of REDD as an incubator—not just for research and development but also for organizational constructs—has proven to be a flexible model for inventing APL's future and responding rapidly to new opportunities.

Now that REDD has grown to include over 500 people, its leadership created three branches to manage the department's expanding portfolio of projects. The current branches are

- Health and Biological Sciences;
- Concept Design and Realization; and
- Intelligent Systems and Physical Sciences.

REDD's challenge going forward will be to ensure that the culture it has built continues to thrive in this new organizational model. Of course, growth always presents this challenge, but APL's research organization is poised to meet it. REDD today is a vibrant, experimental organization with a talented technical staff and an equally capable team of administrative and support professionals. Its work is exciting and rewarding.

## CONCLUSION

APL is dedicated to applying science and technology to the complex problems of its sponsors, the nation, and society as a whole. Key to this ability to solve complex systems-level problems has been timely access to basic and applied research results that are linked to the problem at hand. The Lab's research center, in any of its eight incarnations, has stood at the center of the creation of this knowledge base for the last 70 years. During the center's history, the pendulum has swung between pure research and focused application development several times, even during a single incarnation. Each of the new research center organizations has ultimately achieved stability as the Laboratory grown and evolved with the times. REDD, the latest incarnation of the research center concept, is expected to have far-reaching impact. The integration of strong engineering and prototype development with a basic and applied science research organization has already led to many notable organizational achievements, including the ISC, AMCOE, and the new APL mission area in national health. The future of research at APL is very bright.

## REFERENCES


[1]Gibson, R. E., "Reflections on the Origin and Early History of the Applied Physics Laboratory," *APL Tech. Dig.* **15**(2), 2–32 (1976).

[2]Gibson, R. E., "Frank Trelford McClure (1916–1973)," *APL Tech. Dig.* **13**(4), 3–7 (1974).

[3]"The Milton S. Eisenhower Research Center Issue," *Johns Hopkins APL Tech. Dig.* **1**(1), 1–72 (1980).

[4]"The Milton S. Eisenhower Research Center–I," *Johns Hopkins APL Tech. Dig.* **7**(1), 1–125 (1986).

[5]"The Milton S. Eisenhower Research Center–II," *Johns Hopkins APL Tech. Dig.* **7**(2), 128–239 (1986).

[6]"Milton S. Eisenhower RTDC 50th Anniversary Issue," *Johns Hopkins APL Tech. Dig.* **18** (2), 165–341 (1997).

[7]Krimigis, S., "James A. Van Allen (1914–2006): From Iowa to APL to Iowa to Space," *Johns Hopkins APL Tech. Dig.* **33**(3), 162–164 (2016).

[8]Guier, W. H., and Weiffenbach, G. C., "Genesis of Satellite Navigation," *Johns Hopkins APL Tech. Dig.* **18**(2), 178–181 (1997).

[9]Danchik, R. J., "An Overview of Transit Development," *Johns Hopkins APL Tech. Dig.* **19**(1), 18–26 (1998).

[10]Massey, J. T., "Genesis of the Collaborative Biomedical Program," *Johns Hopkins APL Tech. Dig.* **1**(1), 5–6 (1980).

[11]Johns, R. J., "A Perspective: Collaborative Biomedical Research: Past, Present, and Future," *Johns Hopkins APL Tech. Dig.* **12**(2), 103–104 (1991).

[12]Ko, H. W., "Biomedical and Biochemical Technology at APL," *Johns Hopkins APL Tech. Dig.* **24**(1), 41–51 (2003).

[13]Bankman, I. N., Spisz, T. S., and Pavlopoulos, S., "Two-Dimensional Shape and Texture Quantification," in *Handbook of Medical Imaging*, I. N. Bankman (ed.), Academic Press, Orlando, FL, pp. 215–230 (2000).

[14]Charles, H. K. Jr., Beck, T. J., Feldmesser, H. S., Magee, T. C., Spisz, T. S., and Pisacane, V. L., "Precision Bone and Muscle Loss Measurements by Advanced, Multiple Projection DEXA (AMPDXA) Techniques for Spaceflight Applications," *Acta Astronautica* **49**(2–10), 447–450 (2001).

[15]Charles, H. K. Jr., Feldmesser, H. S., Magee, T. C., and Beck, T. J., "Advanced, Multiple-Projection, Dual-Energy X-Ray Absorptiometry System: Precision Bone Loss Measurements on Earth and in Space," *Johns Hopkins APL Tech. Dig.* **28**(3), 212–213 (2010).

[16]Waltrup, P. J., White, M. E., Zarlingo, F., and Gravlin, E. S., "History of Ramjet and Scramjet Propulsion Development for U.S. Navy Missiles," *Johns Hopkins APL Tech. Dig.* **18**(2), 234–243 (1997).

[17]Murphy, J. C., Dubbel, D. C., and Benson, R. C., "The Security Technology Institute for Counterfeit Defense," *Johns Hopkins APL Tech. Dig.* **18**(2), 295–301 (1997).

[18]Bryden, W. A., Benson, R. C., Ecelberger, S. A., Phillips, T. E., Cotter, R. J., and Fenselau, C., "The Tiny-TOF Mass Spectrometer for Chemical and Biological Sensing," *Johns Hopkins APL Tech. Dig.* **16**(3), 296–310 (1995).

[19]Fischell, R. E., "The Development of Implantable Medical Devices at the Applied Physics Laboratory," *Johns Hopkins APL Tech. Dig.* **13**(1), 233–243 (1992).
[20]Cutchis, P. N., Hogrefe, A. F., and Lesho, J. C., "The Ingestible Thermal Monitoring System," *Johns Hopkins APL Tech. Dig.* **9**(1), 16–21 (1988).
[21]Wozniak, J. J., and Leong, K., Single-use, self-annulling injection syringe, U.S. Patent 4781683 A, filed 22 Apr 1987, and issued 1 Nov 1988.
[22]Franson, J. D., and Jacobs, B. C., "Quantum Computing," *Johns Hopkins APL Tech. Dig.* **18**(2), 188–192 (1997).
[23]Semmel, R. D., Immer, E. A., Silberberg, D. P., and Winkler, R. P., "Knowledge-Based Query System Formulation for Integrated Information Systems," *Johns Hopkins APL Tech. Dig.* **18**(2), 261–270 (1997).
[24]Merkle, A. C., Kleinberger, M., and Uy, O. M., "The Effects of Head-Supported Mass on the Risk of Neck Injury in Army Personnel," *Johns Hopkins APL Tech. Dig.* **26**(1), 76–83 (2005).
[25]Ravitz, A. D., McLaughlin, M. P., Beaty, J. D., Tenore, F. V., Johannes, M. S., et al., "Revolutionizing Prosthetics—Phase 3," *Johns Hopkins APL Tech. Dig.* **31**(4), 366–376 (2013).

## APPENDIX. BIOGRAPHIES OF RESEARCH CENTER LEADERS FROM 1972 UNTIL 2010

For more on Ralph E. Gibson's bio, see the article on APL's directors by H. E. Worth, in this issue. For Frank T. McClure's bio, see Ref. 2. Jim Schatz's biography appears at the end of this article.

**Robert W. Hart**, a theoretical physicist, served APL for 38 years. He was chairman of APL's Milton S. Eisenhower Research Center (MERC) from 1972 to 1982. Before leading MERC, he had supervised the Special Problems Research Group in the Center. Beginning in 1980, he served as the first chairman of the committee that recommends the Independent Research and Development (IRAD) program areas and yearly funding allocations. From 1982 until he retired in 1989, he served as assistant director for research and exploratory development. He also held a part-time appointment as an associate professor of ophthalmology at the Johns Hopkins School of Medicine. Hart made significant contributions to the development of theories on electromagnetic wave scattering of optimal ramjet performance, unstable burning of solid rocket motors, and low beamrider missile and map matching guidance systems. He also contributed to biomedical research to improve knowledge of the human eye. In 1989, Dr. Carl Bostrom, director of APL at the time, announced the establishment of the Robert W. Hart Prize for Excellence in Independent Research and Development at APL, which includes two annual prizes, one each for the best research project and the best development project.

**Theodore O. "Ted" Poehler**, whose relationship with Johns Hopkins University and APL spanned more than 60 years, was director of APL's Milton S. Eisenhower Research Center (MERC) from 1983 to 1989. After earning his doctoral degree from Johns Hopkins in 1961, Poehler began his career as a researcher at the U.S. Army's now-defunct Ballistic Research Laboratory. He served in the U.S. Army at the Aberdeen Proving Ground from 1962 to 1963. In 1963, he joined APL and held several positions, including assistant supervisor in the Plasma Dynamics Group and supervisor of the Quantum Electronics Group. In the 1980s, Poehler served in several roles at Johns Hopkins, including director of part-time graduate programs at the Whiting School of Engineering. In the 1990s he served as the Whiting School's associate dean of research and as a research professor in electrical and computer engineering and in materials science and engineering. He served as vice provost for research from 1992 to 2008. Ted died in 2016.

**Donald J. Williams** was director of APL's Milton S. Eisenhower Research Center (MERC) from 1990 to 1996. He received a B.S. in physics from Yale University in 1955 and, after 2 years in the Air Force, received M.S. and Ph.D. degrees in nuclear physics, also from Yale, in 1958 and 1962, respectively. He joined APL's Space Department in 1961, where he participated in developing APL's early space research activities. In 1965, he went to NASA Goddard Space Flight Center, and in 1970, he was appointed director of NOAA's Space Environment Laboratory. In 1982, he rejoined APL's Space Department. Dr. Williams worked on various NASA, NOAA, DoD, and foreign satellite programs. He was a member of and chaired numerous committees advising and defining the nation's space research program. His research activities, which resulted in over 200 publications, were in space plasma physics with emphasis on planetary magnetospheres.

**John C. Sommerer**, who joined APL in 1980, was director of APL's Milton S. Eisenhower Research and Technology Development Center (RTDC) from 1996 to 2007. He holds a doctorate and a master's degree in physics from the University of Maryland and Johns Hopkins, respectively, and master's and bachelor's degrees in systems science and mathematics from Washington University in St. Louis. From 2008 until he retired in 2014, he headed APL's Space Department and briefly served as APL senior fellow for national space policy. Before assuming these roles, he held technical and management positions in five departments, leading the development of a key Lab strategic plan and helping APL to establish an international reputation in nonlinear dynamics, making both theoretical and experimental contributions to the field. His dynamics research has been featured on the covers of both *Science* and *Nature*, and he served on several National Academies–chartered technical advisory bodies for the U.S. government. Sommerer also chaired the Naval Research Advisory Committee as a special government employee.

**Bharat Doshi**, an internationally recognized authority in optical and wireless networking technologies, was director of APL's Milton S. Eisenhower Research and Technology Development Center (RTDC) from 2007 until 2010. He received a bachelor's degree in mechanical engineering from the Indian Institute of Technology and earned master's and doctorate degrees in operations research from Cornell University. Before becoming director of RTDC, he had been a professor of electrical and computer engineering at the University of Massachusetts, Amherst. From 2003 to 2005, he worked in what became APL's Applied Information Sciences Department, leading the office responsible for developing advanced information-processing and networking concepts. Doshi joined APL after a distinguished 24-year career at Bell Labs/Lucent Technologies. After stepping down from his position in RTDC, he became APL's first global science and technology outreach manager. He is a fellow of the Institute of Electrical and Electronic Engineers and a Bell Laboratories fellow. He holds 40 patents, has published more than 120 technical papers, served on multiple advisory boards to U.S. government agencies, and edited several technical journals. He retired in 2015.

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James R. Schatz is head of APL's Research and Exploratory Development Department. He holds degrees in mathematics and computer science and a Ph.D. in mathematics from Syracuse University. He joined APL in 2009. Before becoming Head of REDD, he served as acting managing executive of APL's Applied Information Sciences Department, which developed advanced information technology for critical national challenges. Prior to joining APL, Schatz spent 15 years as a code breaker at NSA and went on to serve an additional 15 years as chief of the Mathematics Research Group, deputy director of research, and director of the Research Directorate. Schatz's career accomplishments have been recognized across academia, industry, and government with several prestigious awards, including the National Intelligence Distinguished Service Medal and Distinguished Executive Presidential Rank Award. His e-mail address is james.schatz@jhuapl.edu.

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Harry K. Charles Jr. is a member of the APL Principal Professional Staff and the program manager and group supervisor for the APL Education Center in the Research and Exploratory Development Department. He has a B.S. from Drexel University and a Ph.D. from the Johns Hopkins University, both in electrical engineering. Dr. Charles has over 40 years of experience in the microelectronics field and is a specialist in electronic packaging. He has over 210 major technical publications, holds 17 U.S. patents, and is a life fellow of both the Institute of Electrical and Electronics Engineers (IEEE) and the International Microelectronics and Packaging Society (IMAPS). He has been internationally recognized for his research and teaching activities on several occasions. As a teacher, he has developed courses and taught in the Engineering for Professionals program since 1979 and is currently a student advisor and the program chair for Applied Physics. Dr. Charles is also the editor-in-chief of APL's *Technical Digest*. His e-mail address is harry.charles@jhuapl.edu.