CONTINUOUSLY REIMAGINING NAVAL POWER
In 1946, the Office of Naval Research (ONR) began its first year of existence with a research budget of about $20 million—all of it devoted to basic research. Today, more than 75 years later, ONR manages a diverse portfolio of more than $5 billion, with research partners across government, industry, and academia, both in the U.S. and around the world. The command has been responsible for groundbreaking basic research, innovative naval prototypes, and game-changing programs of record for America’s Sailors and Marines. Along the way, ONR-sponsored researchers have been awarded more than 70 Nobel Prizes. At nearly every stage in its long history, through peace and wars both hot and cold, ONR has always punched above its weight.

Today’s U.S. Navy and U.S. Marine Corps are the finest sea services in the world, due in large measure to ONR’s patient, targeted, and expert management of countless projects that have resulted in technology found on nearly every aircraft, ship, submarine, land vehicle, and server in the fleet and force. Even more broadly, ONR’s focus on the oceans and their intersection with the air, the shore, and space has been profoundly effective—and given rise to a host of innovations that have benefited not only the services but society writ large. Project Whirlwind in the 1940s and 1950s created the first real-time computing system, a central component of ship, aircraft, and unmanned vehicle monitoring systems (as well as that of every modern car and even of many homes). Meteorologists have become progressively more accurate at forecasts that affect warships and civilian craft alike because of ONR’s investments in weather predictive technologies. ONR’s support for basic research in the production of gallium nitride, a compound that does not occur naturally, has led to the material’s incorporation into the newest generation of high-powered military electronics and radars, as well as into every modern LED display in consumer electronics. And, at the core of our mission, ONR research has led to a host of groundbreaking defense capabilities that have enabled our Sailors and Marines to complete their missions and come home safely.

A more detailed telling of these discoveries and innovations—which are still only a fraction of the complete story of ONR’s impact and legacy—is contained within the pages of this publication. We highlight here the significance of the past three quarters of a century and ONR’s vital contributions to science and technology and the warfighting effectiveness of our Sailors and Marines, as we look forward to the future as the 21st century unfolds.

Now more than ever, science and technology is a collaborative endeavor that is diverse, equitable, and inclusive. From our support for small businesses and science, technology, engineering, and mathematics (STEM) education to our partnerships with laboratories and other organizations, our story is also their story.

ONR is serving an essential role helping the Navy and Marine Corps to maintain technological superiority and dominance in an ever-changing and ever-challenging world. ONR continues “to plan, foster, and encourage scientific research”— and to reimagine naval power.
In August 1946, President Harry S. Truman signed Public Law 588, a bill that formally established the Office of Naval Research. Even though the organization that was “created” with this legislation had been doing real business for more than a year as the Navy’s Office of Research and Invention, this act nonetheless was more than simply a formality; it codified a new relationship between the U.S. government and science that heretofore had only been a temporary arrangement for the sake of the exigencies of war.

Although it was congressional action that had led to the founding of ONR during that first full summer of the Cold War, the concept of a permanent military agency supporting basic research in civilian industry and academia had been operating in practice through the efforts of the Secretary of the Navy for nearly a year and a half. Practically speaking, there was little to change in how the office conducted itself on a day-to-day basis except its letterhead. However, the change this organization would bring about in the Navy, and on science itself, would be profound. More than 75 years later, this organization is still reimagining naval power every day.
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**A SCIENCE AND TECHNOLOGY RESEARCH FAMILY**

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- **Office of Naval Research (1946)**
- **National Science Foundation (1950)**
- **Air Force Office of Scientific Research (1951)**
- **Army Research Office (1951)**
- **Defense Advanced Research Projects Agency (1958)**

The idea for this organization had its immediate roots in the massive industrial, military, scientific, and technological endeavors involved in the U.S. war effort during World War II. After the global crisis following the Fall of France and the Battle of Britain in the summer of 1940, Vannevar Bush, president of the Carnegie Institution, argued for the creation of the National Defense Research Committee to help coordinate the efforts of civilian scientists and inventors for the sake of national defense. Established by order of President Franklin Delano Roosevelt, the organization would soon expand and, the following year, be renamed the Office of Scientific Research and Development (OSRD). This agency would go on to manage a vast science and technology operation involving thousands of scientists and engineers at universities and industries around the country with contracts totaling more than $500 billion between 1940–46. Major outcomes included work on proximity fuzes, airborne and shipboard radars, and the beginnings of the Manhattan Project. Organized by various scientific and technology areas and projects, OSRD also had partner organizations within the War and Navy Departments. It would be a group of young officers within the Navy’s Office of the Coordinator of Research and Development, the so-called “Bird Dogs,” who would be the first to advocate for a separate Navy organization using OSRD’s basic structure.

The use of government contracts to enlist the creative efforts of civilian scientists and engineers was a wartime measure seen by many observers at the time as a temporary arrangement—much as similar cooperative experiments between the government and the civilian world had been in World War I and the Civil War. Vannevar Bush, in his seminal work *Science: The Endless Frontier*, made a convincing argument for the continuation of the partnership between government and science into the postwar era. It would be the Navy looking toward the short-term, however, that would be the first to make Bush’s theoretical arguments into vivid, practical reality.

The organization that would become the Office of Naval Research initially was founded, like so many lasting institutions, with mainly immediate aims in mind just as the war was coming to a conclusion in 1945. It was the creation of Vice Adm. Harold Bowen, whose primary goal—according to historian Harold Sapolsky in his history of ONR, *Science and the Navy*—was to use the new organization as a platform for spearheading the Navy’s adoption of nuclear power. The Office of Research and Invention, however, would outlast Bowen’s political ambitions—and lose the leadership of naval nuclear energy to then-Capt. Hyman G. Rickover—to create something far greater: the transformation of American science and technology. Broad congressional support for postwar science helped Bowen’s creation—established initially by order of the Secretary of the Navy under the War Powers Act—achieve permanent status in the summer of 1946 with the passing of Public Law 588. Understanding why this act was transformative involves understanding the slow but steady growth of the connections between science, technology, and Navy in the century and a half between the sea services’ establishment and the foundation of ONR.
Dreadful accidents with early shell guns, such as the explosion of the “Peacemaker” gun aboard the USS Princeton in 1844 that resulted in the deaths of the Secretary of State and the Secretary of the Navy and multiple others injured, eventually resulted in the move toward careful testing of new gun designs by the time of the Civil War. Library of Congress illustration

In the early days of the republic, from the 1790s to the Civil War era, the small U.S. Navy could not compete in size with the dominant navies of the age—but it could build ships of high quality incorporating the best technology of the time. In conflicts with France, the Barbary states of North Africa, and most notably Great Britain in the War of 1812, American ships distinguished themselves for their swift speed, sturdy construction, and well-trained crews. Active experimentation with new technology was still in its infancy, and still relied largely on the serendipitous discoveries of individual inventors. The first organizations that would help accelerate the adoption of new technologies appeared with the creation of what would become the U.S. Naval Observatory in 1830, and the first bureau system in 1842 (the predecessor of today’s systems commands).

In the first decades of the 19th century, the U.S. Navy cautiously experimented with major new technologies—the shell gun and steam power. With the full-scale adoption of these technologies by the time of the Civil War, the Navy began establishing testing stations that would help to refine and perfect these powerful and challenging inventions. Beginning with gunnery testing at the Washington Navy Yard and in Annapolis, these stations would grow during the second half of the 19th century to include facilities for testing torpedoes, new propellants, new hull shapes, and eventually early aircraft, all of which were vital components of the naval revolution that would create the “New Steel Navy.”

This infrastructure—what largely continues today as the naval surface, undersea, and air warfare centers around the country—was the essential science and technology backbone that would help the Navy incorporate the latest in naval technology in its massive expansion at the beginning of the 20th century. For decades, the labor force at these testing stations and the bureaus that oversaw them consisted of naval personnel. It would be World War I and the appearance of some of the most formidable naval technologies yet—the submarine and the modern sea
The brainchild of inventor Thomas Edison during World War I, the U.S. Naval Research Laboratory was founded in 1923. It would provide the Navy with its first permanent organization dedicated to basic scientific research.

The David Taylor Model Basin, seen here around the time of its construction in 1898, was one of the world’s first tow tanks for testing new hull shapes. Facilities such as these in the late 19th and early 20th centuries helped the Navy to test and build the technologies that facilitated its rise as one of the world’s largest navies by the time of World War I. National Archives photo

With the beginning of World War II and the establishment of OSRD, the Navy’s Office of the Coordinator of Research and Development acted as a kind of middle man between civilian scientists and engineers and the larger national organization. The coordinator—initially the civilian Jerome Hunsaker, and later Rear Adm. Julius Furer—was limited in his scope and power. "(The office) did not coordinate the research work of the Navy’s material bureaus," writes Sapolsky. "Neither its small staff nor the bureaus would have permitted such a venture. Rather, it acted as a liaison agency between research organizations within the Navy and those outside, especially the civilian directed committees and divisions of OSRD." A group of young reservist officers in the Office of the Coordinator, headed by Lt. Bruce Old and Lt. Ralph Krause, known now as the "Bird Dogs," foresaw a larger and longer-term role for a science-supporting agency within the Navy, one that would outlast the emergency measures of the war. Their design, headed by a flag officer and supported by a research advisory committee, would support civilian scientists in basic research that would be of mutual benefit both to science and the sea services. The plan was initially rejected in 1944, but would eventually provide the basic structure for the new organization, the Office of Research and Invention, created by order of Secretary of the Navy James Forrestal in the spring of 1945.
Concomitantly, there were changes also within the Department of Defense. Many of the Navy’s laboratories were started during World War II. Among these were the Naval Electronics Laboratory in San Diego, the Naval Ordnance Laboratory in Corona, the Naval Ordnance Test Station at China Lake, and the Underwater Sound Laboratory in New London. They now had to be integrated permanently into the Navy’s research and development establishment. Laboratories became more numerous also in the other services, and non-profit organizations were created to satisfy special needs. Along with the earlier parallel Research Offices in the Departments of the Army and the Air Force, there now appeared within the Office of the Secretary of Defense the Advanced Research Projects Agency, supporting research both inside and outside the Department of Defense. If the outlays for space and atomic energy are added to defense, a figure of ninety percent of the total R&D is reached. Such heavy Government investment clearly must be made for good cause: Our government does not spend nearly fifteen percent of its budget in the research and development business because science has a powerful lobby; in fact, scientists are still rather untutored at the game; nor because the United States is hungry for a better understanding of nature, or what lies on the other side of the moon; nor—finally—as a contingency investment against the risk that some other nation will surpass us. Each of these factors certainly plays a part, but basically the investment is made because our society has understood the dependence of its future on science and technology.

It is fundamental to the approach of basic research that scientific truth must be pursued on its own terms, governed by internal standards of relevance, and free from pressures of external purpose. The lifeblood of good science requires respect for and faith in this internal integrity of science. Basic research cannot directly confront social, or political, or military purposes. This is not a weakness, but a quintessential characteristic which give research its strength. If, therefore, the government is to strike a bargain with research, if it is to support it in the fashion that ensures best performance, there is need for a special buffer organ which sees to it that the interest of both parties are advanced. This buffer is the government organization which functions as a “middle man” between the scientific, generally discipline oriented communities and the operating government agency with its mission purpose. ONR functions in this manner for the Navy. As such, its success in the deepest sense has been the result of the creative role which it has played between the researcher in the private community and the long-term needs of the Navy. ONR has deliberately not compromised the motives of the researchers in academic establishments or nonacademic laboratories; at the same time, however, it has sought to shape an overall program of research which would assure contributions to the solution of long-term Navy problems. Moreover, as new technologies have opened up, ONR has actively promoted the Navy’s commitment to them so that the line organizations with development responsibility might begin to learn something about them for later practical exploitation.

Still, it will happen occasionally that some elements of the Navy, primarily exposed to the pressures of immediate requirements, entertain doubts about what ONR is doing. For related reasons, the academic researcher occasionally forgets that the Office of Naval Research is a part of the Navy. Both attitudes are consequences of the special circumstances with which any research-supporting organization must learn to cope if it is to be an actively contributing intermediary between research and practical need.

Most recently, the Material Establishment of the Navy has started to undergo a far-reaching reorganization to adapt it more effectively to current and foreseeable needs in coping with the engineering and management complexities that have followed in the wake of modern science. At the same time, the operational commitments of the Navy are dictated to an ever larger degree by complex and shifting patterns of interdependence, a fact which widens the spectrum of requirements and calls for tools of increasing power in their identification. The accelerated advance and diversification of science, finally, brings with it the potential of a greatly increased range of options for meeting such future requirements. If there is one thing, above all others, for which the Navy today needs the mentality that ONR has fostered and which it represents on the Navy team, then it is for the purpose of helping to make increasingly cogent choices in this increasingly demanding environment.
These are simple questions with complex answers—answers that depend very much on who is asking them, and, more important, when they’re asking them. Since the end of World War II, the Office of Naval Research has played a vital role in reimagining the way science and technology are managed and supported, and how these two questions get answered. By channeling federal resources to American science, ONR also has helped shape the Navy and Marine Corps—and indeed the world—of today. Historian Gary Weir writes in *An Ocean in Common* that the Office of Naval Research has played a vital role in reimagining the oceans and ocean science, and technologies that helped launch revolutionary projects and reimagined information itself, atmosphere and space, and many others. ONR-sponsored and -managed efforts have helped to reimagine the oceans and ocean science, revolutionizing the field of oceanography and revealing many of the mysteries of the 71 percent of the Earth that had been largely unknown before the 20th century. ONR has also reimagined the ship, providing new means and methods for building, protecting, and using ships at sea. It has also reimagined aerospace, pioneering new concepts and designs for aircraft as well as providing the means to explore the upper atmosphere and space, and reimagined information itself, launching revolutionary projects and technologies that helped build the modern information age. And ONR has reimagined human performance, expanding the limits of how far and how deep humans can go. The Office of Naval Research continues to reimagine the future of naval power.

Machine learning, nanoscience, ocean science, advanced materials, remote sensing, unmanned systems, medical research, power and energy, space, and many others.

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ONR Global’s mission is to serve as the enduring Navy and Marine Corps global presence in technical and operational communities, investing in trusted partnerships to discover and connect science and technology leaders for sustained maritime security. This integral, internationally oriented arm of ONR predates its parent organization’s establishment. Originally founded as a scientific liaison mission in London in the midst of World War II in 1941 and run by the Office of Scientific Research and Development, the London Mission was shifted to the Navy in March 1946. For many years it was ONR London, maintaining close connections between European and American scientists and the naval research establishments on both sides of the Atlantic. In 1974, a Tokyo office was added, beginning a process of expansion that has led to a now truly global reach, with additional offices in Prague, Czech Republic; Santiago, Chile; São Paulo, Brazil; Singapore; and Melbourne, Australia. ONR Global coordinates the liaison visit program of U.S. scientists going overseas as well as the visiting scientists program of foreign scientists coming to the United States. In addition, ONR Global also runs a collaborative science program that connects international and U.S. agencies and organizations for short- and long-term projects around the world, and provides research grants to principal investigators outside the United States.

NavalX serves the Navy and Marine Corps as an innovation and agility cell, supporting and connecting initiatives across the Department of Defense. NavalX connects teams with tools, training, and resources—enabling people to think differently and deliver more effective solutions to warfighters. Founded in 2019 by James Geurts (then the Assistant Secretary of the Navy for Research, Development and Acquisition), NavalX is staffed by government civilians, Marines, Sailors, and partners across the Department of Defense. Innovation nodes are located across the world alongside an online network of government, military, industry, and academia partners.

The U.S. Naval Research Laboratory

Established in July 1923, the Naval Research Laboratory (NRL) was the brain child of inventor Thomas Edison, who saw tremendous potential for the government to set up its own laboratory to conduct research that otherwise might not have received support. NRL is the Navy and the Marine Corps’ corporate laboratory charged with the mission of conducting basic and applied research in a broad, multidisciplinary program to advance science and technological development for the National Defense Strategy. NRL has been connected to ONR since 1946. The laboratory developed the first U.S. radar, used on naval vessels during World War II. NRL also has a long history of advances in space exploration, developing some of the earliest satellites in the 1950s and the first satellite tracking system, as well as one of the first satellite navigation systems, Timation. Today, NRL conducts research in a wide range of fields, including meteorology, advanced materials, autonomous systems, space systems and technology, advanced sensors, information security, directed energy, radar, human-robot interaction, and numerous other areas of research.

Chief of Naval Research Rear Adm. Lorin Selby (center left) and Rear Adm. James Parker CBE of the Royal Navy cut a ribbon to celebrate the grand opening of the London Tech Bridge in June 2022. A collaborative effort between NavalX, ONR Global, and the Royal Navy, the tech bridge will connect government labs, industry, academia, and other military branches to facilitate innovative technology projects. Photo by Michael Walls.

PMR-51

PMR-51 is the U.S. Navy Office of Low Observable/Counter Low Observable Policy, Technology and Advanced Projects operating as a field activity of the Office of Naval Research. The office also serves as the Office of Primary Responsibility for Navy and Marine Corps Low Observable/Counter Low Observable policy.
REIMAGINING THE OCEANS
On Jan. 23, 1960, Navy Lt. Don Walsh and Swiss engineer Jacques Piccard descended to the deepest spot in the world ocean, the Challenger Deep near the Pacific island of Guam. They accomplished this in the bathyscaphe Trieste, a deep-diving vessel consisting of small spherical crew spaces slung underneath large floats resembling balloons in both shape and function. The goal of the mission was to prove the viability of human exploration in such a harsh environment—as well as understand how temperature, pressure and sound interact at great depths.

The trip had some nerve-wracking moments: A viewport cracked during the descent, and much of the trip was spent out of contact with the surface. But Walsh and Piccard successfully reached the lowest depth of 35,814 feet and returned safely.

Neither man saw much at the ocean’s bottom, since a cloud of particles engulfed the Trieste when it hit bottom, preventing them from making further observations. Still, the successful dive ushered in a “golden age” of manned underwater exploration in the 1960s and 1970s, in which submersibles helped make extraordinary discoveries in biology, geology, chemistry, oceanography, and other fields.

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An excerpt from a 2014 oral history interview with Don Walsh:

**Don Walsh (DW)**

Well I’m going something that may seem a bit [inaudible], and that is, it was just a longer day at the office. Because as I’ve said, we for seven months made increasingly deeper test dives. It’s like flying an airplane: whether you’re going just around the pattern shooting landings or going across country, your manipulations in preflighting and after the flight, putting it away, shutting everything down, so you’ve got check-off lists and all of it. Exactly the same. The only difference between those two points is the length of the flight, which converts to time. In our case it’s the depth of the water, which converts to time. But whether we dove a hundred feet in Guam harbor, the pre-dive procedures and post-dive procedures were the same, exactly the same. So that’s what I mean a longer day at the office. The distance between those two points was water depth. A hundred feet, it’s very quick. Thirty-six thousand feet, nine hours. It took us five hours and some change to get down, we spent a half-hour on the bottom, and the rest of the time coming up. And that was it. We did not see anything at the bottom once we landed because the bottom sediment stirred up, and it was like somebody painted our viewport white.

So it always happened, all the dives we ever made. That happens, you expect it, you land a little cloud of sediment comes up. By the time you call topside, tell them where you are, what you’re doing, and get the cameras out, set ‘em up to start taking pictures—we had still and movie cameras—the cloud drifts away and you’re ready to go to work. This dive it didn’t, it just persisted, and there was no apparent change in the density of the cloud. If we saw a trend, we might have stayed down a little bit longer to...
be able to see. So we never saw the seafloor once we were on it. As we approached the seafloor, we could see it coming up, and we did see about a foot-long flatfish, like a halibut or soul, small. But that told us quite a bit, just that one glimpse, because that’s a bottom-dwelling form, two eyes on one side. And if there’s one, there’s more. And that tells you also there’s sufficient oxygen and food at that depth because they’re bottom dwelling. So that’s something coming down just sitting there. And finally, it’s a fairly high-order marine vertebrate. As life in the sea goes, it’s fairly high order in the evolutionary chain. Because we saw all sorts of invertebrates, shrimps, jellyfish, that kind of thing, all expected—everybody...

**Colin Babb (CB)** 
On the bottom or on the way down?

**DW** On the way down, you just go through these things. And they’ve been found before. What was the name of the… a Danish expedition, Galathea expedition in the 1950s. They trawled down to about 25,000 feet, pretty deep. And they brought up all these invertebrates, worms, jellyfish; that kind of thing. And finally, it’s a fairly high-order marine vertebrate. As life in the sea goes, it’s fairly high order in the evolutionary chain. Because we saw all sorts of invertebrates, shrimps, jellyfish; that kind of thing, all expected—everybody...

**CB** But it was something that was moving?

**DW** No, it was just sitting there.

**CB** It was just sitting there.

**DW** But, you know, that’s the nature of science. I didn’t see any of those ichthyologists over my shoulder. And they may be right; maybe we weren’t ichthyologists, we weren’t scientists, we didn’t know what we were seeing.

**CB** But it was something that was moving?

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**DW** But, you know, that’s the nature of science. I didn’t see any of those ichthyologists over my shoulder. And they may be right; maybe we weren’t ichthyologists, we weren’t scientists, we didn’t know what we were seeing.

**CB** But it was something that was moving?

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PLATE TECTONICS AND HYDROTHERMAL VENTS

In early 1977, ANGUS (Acoustically Navigated Geophysical Underwater System) was lowered to the depths off the Galapagos. Built at Woods Hole for Project FAMOUS, ANGUS was a 2-ton steel cage equipped with cameras and powerful strobe lights. ANGUS was one of the first towed sensor vehicles of the type that would later be used to search for the submarines USS Thresher (SSN 593) and USS Scorpion (SSN 589) and the liner RMS Titanic. Woods Hole Oceanographic Institution photo

The plate tectonics revolution that culminated in the late 1960s fundamentally rearranged the understanding of Earth processes. Plate tectonics states the Earth’s outer shell comprises several large plates gliding over the rocky inner layer above the core.

In 1973—as part of Project FAMOUS (French-American Mid-Atlantic Undersea Study)—Robert Ballard, a long-time ONR principal investigator, and other scientists descended 10,000 feet to the Mid-Atlantic Ridge, a mountainous seam stretching along the center of the Atlantic Ocean. The expedition involved ONR funding and assets such as the deep-sea submersible Alvin. Instead of muddy and uniform, the ocean floor revealed itself as a diverse landscape of rocks, lava and geological features of all shapes and sizes—shifting contemporary conceptions of the sea bottom. This revelation confirmed the role of plate tectonics in the formation of the Earth’s outer skin.

Plate tectonics also inspired the idea of seafloor hot springs that could sustain life. In 1977—again with the support of ONR funding and assets—Ballard’s team discovered deep-ocean thermal vents, nicknamed “black smokers,” off the coast of South America. The presence of large colonies of clams, mussels, worms and crabs around these scalding vents demonstrated that organisms could thrive without sunlight—the energy source for most life on land—in a process known as chemosynthesis.
The 1950s saw beginnings of the Navy’s Sound Surveillance System (SOSUS), which could track submarines by their faint acoustic signals—via specialized microphones called hydrophones, which were placed on the ocean floor. Facing a significant threat from Soviet submarines with the advent of the Cold War, a research committee led by G.P. Hartwell of the University of Pennsylvania recommended that the Navy devote $10 million annually to building systems capable of tracking submarines at sea using the newly discovered SOFAR channel—the region in the oceans where sound can travel over hundreds or even thousands of miles. In 1950, the SOSUS project began when the Office of Naval Research contracted with Western Electric to build long-range underwater sensors. By the end of the decade, listening stations were established in both the Atlantic and Pacific; in 1961, the SOSUS system eventually consisted of numerous seafloor arrays in the Pacific and Atlantic controlled from shore stations, such as this one at Canadian Forces Station Shelburne, Nova Scotia. U.S. Navy photo

The new system was able to track the new ballistic submarine USS George Washington (SSN 598) as it transited to the United Kingdom, and the first detection of a Soviet submarine came the following year. SOSUS eventually was capable of detecting submarines around the world and became a centerpiece of Cold War defense. Since then, as submarines have gotten quieter, ONR has sponsored the development of sophisticated, air-dropped sonobuoys deployed in strategic areas of the ocean. Signal processing enabled by transmitters and receivers allow operators to track submarine movement across a vast field of sonobuoys.

Starting in the early 2000s, ONR has worked to develop multistatic active acoustic submarine detection systems. A multistatic system is characterized by one receiver receiving transmissions from more than one transmitter, and vice-versa. Acoustic systems in the ocean exhibit this behavior most effectively over the continental shelf, where sound waves can fill the water column through reflections from the bottom and surface. Modern multistatic transmitters use coherent waveforms rather than explosions. Work at ONR has focused on multistatic coherent active air-dropped sonobuoys operating over the continental shelf. Early work developed flex tensional transmitters that allowed performance criteria to be met in a smaller volume, in-buoy signal processing to aid in monitoring large sonobuoy fields, and cross-receiver contact fusion that allows operators to track submarines across a field of sonobuoys. Work in the late 2000s focused on placing a field of transmitters and receivers for best performance, predicting evolving field performance from in-situ environmental measurements, and tracking motion of sonobuoys after deployment. Environmental measurements and sonobuoy tracking are combined to predict when replenishment of the sonobuoy field is needed.

Current developments feature ping control algorithms to prevent mutual interference when one receiver is receiving transmissions from more than one transmitter, and improved batteries to enable transmitters to operate more rapidly or longer. Many of the ONR developments have transitioned to the Multistatic Active Capability (MAC) program of record, which started in the early 2000s soon after the ONR program began.
REMUS was originally conceived of as one component of a set of vehicles, sensors, and electronics that would be incorporated into the Long-term Environmental Observatory, a project at the Institute of Marine and Coastal Science at Rutgers University run by J. Frederick Grassle and supported by ONR. LEO-15 (so called because it was intended to be operated in 15 meters of water at Little Egg Inlet on the coast of New Jersey) was formulated in the early 1990s as the first coastal observatory that would link a suite of sensors by fiber-optic cable to a shoreline laboratory and the internet, providing long-term, real-time data on the coastal environment.

Although intended as an oceanographic research platform, REMUS quickly gained the interest of the Navy for use in the fields of mine countermeasures and, later, explosive ordnance disposal. During the invasion of Iraq in 2003, a special team using REMUS and dolphins helped clear the port of Umm Qasr of sea mines. While the REMUS was used for the general survey of the harbor to identify suspected targets, specially trained dolphins were able to pinpoint which targets actually were mines. The operation was the first practical military use of REMUS, as well as the first use of such technology in concert with marine mammals.

REMUS vehicles have been used around the world for ocean surveying, including the successful search for Air France Flight 447, which crashed in the South Atlantic in 2011, as well as the discovery of the wreck of the American World War II cruiser, USS Indianapolis (CA 35), in 2017.
Tharp collaborated with Bruce Heezen, who studied under Maurice Ewing at Columbia and would remain at Lamont until his death in 1977. University of Iowa Archives photo

The first detailed three-dimensional map of the Earth’s seafloor was completed in 1957 by Marie Tharp and Bruce Heezen. This painting by Heinrich Berann was based on the map. Library of Congress illustration

Tharp worked to develop the first seafloor map at Columbia University’s Lamont Geological Observatory (now Lamont-Doherty Earth Observatory). Tharp was one of the first women to work at the observatory. Lamont Geological Observatory photo

With the importance of submarines to modern naval warfare firmly established during World War II—and heightened by the development of deadlier, deeper-diving nuclear submarines in the early 1950s—the U.S. Navy was keenly interested in acquiring accurate maps of the world’s oceans. After the war, ONR funded efforts at Woods Hole Oceanographic Institute, the Scripps Institution of Oceanography and the Lamont Geological Observatory at Columbia University to collect the sonar sounding data that eventually would be used to create such maps.

In 1957, Bruce Heezen and Marie Tharp at Lamont created a map of the North Atlantic that was the first to incorporate everything that had been gathered about the seafloor since the war. Notably, it was the first map to show in detail the so-called Mid-Atlantic Ridge—and later led directly to the concept of seafloor spreading, which would become a central component of the theory of plate tectonics developed in the 1960s. In 1977, Heezen and Tharp would produce another map covering all of the world’s oceans.

Since the 1990s, ONR has sponsored research creating even more detailed and comprehensive maps of the ocean floor, combining satellite data and traditional acoustic depth measurements.
Tropical cyclones are among the most significant peacetime threats to the safety of naval personnel and assets. For decades, the reliable prediction of tropical cyclone intensity has been one of the greatest challenges in meteorology.

Prior attempts to model and predict the intensity of hurricanes were unsuccessful because of insufficient data resolution, inadequate representation of lower atmosphere physical processes and a lack of coupling to the ocean to represent air-sea interactions.

Over the last two decades, ONR sponsored the development of two unique systems to improve understanding of hurricanes: the Coupled Boundary Layer Air-Sea Transfer (CBLAST)-Hurricane initiative and the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS-TC).

CBLAST monitors the exchange of heat, moisture, and momentum in the extreme conditions beneath hurricanes. When implemented in high-resolution dynamic models, the accumulated data can simulate a realistic pressure-wind relationship in a hurricane.

Used for tropical cyclone prediction, COAMPS-TC provides additional understanding of storm-scale processes, ocean influences and high-altitude processes.

The image at left shows a 48-hour COAMPS-TC forecast of wind speed with Hurricane Delta nearing landfall along the Louisiana coast valid on Oct. 9, 2020. The graph at right shows a comparison of the COAMPS-TC maximum wind speed forecast (red) with the observed estimate (black). COAMPS-TC was recognized as the world’s most accurate hurricane intensity model during the 2019 Atlantic hurricane season. U.S. Naval Research Laboratory illustration.
Giders are oceanographic surveying platforms that, as their name implies, glide through the water without propellers or other standard forms of propulsion. Since their introduction in the 1990s, there are now numerous types and sizes of gliders, but all of them share several fundamental attributes: they have extremely long endurance and the speed and direction of currents, from instruments placed either on shore (such as from a dock) or aboard a ship. Shore-based study obviously limited collectors to shallow and coastal waters, and while ships could reach the deepest of waters, their great expense meant they could stay on station for only brief periods (days or weeks).

In 1954, British oceanographer Kenneth Bowden presented in Deep-Sea Research the brief history up to that time of the highly limited (and unsatisfactory) efforts by a handful of research ships to take direct measurements of subsurface currents. In a subsequent letter to the editor, Bowden’s American colleague, Henry Stommel, suggested that future direct measurements could be accomplished with “an unmanned sub-surface buoy or float, devised so as to float at a nearly constant depth, or along an isopleth [a line connecting points with equal values] of temperature of density.” These buoys would drop explosive charges periodically, at a depth that matched a particular region’s SOFAR channel, or Sound Fixing and Ranging, for transmitting sound over long distances. The channel is the depth at which sound travels the slowest—and consequently propagates the farthest—because of the combined effects of temperature and pressure. This depth varies with local conditions, so floats would be set at a depth that matched a particular region’s SOFAR channel. The old limitations of distance and time were overcome, allowing researchers to follow floats for months at a time from relatively remote locations, but floats and buoys still could only send basic information such as location—or, if they contained other sensors, they needed to be retrieved to download the data they collected.

Soon after, an oceanographer at the United Kingdom’s National Institute of Oceanography, John Swallow, conducted research aboard the RRS Discovery II with a rudimentary float very much along the lines of what Stommel had described, except that what would soon be called a “Swell float” used short-ranged pings from a ship-based echo-sounder to determine the float’s position. In addition, the ship needed to be relatively close (hundreds of meters) to the float. Though still involving expensive ship assets, the Swallow float was a significant advance. Subsequent innovations have essentially preserved the basic idea of increasing the distance possible between a float or platform and its data receiving station.

By 1969, Yale researcher H. Thomas Rossby and Woods Hole Oceanographic Institution researcher Doug Webb were working on how to track Swallow floats beyond 1,000 kilometers (621 miles) range. These floats relied on using the so-called “SOFAR channel,” or Sound Fixing and Ranging, for transmitting sound over long distances. The channel is the depth at which sound travels the slowest—and consequently propagates the farthest—because of the combined effects of temperature and pressure. This depth varies with local conditions, so floats would be set at a depth that matched a particular region’s SOFAR channel. The old limitations of distance and time were overcome, allowing researchers to follow floats for months at a time from relatively remote locations, but floats and buoys still could only send basic information such as location—or, if they contained other sensors, they needed to be retrieved to download the data they collected.

With the advent of satellite communications and data networking, truly wide-ranging collection platforms became a possibility. By the late 1980s, a joint effort by Scripps Institution of Oceanography and Woods Hole produced the Autonomous Lagrangian Circulation Explorer (ALACE). These floats, like their Swallow and SOFAR predecessors, situated themselves within the water column, but could now control buoyancy to measure a greater vertical range, and, crucially, could relay their data by satellite, making them far more independent.

Doug Webb, who had collaborated on ALACE as well as the earlier SOFAR floats, began sketching out the ideas for what would become the glider in the 1980s. It would be his colleague Henry Stommel (now near the end of his career) who would popularize these ideas with his speculative piece, “The Stommel Mission,” in 1989. Nominally set in 2021 and written by a fictional researcher reflecting on 25 years of work at the “Stommel Mission Control Center,” Stommel envisioned a fleet of hundreds of “Stommel floats” collecting data year-round for a “World Ocean Observing System.” Naming these floats after Joshua Slocum, the first person to sail alone around the world, Stommel wrote that “they migrate vertically through the ocean by changing ballast, and they can be steered horizontally by gliding on wings at about a 35-degree angle.”

Webb worked with Stommel and a group at Woods Hole to develop the first rudimentary Slocum glider, which was tested in 1991. The first complete glider made its first sea trials in 1998 at Rutgers University’s LEO-15 offshore coastal observatory and in Seneca Lake, New York. Since then, the numbers and varieties of gliders have grown considerably. The Naval Oceanographic Office alone operates more than 150 gliders; many hundreds more are used by institutions and universities around the world. Today, although there is no single “Stommel Mission Control Center,” gliders form the backbone of a series of sensor networks, both civilian and military, that monitor the world’s oceans in near-real time or in real time, providing data for everything from climate change to maritime domain awareness.

Nearly all of the work was supported by the Office of Naval Research. Stommel and Webb, their efforts over many decades so essential for the development of technologies for physical oceanographers, were long-time ONR performers throughout their careers.
Of vital importance both to military researchers during the many decades of the Cold War, as well as to civilian scientists in the search to understand the unique attributes of the polar regions for the study of everything from human physiology to climate, polar research has been a central concern for ONR since its inception. Less than two weeks after its formal establishment in August 1946, the Office of Naval Research initiated the process of creating what would become the Naval Arctic Research Laboratory, located at Pt. Barrow, Alaska. The laboratory was up and running a year later.

The Arctic Research Laboratory was only a part of ONR’s involvement in polar studies, which included temporary ice stations, remote sensing, submarine expeditions, and many other projects. Research results from the Arctic include major advancements in the understanding of atmospheric circulation patterns and pollutant pathways; the mechanical, electrical, and chemical properties of sea ice; the statistics of sea ice extent, variability, drift, and thickness; the modeling of the propagation of sound; the vital importance of the polar regions to global ocean circulation; the unique aspects of the region’s internal wave spectrum; and the region’s key role in global carbon sequestration and climate change. In addition to their importance to the study of climate and weather, these discoveries have provided essential knowledge for the optimization of personnel, vehicles, and systems in the conduct of naval operations in the polar regions for the past 75 years.

Longtime ONR program manager Dr. Maxwell E. Britton was quoted in a 1969 history of the Naval Arctic Research Laboratory as saying that "one distinguished Canadian has expressed the view that results from the research of a single permafrost researcher at the Arctic Research Laboratory enabled savings in the cost of construction of the Distant Early Warning line [the Cold War-era radar stations that warned against bomber and missile attacks into the United States] greater than all the money spent on the ARL in its entire history." Dr. Britton went on to express the view that results from the Arctic Research Laboratory as saying that "one distinguished Canadian has expressed the view that results from the research of a single permafrost researcher at the Arctic Research Laboratory enabled savings in the cost of construction of the Distant Early Warning line [the Cold War-era radar stations that warned against bomber and missile attacks into the United States] greater than all the money spent on the ARL in its entire history.”

Now in its eighth decade of support for research in the Arctic and Antarctic, the involvement of ONR to lead initiatives that enable research in the Arctic and Antarctic. ONR continues to lead initiatives that enable research in the Arctic and Antarctic. ONR is the U.S. representative lead in the International Cooperative Engagement Program for Polar Research, which entered into a memorandum of understanding in 2020. In addition to the United States, participating nations include Canada, Denmark, Finland, New Zealand, Norway, and Sweden. The agreement establishes general provisions for the conduct of basic research as well as to development and testing in the polar regions and creates a collaborative forum in which the seven participating nations can initiate, conduct, and manage polar research projects as well as arrange supporting material and equipment sharing. The memorandum also facilitates the exchange of information to harmonize participants’ defense and national security requirements and to define future cooperative efforts.
Although it was once an object of imagination, theory, and science fiction, the electromagnetic railgun finally made the leap from laboratory concept to weapon-grade technology. Using a massive electrical pulse rather than a chemical propellant, the railgun can launch projectiles much farther than the 13-nautical-mile range of the U.S. Navy’s standard 5-inch naval gun. Previous incarnations of the railgun suffered from limited muzzle energy and could fire only a few shots before the launcher needed to be replaced. Today, however, the railgun has increased its muzzle energy substantially and can shoot hundreds of projectiles before requiring refurbishment. Enlisting America’s best and brightest, The Office of Naval Research established a national team comprising naval warfare centers, national laboratories, academia, and contractors with expertise in material science, modeling and simulation, and experimental design. In the process, ONR raised a new generation of world-class railgun researchers and a core government team to guide this transformational technology forward.

The Electromagnetic Railgun is shown here at the terminal range located at Naval Surface Warfare Center Dahlgren Division. Photo by John F. Williams

A high-speed camera captures a world-record-setting, 33-megajoules shot in December 2010 by the railgun at the Naval Surface Warfare Center Dahlgren Division. Photo by U.S. Navy

Dan Wise, from the Naval Surface Warfare Center, Dahlgren Division, prepares to take readings following a successful test of the railgun installed at the test facility in Dahlgren, Virginia. Photo by John F. Williams

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The railgun was initially envisioned for land attack until its potential warfighting advantages sparked examination of other vital missions. Modeling and analysis established a real potential for it to enhance integrated air and missile defense and anti-surface warfare. ONR developed and tested railgun barrels capable of firing many rounds per minute—as well as the associated power and auxiliary systems needed to make that possible. Although the program ended in 2021, the state of the art in power and energy systems, materials research, ballistics, and a host of other areas was advanced considerably over the course of the Innovative Naval Prototype program.

Former Chief of Naval Research Rear Adm. Matthew Klunder shows off a Hypervelocity Projectile (HVP) to CBS News reporter David Martin during an interview held at the Naval Research Laboratory’s materials testing facility in 2014. A next-generation guided projectile capable of being fired from a variety of gun systems, the HVP is among the many ancillary technologies and systems developed as a part of the Electromagnetic Railgun program. Photo by John F. Williams
**EXPLOSION RESISTANT MATERIALS**

Following the attack on USS Cole (DDG 67) in 2000, ONR partnered with the Naval Surface Warfare Center Carderock Division to assess hull structures along the waterline of combatant ships and to develop technologies that would strengthen ships' hulls and avert rupture from a close-in underwater explosion. As a result of this investigation, a specific polymer was identified—explosive resistant coating (ERC)—that would mitigate the effects of an explosion if the material were applied to a ship’s hull.

After the events of September 11, 2021, research efforts were intensified to broaden the use of ERC as part of various systems to protect against blast and ballistic penetration. These investments resulted in predeployment armor upgrades that were used by the Marine Corps during Operation Iraqi Freedom to improve the protection of high-mobility multipurpose wheeled vehicles against ballistic penetration, land mines, and improvised explosive devices. In addition, a spray-on ERC armor called “dragon shield” was developed and fielded within several months and installed on various military vehicles in theater.

During the 2000s and early 2010s, ONR supported several programs at Navy laboratories and multiple universities to develop a solid understanding of the behavior exhibited by these types of polymers under the extreme conditions of blast and ballistic penetration. In 2008, ONR initiated investigations of how ERC could be used to offer protection against mild traumatic brain injury. Test results on instrumented mannequins subjected to blast events have demonstrated that a specific ERC applied to the exterior of helmets can mitigate effects of blast pressure significantly without increasing weight. Recent experiments on extreme pressure and strain rate conditions revealed that the shear strength of ERC is greater than all engineering materials, on a weight basis.

In 2011, R&D Magazine honored ONR scientist Dr. Rosdy George S. Barsoum with an “R&D 100” award for the development of a revolutionary coating material that is blast- and fire-resistant. The special high-tech surface technology, HybridSil Fire/Blast, acts like a force field that surrounds and protects any type of surface, making it blast-, ballistic-, and fire-resistant.
Twenty-first-century advances are making it possible to use ever larger surface naval vessels to perform missions at sea with minimal human intervention. In 2002, as the U.S. Navy’s interest in unmanned surface vehicles (USVs) began to increase, the Office of Naval Research initiated several science and technology programs to help these craft perform naval missions. These programs addressed platform design, payloads, and autonomous control as well as launch, recovery, and refueling.

This work resulted in USVs capable of performing missions previously possible only with much larger, more expensive, manned platforms—and led to an acquisition program.

Technical challenges remain, however, such as determining the amount of human oversight and communications bandwidth required to operate USVs.

In 2004, ONR initiated a program for autonomous control, using algorithms and sensors, with only a limited human supervisory role. This was a substantial technical challenge because of the harsh dynamics of the sea surface and the potentially high density of other maritime traffic.

The autonomous control system developed in the program has been installed on 14 different USV types, and has participated in numerous fleet experiments and demonstrations. One of these, the USV Swarm demonstration in 2014, used five USVs under autonomous control to perform escort and surface attack missions.

Attention is now turning to autonomous control of larger USVs that will have bigger payload capacities, much longer ranges, and the ability to operate in higher sea states. This will create many new opportunities to use USVs in a wide range of naval missions.
Some of the most important, ground-breaking research on the world’s oceans over the past eight decades have taken place on the U.S. Navy’s research vessels. The U.S. Navy’s fleet of oceanographic research vessels traces its history back more than 70 years. Following World War II, the government supported a wide range of academic oceanographic research—and the oceanographic fleet included a hodgepodge of converted wartime vessels: tugboats, minesweepers, subchasers, and escort vessels. In June 1952, the Office of Naval Research established a panel to spark the ocean community’s interest in ship design and solicit recommendations for a purpose-built research vessel. ONR also sponsored a conference focusing on oceanographic ships, which generated important characteristics for research vessels and led to a 1955 Navy design study that investigated their feasibility. The result was the design for the Auxiliary General Oceanographic Research (AGOR)-class oceanographic ship, funded in 1960 to support the Navy’s “Ten Year Program in Oceanography”—which called for 20 research ships, including 12 for academic institutions. These latter ships are owned by the Navy but operated by universities or research organizations such as Woods Hole Oceanographic Institution.

Construction on the 283-foot, 1,370-ton research vessel Robert D. Conrad (AGOR 3) was completed in 1962, with 11 other ships that followed over the next five years. By 1966, however, their limitations were recognized. So the AGOR 14 class was designed, incorporating new propulsion concepts for station keeping and maneuverability. Only two ships of this class were built: R/V Melville (AGOR 14) in 1969 and R/V Knorr (AGOR 15) in 1970.

At the same time, however, ONR became a major partner in the creation of the University National Oceanographic Laboratory System (UNOLS), established in 1971. This consortium of federally supported research vessels and university operators provides overall direction of the nation’s oceanographic research fleet. ONR manages the largest, most-capable, longest-duration vessels within UNOLS.

In 1984 a new Secretary of the Navy/Chief of Naval Operations “Navy Policy on Oceanography” included a requirement for replacement of the aging AGOR 3 class. This initiative involved a major overhaul of Melville and Knorr, and design and construction of the AGOR 23 class—with deliveries in 1991 (R/V Thomas G. Thompson), 1996 (R/V Roger Revelle), and 1997 (R/V Atlantis). Melville and Knorr were themselves replaced in 2016 with R/V Sally Ride (AGOR 28) and R/V Neil Armstrong (AGOR 27), respectively.
Beginning service in 1962, FLIP has the vague appearance of a baseball bat in general dimensions when horizontal—a resemblance entirely warranted, since the original design concept was indeed a slightly modified Louisville Slugger. Photo by John F. Williams.

The vessel’s most iconic feature is that every major fixture on aboard is capable of being swiveled 90 degrees, so that everything from showers and toilets to the galley stove can be turned correctly when FLIP is in either vertical or horizontal orientation. Photo by John F. Williams.

Though it had to be towed to its research locations, FLIP has been as far afield as Hawaii and the Caribbean. From the horizontal, on-board hydraulics and ballast tanks ‘flip’ the vessel (in about 30 minutes) to the vertical, producing the world’s most stable at-sea laboratory, capable of riding out swells while providing sensor data 300 feet into the water column. Photo by John F. Williams.

One of the most unusual sea-going vessels ever constructed helped several generations of researchers uncover the ocean’s secrets for six decades—R/P FLIP, or the Floating Instrument Platform.

The Marine Physical Laboratory at Scripps Institution of Oceanography, under the direction of Fred Spiess, took the lead and created a feasible design for FLIP. Researchers developed the spar buoy shape, size (355 feet), and capabilities of this one-of-a-kind research platform. They also conducted painstaking experiments, even testing a tenth-scale operating version in a lake near San Diego.

FLIP was constructed in six months at the Gunderson Brothers yard in Portland, Oregon. The initial cost, funded by the Office of Naval Research, was less than $600,000 (about $5.8 million in 2022 dollars). After successful testing in Dabob Bay, Washington, FLIP was launched in June and delivered to the Navy in August 1962.

FLIP could carry a research team of 11 people and a crew of five, and sustain research operations for up to 30 days without resupply. Incapable of its own propulsion, FLIP was towed to its research location. Nonetheless, it operated around the world. Because it operated in both horizontal and vertical positions relative to the surface of the ocean, FLIP’s interior furnishings—chairs, tables, and, most famously, its toilets—were mounted so they can be turned to either position.

After sea trials, FLIP was towed to San Diego and commenced Pacific operations at Scripps. Its unique capabilities as an ocean measurement platform with very low motion led to its continued use for 60 years and more than 400 “flips” supporting a variety of ONR research initiatives, including long-range sound propagation, thermal structure of the ocean, amplitude and direction of internal waves, marine mammal acoustics, air-sea interaction, and weapon system development.
Modern naval surface vessels often bristle with a dizzying array of antennas, dishes, and other electronic emitters and receivers to meet radar, electronic warfare, information operations, and communications requirements. This has resulted in a host of compromises and problems, such as antenna package, electromagnetic interference, and increased ship radar cross section (a measure of a ship’s detectability by radar). There are also logistical issues because each individual system comes with its own set of requirements for training, maintenance, spare parts, repair personnel, and operators. To address these issues, starting in the early 1990s, the Office of Naval Research invested in a variety of technologies to enable very wideband, multifunction radio frequency (RF) systems. These included wideband apertures and amplifiers, multibeam-capable RF chips, RF filters, packaging techniques, and coding systems. These technologies were then combined to create a common set of broad-band apertures, signal and data processing, signal generation, and display hardware. In 2004, the Advanced Multifunction Radio Frequency Concept demonstrated that radar, electronic warfare, and communications functions could perform simultaneously using this common equipment and a Low Level Resource Allocation Manager (LLRAM) to manage it.

ONR followed this effort with the Multifunction Electronic Warfare Future Naval Capability program. This was the technology demonstrator for the Surface Electronic Warfare Improvement Program (SEWIP) Block 2, and provided an enhanced electronic support capability by means of an upgraded antenna and receiver and an open combat system interface for the AN/SQQ-32—an electronic warfare system that provides powerful countermeasure protection for small and mid-sized surface ships. The program transitioned this capability to the AN/SQQ-32(V16), which is currently deployed on a large number of U.S. Navy surface ships. Success of both of these programs led to the Integrated Topside (InTop) Innovative Naval Prototype program.

InTop developed several prototypes to deliver increased Surface Navy capabilities across the electromagnetic spectrum and to reduce the number of stand-alone systems needed for sensors, electronic warfare, information operations, and communications. The first InTop prototype, which was the technology demonstrator for SEWIP Block 3, has transitioned, along with the LLRAM, to the AN/SQ-32(V7) system that is being put into service in the fleet. This provides the AN/SQ-32(V7) with the capability to outpace current threats while simultaneously allowing for multiple communication links and a frequency extension for the information operations community.

The InTop and Electromagnetic Maneuver Warfare Command and Control Innovative Naval Prototype programs also developed the Flexible, Distributed Array Radar, which is an eXtreme element, digital radar prototype that consists of two dual polarization, S-band radars with a radar-to-radar communication function that enables networking and synchronization. This allows the radars to work in a distributed fashion to provide benefits in target detection and tracking, as well as electronic protection. The success of this program has led to multiple future Naval Capability programs at ONR that are transitioning many of these capabilities into the AN/SPY-6 family of radar systems through the Advanced Distributed Radar program.

In addition, the two Innovative Naval Prototype programs developed a Low-Band RF Intelligent Distribution Resource demonstrator to show that a single multifunction system could simultaneously support Link-16 (a NATO datalink network); Identification, Friend or Foe (IFF); the tactical air navigation system (TACAN); information operations; and electronic warfare while improving on the capabilities of these systems at the same time. In addition to a successful demonstration of these capabilities, the demonstrator effort transitioned an Antenna Processor Interface Module to the Naval Air Traffic Management Systems Program Office (PMA-213) as a government-owned, all-digital replacement for the AN/UPX-41/UPX-45 IFF interrogator systems.

ONR’s Innovative Naval Prototype programs also have contributed systems that are being installed with the latest upgrades to the AN/SLQ-32(V6) and (V7) electronic warfare systems, which are found on vessels such as guided-missile destroyers (seen here, the SQ 32 is in between the two Dolgi radar arrays on the superstructure, just above the head of the person on the right). Photo by MCSN Timothy A. Carley Jr.

The Integrated Topside and Electromagnetic Maneuver Warfare Command and Control Innovative Naval Prototype programs resulted in a number of transitions that are going into the Navy’s AN/SPY-6 air and missile defense radar system, currently being tested at a site in Moorestown, New Jersey. Photo by U.S. Navy

Finally, the Electromagnetic Maneuver Warfare Command and Control program performed initial development of a High-Level Resource Allocation Manager, with a goal of translating commanders’ intent for mission priorities and tasking into force-level task, resource, and spectrum priorities. Early efforts on the manager delivered an Emissions Control Tactical Decision Aid that transitioned into the Navy’s Maritime Tactical Command and Control program.

Both Innovative Naval Prototypes have delivered systems that will provide unprecedented capability for dominance in the electromagnetic spectrum. By using open architectures, they have delivered those capabilities while providing a path for continuous affordable upgrades.
In 1962, ONR hired cereal maker General Mills—which back then had a manufacturing arm dedicated to military contracts—to work with Woods Hole to construct Alvin. The contract bid was for $498,500 (around $4,900,000 in 2022), and involved designing the submersible to dive to 6,000 feet.

Taking a cue from Trieste, which itself was modeled after balloons capable of ascending to the stratosphere, General Mills subcontracted a steel mill in Pennsylvania to make six-foot-diameter steel plates and cut them into discs that were then welded together into a strong sphere that could accommodate three people while withstanding crushing deep-sea pressure. Allyn Vine, the Woods Hole oceanographer after whom the submersible was named, later wrote in Oceanus that, “We had tried to think of almost every conceivable situation that might imperil human life, and devised ways to avoid such crises. Alvin’s major safety feature was the crew’s ability to return to the surface by releasing [air] pressure hull...from the sub’s underbody and chassis. In that way, the crew could escape if, say, the sub’s arm or other projection became entangled in debris on the bottom.” Since its 1964 unveiling, Alvin has provided enormous value to both the Navy and the scientific community.

In 1966, two U.S. Air Force planes collided off the coast of Spain. One of the aircraft, carrying a hydrogen bomb, crashed and sank to the bottom of the Mediterranean Sea. Alvin found the bomb for the Navy two months later. In the 1980s, the Navy tasked Woods Hole and Alvin with studying the wreck sites of USS Scorpion (SSN 589) and USS Thresher (SSN 593), two nuclear submarines that sank in the 1960s.

In 1973, Alvin took scientists down 10,000 feet to the Mid-Atlantic Ridge, a mountainous seam stretching along the center of the Atlantic Ocean, for the first time. Instead of muddy and uniform, the ocean floor revealed itself as a diverse landscape of rocks, lava and geological features of all shapes and sizes—altering contemporary conceptions of the sea bottom.

Sponsored by the Office of Naval Research, and launched in 1964, Alvin is the world’s longest-operating, manned deep-sea submersible. It’s still going strong today, with more than 4,800 dives to its credit. The revolutionary vessel is operated by Woods Hole Oceanographic Institution under a charter agreement with the Navy.
Marine growth has long been a nemesis of ships’ hulls—but new materials now can keep hulls clean without damaging the environment. For more than 30 years, the Office of Naval Research has led global research in the fundamental understanding of marine surface fouling and the development of new approaches and ship hull coatings to combat it.

Fouling is a term that describes the settlement and growth of marine plant and animal organisms on submerged structures. The fouling of ship hulls has negative effects on speed and fuel efficiency, and can result in increased greenhouse gas emissions and the release of toxins in the marine environment. Antifouling compounds that are applied to ship hulls have traditionally included toxins to kill the organisms. New coatings, known as fouling release coatings, do not employ environmentally harmful toxins. They allow some level of fouling, but the adhesion is weak enough to dislodge when the ship moves through the water.

In the past, the U.S. Navy looked to hydrophobic coatings (based on materials that repel water), such as silicone rubber. Recent research has confirmed that some types of hydrophilic materials (that attract water) create a thin boundary that many marine organisms cannot penetrate. Fundamental studies have showed that both types can be effective fouling release strategies, depending on the species of organism.

As a result of this discovery, several polymer approaches were developed to incorporate both hydrophilic and hydrophobic characteristics into polymers, a now common approach and additive to commercial silicone-based coatings that are environmentally benign and do not release toxins into the marine environment.

Several Navy ships are evaluating these new hull coatings. These benefits afforded by the reduction of marine fouling on ship hulls compared to currently used paints and coatings.

Today, ONR continues to research a new generation of coatings for a wide variety of applications and platforms. These include a new class of materials that are “omniphobic.” ONR is sponsoring work by Dr. Anish Tuteja, an associate professor of materials science and engineering at the University of Michigan, to develop a new type of chemical coating that is clear, durable, can be applied to numerous surfaces, and sheds just about any liquid.

Of particular interest to the Navy is how omniphobic coatings can reduce friction drag—resistance created by the movement of a hull through water—on ships, submarines, and unmanned underwater vehicles. Besides reducing friction drag, Tuteja envisions other Navy uses for the omniphobic coating—including protecting high-value equipment such as sensors, radars, and antennas from weather.

Sea growths, such as these barnacles being scraped from the bottom of a rigid-hull inflatable boat, and other biofouling organisms can seriously affect the performance of ships, vessels, and other platforms and systems. The Office of Naval Research has been at the forefront of combating this pesky and persistent problem. Photo by MC3A Christopher Frost
USS Ponce (AFSB(I) 15) conducted an operational demonstration of the Laser Weapon System while deployed to the Arabian Gulf in 2014. Photo by John F. Williams

Charles Townes, seen here with a ruby mazer amplifier, was a pioneer in directed-energy research. Photo courtesy of Bell Labs.

The Office of Naval Research has been a leader in the development and demonstration of solid-state lasers since the early 2000s. This practical use of lasers today, however, comes after many decades of ONR’s support, including for some of the earliest basic research in directed energy in the late 1940s and early 1950s. The work of Charles Townes at Columbia University resulted in the development of the “maser”—microwave amplification by stimulated emission of radiation—a predecessor to the laser that operates in the nonoptical range of the light spectrum. Townes also would be a major contributor to the eventual development of the laser in the early 1960s. Since then, ONR has invested in a wide range of directed-energy systems, including chemical and gas lasers as well as free-electron lasers, helping to create and sustain a sizeable research and industrial infrastructure capable of producing today’s sophisticated systems.

Laser weapons provide many advantages to warfighters. The cost per laser engagement shot is less than $1, and lasers have an extensive magazine capacity that is limited only by the amount of fuel available to generate electrical power for the laser. Lasers also provide scalable effects, from nonlethal dazzling to destructive damage capable of causing structural or thermal damage to platforms that will cause a vehicle to lose control and crash. In addition, the large telescope and optics associated with laser systems can be used to provide a ship’s crew with an organic intelligence, surveillance, and reconnaissance capability.

Laser weapons operating today are focused on countering unmanned air systems, small boats with topside ordnance or equipment, as well as adversaries’ sensors. More advanced and powerful laser weapons are being designed to address the full spectrum of threats that warships may face in the future, including high-speed antiship cruise missiles.

Today’s naval laser weapons programs have evolved quickly to provide more powerful and robust capabilities with each increment. The initial Maritime Laser Demonstration program was followed by the Laser Weapon System Demonstrator (LWSD) that was developed as part of the Solid-State Laser Technology Maturation program. LWSD has been installed on USS Portland (LPD 27) and approved for operational use. The Laser Weapons System Demonstrator—the latest directed-energy system to be deployed aboard a warship—was installed on USS Portland (LPD 27) in 2018. Photo by Lance Cpl. Patrick Katz

The first ship-based solid-state laser program was the Maritime Laser Demonstration program, which included a limited demonstration that validated the capability of laser weapons to engage unmanned small boats at tactically relevant ranges during testing on the Navy’s Self Defense Test Ship off the coast of California. This was followed by the development of LaWS with a demonstration on USS Dewey (DDG 105) and then with an enhanced version that was deployed on USS Ponce (AFSB(I) 15) in the Arabian Gulf from 2014 until Ponce’s retirement in 2017. During this time, LaWS was operated on average more than 23 hours per day and provided the crew with enhanced visual situational awareness that was not previously available. LaWS was followed by the Laser Weapon System Demonstrator (LWSD) that was developed as part of the Solid-State Laser Technology Maturation program. LWSD has been installed on USS Portland (LPD 27) and approved for operational use.

Built on the successes and lessons learned from previous programs to provide naval operators with improved weapons capability.

The Laser Weapons System Demonstrator—the latest directed-energy system to be deployed aboard a warship—was installed on USS Portland (LPD 27) in 2018. Photo by Lance Cpl. Patrick Katz

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REIMAGINING AEROSPACE
The Electro-Optical Targeting System (EOTS) for the F-35 Lightning II is an affordable, high-performance, lightweight, multifunction system that provides precision air-to-air and air-to-surface targeting capabilities. The system provides high-resolution imagery, automatic tracking, infrared search-and-track, laser designation with range finding, and laser spot tracking at greatly increased standoff ranges.

The Office of Naval Research ManTech program’s Electro-Optic Center conducted various projects, which are significantly improving the affordability of the F-35 EOTS. The Navy ManTech Program is a world-class industrial preparedness program focused on affordability improvements for key naval platforms.

Funded by the Air Force, Navy, and the Defense-Wide Manufacturing Science & Technology Program, the EOTS efforts have optimized manufacturing processes for F-35 infrared components, including the integrated Dewar cooler (IDC) and the focal-plane array (FPA).

Through the effort of ONR’s ManTech program, the projects will save more than $200 million for the F-35 program. This was achieved through a four-phase process:

1) Automated the mid-wave infrared IDC assembly and implemented manufacturing processes, tools, and equipment to reduce touch labor, increase yields, and improve the reliability of the production line. The project increased the Manufacturing Readiness Level while reducing the cost per IDC by 19 percent, saving more than $117 million.

2) Improved the FPA quick test and the Dewar final vacuum bake, which reduced handling, scrap, labor, and span time resulting in a four-percent reduction in cost per unit.

3) Automated the Dewar cold stack and die cleaning and inspection processes, which will reduce cost, cycle time, and scrap by improving the production, throughput, and yield. The effort reduced the cost per unit by $1,800.

4) Transitions the mid-wave infrared IDC to a high operating temperature advanced detector, which will increase capacity and reduce FPA processing hours and span time and increase the reliability and maintainability of IDC assembly. The project saved more than $62 million for the F-35 program.

According to Lockheed Martin, more than 700 systems have been delivered for the F-35 Lightning II. As the first sensor to combine forward-looking infrared and infrared search and track functionality, EOTS enhances F-35 pilots’ situational awareness and allows aircrews to identify areas of interest, perform reconnaissance and precisely deliver laser and GPS-guided weapons.
In the late 1940s, Project Skyhook balloons provided a stable vehicle for long duration observations at altitudes in excess of 100,000 feet. This photograph shows Skyhook Balloon 93 leaving the deck of USS Norton Sound (AV 11) in March 1949. National Archives photo

Prior to the manned flights of the Strato-Lab vehicle, many test flights were conducted to determine the reliability of the Strato-Lab system. This shows one of those tests in 1955. When sufficient helium was pumped into the balloon to lift the gondola it was attached to the balloon to commence its flight to the stratosphere. Photo courtesy of National Archives and Records Administration, National Archives photo.

On November 8, 1956, the Strato-Lab gondola rises from the Stratobowl near Rapid City, South Dakota, and is about to clear the rim, some 400 feet above the launch site. The balloon, already above the rim, is only partially visible. On this date, two naval observers soared to an unofficial altitude record of 76,000 feet in a spherical aluminum gondola as part of the Strato-Lab project. Photo courtesy of National Archives and Records Administration.

On May 4, 1961, Lt. Cmdr. Victor Prather (left) and Cmdr. Malcolm Ross (right) ascended to a record-setting 113,740 feet altitude. Prather drowned during the recovery of their gondola in the Gulf of Mexico. National Archives photo

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A year before the launch of the Soviet Union’s Sputnik 1 satellite, manned flight reached closer to space using a more traditional method—a balloon. There was, however, nothing very traditional about this particular balloon.

Funded jointly by the Office of Naval Research and the National Science Foundation, this balloon was made out of polyethylene plastic (so it would not expand and explode at high altitudes) two-thousandths of an inch thick, and carried a sealed, pressurized gondola called Stratolab with a crew of two. On November 8, 1956, Stratolab set a world record of 76,000 feet, higher than any humans had ever gone before without the assistance of a rocket.

Polyethylene is a widely used plastic used in various products ranging from shopping bags to detergent bottles and automobile fuel tanks. It can also be slit or spun into synthetic fibers or modified to take on the elastic properties of a rubber. This plastic is what enabled the balloons to function at such altitudes.

Stratolab was an extension of two other ONR-funded projects, Helios and Skyhook, which had developed extreme high-altitude balloons in the late 1940s for atmospheric research. Stratolab’s mission was to extend research into the farthest reaches of the atmosphere, to a point where instruments pointed skyward could measure and observe phenomena in space beyond 96 percent or more of the atmosphere.

Stratolab put a variety of instruments into near-space, from coronographs for measuring the sun’s brightness to telescopes for observing the stars. The program’s ultimate success—an ascent to 113,740 feet on 4 May 1961—was overshadowed by both tragedy and triumph. After landing safely in the Gulf of Mexico, Lt. Cmdr. Victor Prather drowned when he fell from the recovery helicopter.

The next day, astronaut Alan Shepard became the first American in space when his Freedom 7 rocket reached an altitude of just over 101 nautical miles. Shepard wore the same Mark IV spacesuit that had been developed for and tested by Stratolab pilots.

The science behind Stratolab continued on, however. Its full realization began with a series of solar and astronomical observing satellites launched beginning in the 1960s, the most notable of which was the Hubble Space Telescope in 1990. The evolution of the observation of space from space has been carried forward even further with the new James Webb Space Telescope.

HIGH-ALTITUDE BALLOONS TAKE FIRST STEPS TOWARD SPACE

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On 10 July 2013, the X-47B launched from Naval Air Station Patuxent River and landed on the deck of the USS George H.W. Bush (CVN 78), conducting the first arrested landing of an unmanned air vehicle on an aircraft carrier at sea.

The program began in 1999 as a joint Defense Advanced Research Projects/Office of Naval Research effort called the Unmanned Combat Air Vehicle-Navy (UCAV-N) demonstrator, which included technology development in the areas of aerodynamics and flight control, intelligent autonomy, human-machine interface, and low-signature air vehicle design. Significant challenges were involved in applying new technology to the unique and specialized environment of aircraft carriers.

The X-47 program began in 1999, achieving its first flight in 2011. Photo by MC2 Michael Griesford

The X-47B unmanned combat air system demonstrator conducted touch and go landings on the flight deck of the aircraft carrier USS George H.W. Bush (CVN 78). This was the first time any unmanned aircraft had completed a touch and go landing at sea. Photo by MC2 Timothy Walter

On May 17, 2013, an X-47B unmanned combat air system demonstrator conducted touch and go landings on the flight deck of the aircraft carrier USS George H.W. Bush (CVN 78). This was the first time any unmanned aircraft had completed a touch and go landing at sea. Photo by MC2 Timothy Walter

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The Office of Naval Research has invested in developing a fundamental understanding of thermal and environmental barrier coatings for more than 20 years. Gas turbine engine performance in terms of thrust, specific fuel consumption, and range is directly proportional to the temperature of engine combustion gases. The limitations of conventional nickel-base super-alloys had prevented further increases in these temperatures until the introduction of thermal barrier coatings (TBCs). The more heat an engine can produce, the greater the thrust output.

To improve and better predict coating lifetimes and performance, ONR established the first program to develop a scientific understanding of failure mechanisms in TBCs linking laboratory results to actual engine samples. The experimental results were translated into validated computational models and simulations, which elucidated understanding for a variety of mechanistic failure modes in TBCs. These results were provided in the form of maps characterizing the domains within which failure phenomena are most prevalent, and predicted the degradation within each domain, as well as established fundamental principles for the enhancement of performance within each.

The development of understanding of TBCs has led to a subsequent applied research program of an improved thermal barrier coating (Gd$_2$Zr$_2$O$_7$) with half the thermal conductivity of the standard yttria-stabilized zirconia, and improved resistance to spallation (i.e., ejection of material after an impact) and attack by molten sand deposits. The coating is so successful, that within four years, it was transitioned, and is now baseline in most Pratt & Whitney engines including the F135 that powers all models of the F-35 Lightning II aircraft. Current research is exploring molten sand attack, which tends to contain variable ratios of calcium, magnesium, and alumino-silicates, and looking at ways to mitigate this attack on TBCs and other propulsion materials. This research is critical to enable further capability and engine efficiency gains in naval aircraft.

Thermal barrier coatings developed with the support of the Office of Naval Research as a standard feature on the Pratt & Whitney F135 engine, which powers the F-35 Lightning II. Photo courtesy of Pratt & Whitney
With the launch of Sputnik 1 in October 1957, there was a flurry of effort in the United States to send up some kind of answer to the Soviets’ first space flight achievement. Scrambling for a useful payload to send up with the first U.S. satellite—Explorer 1—the one set of instruments ready to go included a cosmic ray detector (essentially a Geiger counter) designed by James Van Allen. His basic research concerning radiation in space at the University of Iowa, which led directly to Explorer 1’s payload, was funded by the Office of Naval Research.

Launched in January 1958, Explorer 1 was followed some weeks later by Explorer 3 with similar instruments on board. The combined data from the two satellites confirmed the first major scientific discovery of the Space Age: there was a series of “belts” of radiation encircling the Earth composed of charged particles trapped by the planet’s magnetic field. Any spacecraft leaving the Earth’s atmosphere would have to be designed to deal with these belts of radiation.

Van Allen was an astrophysicist at the forefront of physics. During his career, he was the principal investigator for scientific investigations on 24 Earth satellites and planetary missions, beginning with the first successful American satellite, Explorer I, and continuing with Pioneer 10 and Pioneer 11. He also helped develop the first plans for an International Geophysical Year.

The Van Allen belts are a collection of charged particles, gathered in place by Earth’s magnetic field. They can wax and wane in response to incoming energy from the sun, sometimes swelling up enough to expose satellites in low-Earth orbit to damaging radiation. The discovery of these belts, named for Van Allen during a meeting of the National Academy of Sciences and the American Physical Society on May 1, 1958, alerted the space programs to new dangers both to electronics as well as to life and limb. In addition, entirely new areas of science were founded as a result of this discovery—such as plasma physics and magnetospheric physics—to investigate the complex relationship between the Earth and the Sun.
A fleet of unique squadron aircraft are operated and maintained by the men and women of the Scientific Development Squadron (VXS) 1 “Warlocks.” The squadron conducts airborne research with its uniquely-configured, research-modified aircraft which include two NP-3Cs, one RC-12 King Air, multiple ScanEagle UAVs and a UV-18 Twin Otter and logs approximately 800 combined flight hours annually.

Located at Naval Air Station Patuxent River, Maryland, the “Warlocks” and the Naval Research Laboratory Military Support Division are primarily responsible for planning, engineering, installing, coordinating, and executing airborne scientific programs.

Capable of conducting flights worldwide in support of a broad spectrum of projects and experiments, VXS-1 provides the Naval Research Enterprise, including the Office of Naval Research, NRL, and numerous government and contractor agencies, with multiple airborne research platforms.

The squadron coordinates closely with Naval Air Systems Command flight clearance authorities and contract design and manufacturing companies to ensure cost-effective and timely solutions to meet research needs.

Historically the squadron has supported a wide array of research projects that include magnetic variation mapping, hydro-acoustic research, bathymetry, electronic countermeasures, gravity mapping, electro-optical and radar research, and remote measuring of water contained in snow.

VXS-1 is the only scientific research and development squadron for the Department of Defense, and provides a pathway for accelerating the latest technology to the fleet.

The squadron has tremendous flexibility—scientists and engineers can install and test the latest technology they are developing in an operational environment anywhere in the world.

Providing proof-of-concept for revolutionary technologies, VXS-1 allows operational fleet commands to receive time-pertinent technological advances to better execute their missions and fill critical capability gaps in their theatre.

The Warlocks history dates back to 1963. In 2004, faced with increasing complexity, operational tempo, and worldwide deployments, the Chief of Naval Operations established the detachment as a stand-alone shore activity, designating it as Scientific Development Squadron (VXS) 1.
REIMAGINING
INFORMATION
For more than 70 years, the Office of Naval Research has invested in atomic physics—the branch of physics concerned with the structure of the atom, its energy states, and its interactions with particles and fields. ONR has made important contributions to the refinement of atomic clocks, the first of which were built in the late 1940s and early 1950s. The pioneering work of Norman Ramsey, supported by ONR, is used in every precise atomic clock deployed today, enabling GPS, multiplatform sensing, and modern wireless communications. Basic research initially supported by ONR in the late 1970s on laser cooling and trapping of atoms and ions—which allow for experiments that observe quantum interactions at extremely low temperatures—led to the most accurate atomic clock devices ever made, which today serve as the primary time standards for both civilian and Department of Defense applications. The high accuracy of these clocks enables precise GPS navigation, the internet, wireless communications, and satellite-based sensors.

In the words of Nobel Laureate William Phillips, speaking about the ONR investments leading to ultra-precise atomic clocks, “It was the long-term support of ONR, support that began when the ideas were vague and unproved, that made all of this possible. In my view, this represents the best aspects of the spirit that has made ONR the premier military research organization in the country (and therefore in the world).”

ONR continues to support the development of chip-scale atomic clocks, bringing orders of magnitude better timekeeping to handheld and other compact platforms at a fraction of the power. In the not-too-distant future, laser cooling and trapping techniques will likely produce the lowest noise inertial measurement sensors and the highest sensitivity, practical magnetic field sensors for biological imaging.

In October 1971, two researchers boarded a commercial airliner with four atomic clocks and proceeded to fly around the world in an eastward direction, comparing the clocks’ timekeeping to another set of atomic clocks that had remained on the ground. The following week, the “passengers” repeated the journey, flying westward. The experiment, which had been made possible with $8,000 from the Office of Naval Research—$7,600 of which was for eight round-the-world tickets—helped to demonstrate the validity of Albert Einstein’s theories of special as well as general relativity, postulated more than 50 years earlier. Joseph Hafele, a physicist at Washington University in St. Louis, and Richard Keating, an astronomer at the U.S. Naval Observatory, set out to prove Einstein’s famous theories, which suggested that the airborne clocks would run more slowly than the ones on the ground, and furthermore that the higher the elevation of the clocks, the faster they would run relative to the motionless clocks below. Not only were both of these basic predictions verified, the experiment also showed a noticeable difference between eastward (i.e., in the direction of the Earth’s rotation) and westward directions. The experiment remains one of the more efficiently economical experiments in ONR’s history, and has helped to ensure that modern GPS satellites are calibrated appropriately.
Plastics are usually used as insulators, but some actually can conduct electricity, opening up a new field of manufacturing. A polymer is a large molecular structure composed of many repeated and linked simple molecules. Because of the relatively large molecular mass, polymers exhibit unique physical properties, including toughness, elasticity, and a tendency to form glasses and semi-crystalline structures. Polymers appear naturally, but can also be synthetically produced. Natural polymers include amber, shellac, wool, silk, and rubber. Common synthetic polymers include nylon, vinyl, silicone, and synthetic rubber.

The discovery of conducting polymers in the late 1970s by Alan MacDiarmid, Alan Heeger, and Hideki Shirakawa was the result of their Office of Naval Research basic research grant and launched the field of electronic polymers. It ultimately led to their 2000 Nobel Prize Award for the discovery and development of conducting and semiconducting polymers.

Polymers were traditionally known for their insulating properties, so the discovery of conducting polymers generated a great deal of interest, but progress was impeded because the new materials were unstable. Funding by ONR in the 1980s led to stable conducting polymers, which were first used as antistatic coatings and are now used in many electronic devices.

In the 1990s, the semiconducting properties of these materials (organic chromophoric molecules, oligomers, and polymers) were developed leading to organic light emitting diode displays, improved optical communications devices, and printable electronics. New opportunities were identified and pursued by ONR, including the adaptation of polymer blends for use in the development of more efficient solar cells.

The field of electronic polymers was established by MacDiarmid and Heeger as a union of synthetic chemist and experimental physicist. This early cross disciplinary research was ahead of its time and at scientific meetings presenters had to regularly define vocabulary for their new collaborators. At first, this field was considered to be outside of the polymer science community who had worked hard to establish structure/property relationships for polymeric materials primarily aimed at mechanical and thermal properties. The nature of ONR basic research programs and the freedom to follow science outside of traditional disciplines enabled both the establishment and nurturing of this field. The field, of course, did need to bring in the polymer science community as the role of morphology is huge in these semiconductors, which have inherently low order compared to inorganic semiconductors, and thus significantly lower charge mobilities.

Going forward, the organic electronic materials will complement current conductors (metals) and semiconductors (silicon). The organic materials will have lower charge mobilities and thus lower performance for some applications. However, organic materials are flexible, light weight, and can be solution printed. They are enabling lower-cost, large-area devices such as OLED displays (now commonly found in computers and televisions) and semitransparent solar cells. They will enable the coating of large surfaces with active devices that easily interface with biology.
Gallium nitride is probably the most important compound you’ve never heard of. A central component of modern consumer electronics, it also helps power military hardware.

Gallium nitride is an important component in the APG-79(V)4 active electronically scanned array radar, which has GaN transmit/receive modules in its array, an upgrade to existing systems on the F/A-18 Hornet and Super Hornet. Raytheon Intelligence and Space Photo

David Storm (left), a research physicist, and Tyler Growden, a National Research Council postdoctoral researcher, at the U.S. Naval Research Laboratory with their molecular beam epitaxy system that develops gallium nitride-based (GaN) semiconductor films in the late 1960s, and with the help of naval research.

The APG-79(V)4 active electronically scanned array radar, which has GaN transmit/receive modules in its array, is an upgrade to existing systems on the F/A-18 Hornet and Super Hornet. Raytheon Intelligence and Space Photo

Gallium itself does not exist in pure form in nature—it is only found by extracting it from other materials such as zinc or aluminum. As a compound, however, with arsenic (GaAs) and especially nitrogen (GaN), gallium produces extremely useful semiconductors for a wide range of electronics.

If you have a Blu-ray disc player in your house, you already own some gallium nitride. The communications infrastructure that supports your 5G cell phone also contains gallium nitride. And if you have a flat-screen LED television, that also has gallium nitride. As a component of lighting technology, GaN makes blue-green lasers and LEDs possible. Without this material, much of the current generation of high-end electronics wouldn’t exist.

Gallium nitride is an important component in the AN/TPS-80 Ground/Air Task Oriented Radar. Deliveries of the new radar to the Marine Corps began in 2018. Photo by Lance Cpl. Ethan Pumphret

GaN and similar semiconductors are now considered essential components of military-grade electronics, providing warfighters with faster computer operations, more reliable communications systems, and improved sensor performance.

As a semiconductor material, GaN devices offer much greater energy efficiency than silicon, the previous industry standard. GaN transistors have roughly one-tenth the resistance of silicon-based transistors, allowing for much higher energy efficiency, faster switching frequency, and smaller power-electronic systems.

Getting to the point of making GaN into a usable material—for the Navy or the commercial world—took nearly 50 years of hard work by researchers in multiple countries, numerous wrong turns, and a tremendous amount of patience. And it all happened with the help of naval research.

The creation of single crystal GaN films in the late 1960s, and the subsequent development of millimeter-wave GaN devices and amplifiers are products of Office of Naval Research sponsorship.

The late Prof. Lester Eastman at Cornell University made major contributions to the development of compound semiconductor devices, and seminal discoveries in GaN device technologies that have enabled the GaN revolution, many directly supported by ONR funding. In addition, he advised 120 doctoral students in solid state electronics, many of whom have made substantial contributions themselves to solid state electronic technology.

Among these is Prof. Umesh Mishra at the University of California, Santa Barbara, who is one of ONR’s key principal investigators on the advancement of GaN radio frequency device technology. The development of millimeter-wave GaN devices and amplifiers can be directly traced to a sequence of ONR Multidisciplinary University Research Initiatives’ investigating high-frequency GaN technology.

Prof. Mishra is a founder of two companies, Transphorm and NITRES, both of which are commercializing GaN technology. He is the recipient of the 2007 IEEE David Sarnoff Award.

Among the numerous Navy and Marine Corps systems that use GaN electronics that are either in service or entering service in the 2020s are: the AN/SLO-32(V)7 electronic warfare system, which is upgrading existing systems on Arleigh Burke (DDG 51)-class guided-missile destroyers; the Next Generation Jammer, an advanced airborne electronic warfare system that is replacing older systems on E/A-18G Growler aircraft; the AN/SPY-6 air and missile defense radar, the first of which is being installed aboard USS Jack H. Lucas (DDG 125) and later on other future surface combatants; the Marine Corps’ AN/ TPS-80 Ground/Air Task Oriented Radar, an expeditionary system that detects unmanned aerial craft, cruise missiles, rockets, artillery, and other low-altitude targets; and the APG-79(V)4 fire control radar for Navy and Marine Corps F/A-18 Super Hornets.

The Next Generation Jammer, which includes technologies developed by ONR, will be fielded in three increments sequentially: the mid-band (first flight tested in August 2020), low-band, and high-band jamming pods. Naval Air Systems Command Photo

There is no water on Mars. And if you have a flat-screen LED television, that also has gallium nitride. And if you have a Blu-ray disc player in your house, you already own some gallium nitride. The communications infrastructure that supports your 5G cell phone also contains gallium nitride.

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PROJECT WHIRLWIND AND REAL-TIME COMPUTING

One of the earliest digital computer projects started out as an attempt to build a better flight trainer in 1944—but ended up as the heart of the first strategic defense network in the 1950s. Its legacy continues today embedded in the circuits of our digital world.

Up to the 1940s, the most sophisticated computers in the world were mechanical—or analog—computers that were incorporated into military equipment such as naval fire control systems or warships. Project Whirlwind began as an effort to create a universal flight trainer using analog computers that would be able to simulate a wide range of test aircraft. Early on, however, it became clear that analog systems would be unable to portray the precise movements of modern aircraft accurately. Project managers began exploring the possibility of using faster digital computers to control the system—but such a thing did not exist, and they would have to build their own from scratch.

Beginning at the Massachusetts Institute of Technology in partnership with the Naval Research Laboratory in late 1944, Whirlwind became within less than a year one of the earliest projects of the Navy’s new Office of Research and Invention—what would soon become the Office of Naval Research. The more famous “first” computers of the time—such as the nondigital Harvard Mark I and the digital ENIAC—were designed to solve a wide range of complex mathematical problems, everything from creating firing tables for artillery to making calculations for the Manhattan Project. In contrast, Whirlwind was among the first attempts to apply digital computing directly to the real-time operation and integration of mechanical and electronic devices. The complexity of digital computing was such that by 1948 the segment of the project dedicated to building a cockpit for the simulator was dropped—and Whirlwind’s mission became simply to build an advanced digital computer.

By the end of the 1940s, Whirlwind was of such importance that its funding took up more than 50 percent of ONR’s budget. Faced with the prospect of developing a computer without an immediately apparent naval mission, ONR’s support for Whirlwind began to decrease in 1949. The Air Force, however, found a use for Whirlwind as the centerpiece of the Semi-Automatic Ground Environment system, or SAGE, which by the end of the 1950s would become the world’s first strategic defense network. SAGE integrated global early warning radar data, enemy bomber and missile tracking, and the ability to give intercept commands to friendly aircraft and missiles into a single system, becoming the digital heart of North American Air Defense Command (NORAD) based at Cheyenne Mountain, Colorado, for more than two decades.

Whirlwind advanced the state of the art of digital computers so far in the 1950s and 1960s that much of current digital computing—and the entire field of real-time computing—owes a debt to this early project. Whirlwind was the first major computer to use magnetic-core memory, the predominant type of random-access memory (RAM) for computers from the 1950s to the mid-1970s, when semiconductors became more widely available. The conceptual legacy of Whirlwind also can be found in everything from the computers embedded in nearly every one of today’s cars to the systems that make possible global maritime awareness—the real-time monitoring of the world’s shipping traffic.

With the increasing prevalence and sophistication of real-time computer systems, ONR’s support for the progress in this field has continued. To maintain these systems, developers use the generalized rate monotonic scheduling theory—GRMS for short—which relies on sophisticated algorithms to make sure the systems stay on schedule and meet timing deadlines. GRMS is a recent development that has had a significant impact on the development of real-time systems and open standards. It was developed by Dr. Lui Sha, a professor at the University of Illinois at Urbana-Champaign, thanks to funding from ONR.

Sha’s pioneering achievement was highlighted in the selected accomplishment section of the 1992 National Academy of Science’s report. He also led a comprehensive revision of Institute of Electrical and Electronics Engineers’ (IEEE) standards on real-time computing. These efforts led to a coherent set of techniques supporting the use of GRMS, which has since become the best practice when developing real-time computing systems.

Sha’s work on real-time computing and safety-critical system integration, such as PALS and SecureCore, has affected many large-scale, high-technology programs. These include Department of Defense technologies ranging from submarines to aircraft such as the F-22 Raptor and F-35 Lightning II.
CHAOTIC butterfly’s wing introduces a small and the random flapping of the system that is sensitive to stimulus, atmosphere is a large, interrelated cause a tornado in Texas. “The of a butterfly’s wings in Brazil can radically alter a future state. The “butterfly effect” to represent originators of chaos theory, used because of the random and location. The term “chaos” is influence the weather at a distant place. It is theoretically possible for that energy to set off a chain of atmospheric reactions that expand in scale and ultimately change the weather at a distant location. The term “chaos” is used because of the random and unpredictable nature of events such as this.

Many nonlinear systems can produce chaotic behaviors. A Navy-relevant example is the effective double pendulum of crane operations on a rocking ship. In this case, the crane operation is the system, and the motion of the ship in response to the actions introduces changes that result in highly irregular and hard-to-control motions. Electronic systems are also sensitive to chaos. In 1990, researchers Tom Carroll and Louis Pecora at the Naval Research Laboratory were looking for a way to make chaotic motion useful when they discovered, to their surprise, that two non-identical electronic oscillator systems behaving chaotically can be synchronized.

One way to think about chaos synchronization is to picture a large group of dancers whose motions are complex and not identical. Each couple in the group can judge what their next steps should be by only watching a small number of other dancers in the group, even only one couple. Then, if we want to have two large groups dance the same complex motions, we need only direct or synchronize the “lead” couples of each group. In the same way, if we pick the right signal from one system and impose it on another similar system, both will fall into synchronized behavior.

The main surprise in chaos synchronization is that although systems such as lasers, cranes, some electronic circuits, and neurons have many internal motions and signals that can behave chaotically, many can be synchronized to other nearly identical systems—but by using only one signal sent between them. The remaining parts of the chaotic systems fall into synchronized motion automatically and both systems maintain the complex motion, but with each part exactly matching the motion of its counterpart in the other system. Hence, to maintain identical complex motion between two lasers or cranes, we often need only send one signal from one to the other.

We do not have to send every detail of the motions of all parts.

This opened the way for a novel approach to secure communications. This involved sending one signal with a buried message only the receiver could recognize, enabling them to match the complex behavior and remove the large chaos signal to read a transmitter’s embedded message. Later, Chee Wei Wong at UCLA developed a method to create optical chaos in the GHz regime for this type of secure communications.

Understanding seemingly practical activities—such as using a crane to unload cargo from a ship—gets a lot more complicated when the crane, the ship, and the unloading spot (which might be another ship) are all moving. The science of chaos synchronization can help in designing and building systems that work in such environments. Photo by Lance Cpl. Alva Myers.
MACHINE LEARNING

The Office of Naval Research has invested in helping computers “think” through uncertainty since the mid-1990s, by way of its support of University of California Los Angeles professor Judea Pearl’s invention: the Bayesian network.

Bayesian networks are graphical models that represent relationships between random variables and related events—a new way of using Bayes’ theorem, which was originally developed in the 18th century by the Reverend Thomas Bayes as a way to solve problems of probability. For instance, Bayesian networks could be used to represent a probable relationship between diseases and symptoms using complex probability models. Given certain symptoms, the network could be used to compute the probabilities of the presence of various diseases.

The development of the Bayesian network framework has had tremendous impact on computer science and opened a field of study for researchers and developers. This framework and its computational approaches are now routinely used in diverse disciplines including data analytics, intelligent systems, computer vision, economics, medicine, social sciences, law, and engineering.

Later work in this field created a mathematical framework for causal inference that has had a significant impact on the social and health sciences. This research not only revolutionized the field of artificial intelligence but also became an important tool for many other branches of engineering and the natural sciences.

In the first quarter of the 21st century, Dr. Larry Carin at Duke University has conducted research in a number of fields, including detection and classification of acoustic targets, detection of electromagnetic targets in highly cluttered environments, dimensionality reduction, compressive sensing, sparse sampling, and machine learning. He has turned promising results into real capabilities that have transitioned to the Navy, National Geospatial Intelligence Agency, Army, and Air Force. Through his interest in acoustic energy and its scatter he developed methods that were able to distinguish the subtle differences between two objects, and, in collaboration with Luise Couchman at the Naval Research Laboratory, these methods were eventually transitioned to the fleet.

Carin’s work in signal sampling also led to new results that significantly increased processing power and bandwidth utilization. His sparse sampling/compressive sensing work segued into time reversal methods for imaging and target detection. He founded a small company, Signal Innovations Group, that specializes in the application of Bayesian methods. Under ONR funding a number of methods were developed and explored by Carin and his students. The results of these efforts led to the transition of techniques for track association into National Geospatial Intelligence Agency systems.

With the rise of digital imagery in the past three decades, the once largely separate worlds of photography and artificial intelligence have become enmeshed. Cameras, once merely the extension of the human eye, now can provide sight to computers and complex systems. ONR has long invested in research into image processing, particularly the work of three pioneering scientists.

Guillermo Sapiro at Duke University has conducted basic and applied research on behalf of the Navy and the Department of Defense since the early 1990s. Sapiro’s research has touched a number of fields, including partial differential equation (PDE)-based image processing, dimensionality reduction, compressive sensing, dictionary learning, and machine learning. He has made fundamental advances in each of these areas. Innovations include edge-preserving histogram-equalization methods; image inpainting for the reconstruction of damaged imagery and compression; and, most recently, combing concepts from machine learning, dictionary learning, and classification to develop a new method and strategy that minimizes the number of samples required to construct a classifier. His image processing tools have transitioned into naval and NGA image-processing suites.

Stanley Osher, a professor at the University of California, Los Angeles, is the co-inventor of the level set method for capturing fast-moving interfaces, which has now found applications in a broad-range of areas, including multiphase flow problems, crystal growth, computer vision, optimal design, inverse problems, and image processing. He was also one of the early pioneers of PDE-based image processing. Osher co-invented the total variation approach for image de-noising, restoration, and object detection, and developed the Split Bregman method for optimization. In 2014, Osher received the highest award in applied mathematics, the Carl Friedrich Gauss Prize.

Jean-Michel Morel, a professor at the École Normale Supérieure Paris-Saclay, is a mathematician whose work covers image and signal processing. His research provided a rigorous mathematical foundation for the use of partial differential equations in image analysis. Morel made seminal contributions in the areas of image segmentation, image de-noising, and image matching. In recent years, he has focused on bridging the gap between formal theoretical models and their applications to real-world problems. To that end, he started a new scientific journal, Image Processing On-Line, which provides a platform for researchers from both industry and academia to critically assess major image processing algorithms, foster sharing of experimental results and provide fast diffusion of algorithms. In 2013, Dr. Morel received the Grand Prize from the French Academy of Sciences, 2015 Longuet-Higgins prize and 2015 Médaille de l’Innovation.

Advances in machine learning and image processing have led to major advances in electromagnetic, acoustic, and optical signal processing, providing more accurate data in almost every realm of sensor usage, such as in this side-scan sonar image.

IMAGE PROCESSING

Target identification in an often cluttered environment has become a significant problem where machine learning has played a role in mitigating. Photo by MC3N Michael J. Leibnicht.
In a different application, such as machine-to-machine communications, Dr. Salman Avestimehr’s seminal research at the University of Southern California in coded distributed computing (i.e., edge computing) has shown how time-varying wireless networks can be more efficient in handling communication overload—without the need to maintain globally networked topology structures—by using a combination of task distribution, proactive computing, and caching. These edge-computing algorithms have been implemented in secure, aggregated versions for distributed federated learning, by FedML (a startup company founded by Avestimehr), directly challenging the current cloud computing paradigm.

ONR has launched multiple software-defined-network research projects since 2016 to improve the modularity and programmability of these types of networks. An ONR program at Cornell developed a new traffic engineering algorithm called SMORE (Semi-oblivious Routing), which compared competing adaptive routing algorithms—assessing their ability to respond to rapid changes in demand, network congestion, routing efficiency, etc. Cornell subsequently collaborated with Facebook (Meta) to model and test traffic engineering/routing at scale using actual traffic on Facebook’s Express Backbone – the social media site’s long-haul network interconnecting its data centers.

The fleet Tactical Grid is a key DMO enabler to increase sensor contributions, spectral maneuvers, and distributed engagement options across an expanded battlespace. Through engagement options across an expanded battlespace. Through ONR researchers. Novel information-theoretic analysis on wireless network capacity by Dr. Syed Jafar at the University of California, Irvine, has spurred an entire field of research in new codes and techniques for managing wireless interference — by filtering out undesired signals at every network receiver, making other users’ interference less intrusive while allowing each user to access half of the total bandwidth.

In the applied research track, a current area of interest is the development of artificial intelligence and machine learning for feedback-based reinforcement learning techniques to improve network adaptation in highly dynamic, contested environments. An ONR program presented a novel approach with a multi-agent, deep-reinforcement learning framework, at the Military Communications Conference 2020. Unlike previous solutions in the literature, this framework trained with realistic routing policies for tactical networks over a wide range of conditions—including variable number of nodes, different data flows with varying data rates and source/destination pairs, diverse mobility levels, and other dynamic behaviors of the network. The objective of the research was to train deep neural network routing policies in a centralized fashion but with policies executed individually at each node based on each agent’s partial observations of the global state (i.e., centralized training and decentralized execution). The reward function objective was to minimize the normalized data packet delivery overhead simultaneously maximizing end-to-end goodput (i.e., good throughput) at which useful data travels in the presence of high dynamics.

Continuing its mission of developing technology for warfighter capabilities, ONR advanced and matured the aforementioned applied research in SDN and traffic engineering for transition to the fleet – via a Future Naval Capability program called Communications-as-a-Service (CaaS). The objective of CaaS is to create an on-demand network for DMO through a combination of tactical data links. A key difference from traditional routing techniques was to incorporate performance constraints (e.g., latency, packet loss, jitter, etc.) required for both kinetic and non-kinetic fires into the network optimization. Some of the key deliverables included: interfaces to various tactical data links or communications systems; techniques for sending communications topologies and performance; algorithms for multi-commodity optimization, distributed resource allocation/scheduling, etc. to establish source-destination paths based on defined service levels, and deterministic networking techniques to assure delivery of the highest priority data within the specified level of service. Resilient networking is a complex and multi-faceted discipline, requiring both fundamental and heuristic understanding of the underlying phenomena and processes to achieve efficiency, agility, and stability for end-to-end data forwarding. In this vein, ONR research thrusts continue to focus on a highly automated and adaptive network control and management sub-system that is real-time enabled for speed and execution by deep-learning precepts.
NANO ELECTRONICS

Technology at the smallest of sizes—even as computing and power capacities continue to grow—is now possible because of 40 years of research into nanoscale electronics. The discovery in the 1970s that power dissipation density remains constant when scaling the transistor device size—in effect, allowing for more computationally powerful circuits per area—has led to a range of smaller, but more powerful, electronics that are enabling a new generation of vehicles, platforms, and sensors in sizes never thought possible before.

The Office of Naval Research’s initiative on nanoelectronics began in the late 1970s with the Ultra Submicron Electronics Research (USER) program—formulated by program officer Dr. Larry Cooper to develop electronic devices with dimensions of 2 nanometers. To put this in perspective, a human hair is about 60,000 nanometers wide and a DNA molecule is 2-3 nanometers wide. It also is worth noting that the USER program predated the celebrated National Nanotechnology Initiative by more than two decades—and had a major impact in helping to shape the vision and strategy of that Initiative.

During the past four decades, many of ONR’s research accomplishments, as well as the generations of nanotechnologists trained under the nanoelectronics program, have made enduring contributions to the success of today’s 10-nanometer transistor devices—which are now prevalent in many high-end electronic gadgets used in military and civilian applications. The nanoelectronics program continues to advance and reach truly molecular scale, and is seeking to control and build electronic devices at the near Angstrom (0.1 nanometer) scale.

A hallmark of ONR’s nanoelectronics program over the years has been the consistent record of identifying, attracting, and providing early support to the world’s best talents in this still-cutting-edge area of science and technology. As a result, ONR-funded researchers have garnered many top scientific awards, including the 2010 Nobel Prize in Physics awarded to Dr. Andre Geim and Dr. Kostya Novoselov of the University of Manchester for their work with graphene.
Protecting computer systems and networks from malicious actors—human or otherwise—has become a major focus of current research. The Office of Naval Research has a long, rich history of supporting basic and applied research in computer science and engineering—the foundations of modern cybersecurity research.

ONR was one of the few Department of Defense research offices that did not abandon sponsorship in the area of computer science and engineering when there was a trend toward total reliance on commercial technology for computing hardware and software. When operations in cyberspace became contested—a problem exacerbated by the homogeneity of computing infrastructure—and software became overly complex, ONR’s continuous research allowed it to lead the way toward a simpler, more robust, and resilient computing environment.

ONR has supported a number of prominent and impactful scientists in cybersecurity.

Edmund Clarke is a pioneer in the use of model checking as a verification technique for computer software, hardware, and finite state concurrent systems, which helped lead to greater effectiveness in detecting system design errors.

Stefan Savage, a leading experimental cybersecurity researcher, led the discovery and exposure of a botnet underground economy. A botnet (also known as a zombie army) is a network of internet computers that, although their owners are unaware of it, have been set up to forward transmissions (including spam or viruses) to other computers. Savage’s work helped law enforcement curtail this shady, often malicious economy. Savage also is part of the first team to expose the cyber vulnerability of modern cars through hacking.

Wenke Lee, a leading expert in cybersecurity, has helped law enforcement agencies such as the Federal Bureau of Investigation dismantle several botnets. Lee also is a lead researcher in enhancing systems security and discovering ways to bypass security networks. His team built a “trojaned” app that not only passed Apple’s security scrutiny, but also was published in the Apple apps market place. Lee pulled the app as soon as it was published to prevent spreading. He currently is working with ONR to fully automate penetration testing for tactical computing and controllers.

Sailors assigned to Navy Cyber Defense Operations Command monitor, analyze, detect, and respond to unauthorized systems and computer networks. The command is responsible for around-the-clock protection of the Navy’s computer networks, with hundreds of thousands of users worldwide. Photo by PO2 Joshua Wahl.
The Office of Naval Research (ONR) Innovative Naval Prototype program, in partnership with the technology company Aurora Flight Sciences, created the Autonomous Aerial Cargo/Utility System (AACUS). The program completed successfully in 2018.

AACUS enables the Marine Corps to rapidly resupply forces on the front lines using cutting-edge technology sponsored by ONR. The system consists of a sensor and software package that can be integrated into any manned or unmanned rotary-wing aircraft to detect and avoid obstacles (like telephone wires, other vehicles or large ground objects) in unfavorable weather conditions, or to facilitate autonomous, unmanned flight. This capability is a welcome alternative to dangerous convoys or manned aircraft missions in all types of weather.

AACUS is designed for simple use; an operator with minimal training can call up the supplies needed and order the flights using only an intuitive handheld tablet.

During successful demonstrations at Marine Corps Base Quantico, Virginia, a Marine with no prior experience with the technology was given a handheld device and 15 minutes of training.

The need for this capability surfaced during Marine Corps operations in Afghanistan and Iraq. Cargo helicopters and resupply convoys of trucks bringing fuel, food, water, ammunition and medical supplies to the front lines frequently found themselves under fire from adversaries—or the target of roadside bombs and other improvised explosive devices.

Vertical take-off and landing (VTOL) systems have significant advantages over other means of resupply, including avoidance of improvised explosive devices and greater speed over trucks that are often limited by hostile conditions and manning constraints, which are mitigated when using unmanned aerial vehicles.

AACUS provides combatant commanders with more capabilities in the field and most importantly deliver desperately needed supplies to warfighters in contested areas. With its autonomous capability pilots and crew will be kept out of harm’s way when delivery to “hot” landing zones is required.
Extremely lightweight but very strong, cellular materials consist of engineered periodic structures or materials of random porosity, which can be employed to meet various naval applications that demand both qualities. Porous materials contain many open or closed cells distributed throughout the material, as in Styrofoam and other plastic foams or certain ceramic materials. Periodic cellular materials can exist if multiple architectures that provide specific angular properties. These cellular structures provide directed properties that are attractive for applications requiring ultralight panels and shells, heat dissipation, or energy absorption (such as vehicle armor for Marines).

Since 1996, the Office of Naval Research has looked to enhance our understanding and explore the different uses of cellular materials. Research sponsored by an ONR multidisciplinary university research initiative has amplified insights into the mechanical, thermal, and impact resistance properties of cellular and porous materials. It added to the fundamental understanding of structural behavior in micro-architecture materials, hierarchical lattices, and 3D additive lattices. This work made it possible to provide an integrated pathway between material behavior, structural design, and component manufacturing, providing new opportunities in the development of lightweight structures and heat-dissipating and impact, ballistic-resistant materials.

ONR core investments have further delineated cellular materials behavior during blast and ballistic events. The Deshpande–Evans ceramic impact model described and experimentally verified the mechanical behavior of energetic materials, providing a new capability to investigate fundamental aspects of material response to multiple ballistic hits. It is currently being embedded into the Department of Energy and Department of Defense Allegra Ballistic Code used in the design of armor.
Next-generation solar cells and batteries are helping to get individual Marines and other ground troops the renewable, portable power they need in the field. The Office of Naval Research has led pioneering research in the field of wearable tactical energy for infantry on foot. The Squad Electric Power Network (SEPN) project was a five-year Future Naval Capability awarded to the Naval Surface Warfare Center Dahlgren Division in 2010-14. It resulted in a wearable, personal power system able to interface with any electrical load and electrical source between four and 34 volts DC, and to sustain a central power source. The Vest Power Manager provided dismounted Marines with a quick, easy-to-use interface that supplies power to their most commonly carried electronic devices (radios, navigation, night vision, and computers).

Another ONR-led effort was the Lightning Pack, a backpack that converts human motion into electricity. This backpack, along with the SEPN-based power manager, is being evaluated to further increase the energy sustainment of dismounted combatants.

SEPN teamed with the Naval Research Laboratory and the Marine Corps Expeditionary Energy Office to create the Marine Austere Patrol System (MAPS), which was demonstrated at the Mountain Warfare Training Center in Bridgeport, California. MAPS integrated a Naval Research Laboratory-developed triple junction solar panel with the Vest Power Manager to sustain Marines over a multiday mission—eliminating battery resupply.

Mobile Solar Power is another related ONR effort. The goal is for lightweight, high-efficiency photovoltaic blankets to displace batteries at the individual Marine and squad levels, as well as to replace generators at the forward operating base level. The technology is producing approximately 0.5 watt/gram, at $350 per watt with 30 percent efficiency. The goal is 1 watt/gram, at $20 per watt or less with efficiencies of at least 20 percent. Several alternative solar cell chemistries are being explored to provide suitable power at decrease cost and weight.
Research into technologies that go in and on ground vehicles has been helping Marines and other warfighters get the most advanced mobility available. The Office of Naval Research has been researching cutting-edge mobility and survivability technologies for Navy and Marine Corps ground vehicles for decades.

State-of-the-art suspensions have been developed—such as magnetorheological fluid dampers and fully active, algorithmic-controlled electromechanical actuators—that provide unsurpassed ride quality and mission rating speeds over challenging terrains. ONR has invested in electric and hybrid electric drivetrains, such as in-hub electric motors, and pursued advanced fuel efficiency technologies to reduce logistical burdens while providing extended operational reach. Technologies to improve platform and crew survivability have been developed, such as rocket-propelled grenade defeat nets, shock absorbing seat mechanisms, and underbody blast and ballistic armors.

The Reconnaissance Surveillance and Targeting Vehicle (RST-V), developed as a technology demonstrator in the late 1990s, served as the test vehicle for a hybrid-electric, V-22 Osprey internally transportable platform with such novel features that it was considered the most advanced tactical vehicle in the world at the time. Starting in 2005, ONR’s Combat Science and Technology Vehicle (CSTV) program led the joint service technology development initiative for the next-generation HMMWV replacement platform. Advanced propulsion, suspension, exportable power, and underbody blast technologies were researched and a full-scale technology demonstrator was constructed to assess performance and to assist the requirements development process. Ten years later, technologies and features developed under the CSTV program appeared on the next-generation platform now known as the Joint Light Tactical Vehicle (JLTV).

Looking further into the future, technologies are being pursued to integrate control of ground vehicle active-chassis effectors with remote terrain sensing to provide predictive rather than reactive chassis control, and to develop advanced lightweight armors to provide unmatched battlefield survivability. Autonomous and unmanned ground vehicles provide yet another leap in maneuverability on the battlefield. ONR has been researching perception and intelligent control and decision making, higher-level reasoning, and scalable, distributed collaboration. The semi-autonomous Gladiator Tactical Unmanned Ground Vehicle (TUGV) transitioned to the Marine Corps in 2006 and provided a multipurpose sensor and weapon capability. ONR continues to push the state of the art by researching more advanced, fully autonomous and manned/unmanned teaming technologies where Marines and robots will work side by side on the battlefield of the future.
The Ground Renewable Expeditionary Energy Network System consists of a series of solar panels that collect energy and store them in four high-energy lithium battery packs. The system allows forward deployed troops the opportunity to use a renewable energy source instead of fossil fuels or batteries that cannot be recharged. Photo by Cpl. Damany Coleman

Marines with 6th Communications Battalion set up a Ground Renewable Expeditionary Energy Network System that will provide power for a Javelin Thrust exercise at Twentynine Palms, California. Marine Corps Photo

MOBILE ENERGY NETWORKS

The proliferation of electrically powered equipment and devices has revolutionized warfare in almost every way possible, but it has also come with a significant price: the need for lots—and lots—of energy. Providing Marines with the power they need while maintaining and enhancing their mobility has resulted in the development of new lightweight, solar-powered systems that bring energy to Marines in the field.

The Ground Renewable Expeditionary Energy Network System (GREENS) is powered by the sun. It is a 300-watt, photovoltaic/battery power system that provides continuous power to Marines in the field. GREENS fills the gap between what a large power generator and a battery can provide. In addition to renewable energy, GREENS also can be combined with generators and vehicle power to provide an intelligent small-scale energy management system. Increased use of renewable energy sources such as GREENS in the battlefield decreases the need for vulnerable fuel convoys and saves lives.

The Naval Surface Warfare Center Carderock Division developed and tested the original GREENS prototype systems. GREENS underwent continuous power testing in 2009-10 in temperatures that exceeded 116 degrees Fahrenheit. Performance exceeded expectations, prompting rapid development and accelerated procurement of the final design by Marine Corps Systems Command.

Beginning in 2011, Composite Technology Development, Inc., under the Navy Small Business Innovation Research program, helped improve the system’s deployability by combining an innovative packable framework array and lightweight, efficient solar technology. The new solar panels reduced panel system weight and volume by as much as 75 percent.
Training naval personnel for the fleet and force has advanced significantly in the past quarter century with the use of virtual and augmented reality technologies. The Office of Naval Research has been at the forefront of building the theoretical concepts, software, and hardware that have made these technologies possible. Among the numerous training systems ONR has helped to develop is the Conning Officer Virtual Environment-Intelligent Tutoring System (COVE-ITS). ONR sponsored university research that combined the science of learning, artificial intelligence, and ship-handling knowledge to build an intelligent tutoring system with a natural language interface that can provide one-on-one coaching in simulated environments that resulted in COVE-ITS, a prototype tutoring program. COVE-ITS addresses several important goals: tutoring people to apply their knowledge in challenging situations, and creating software that assesses performance while instructing students in high-fidelity simulators on ship-driving tasks. The system provides one-on-one training for advanced ship-handling skills to complement both classroom instruction and tools for developing training scenarios, such as underway replenishment.

Tests of COVE-ITS at the Navy’s Surface Warfare Officers School in Newport, Rhode Island, showed it to be very effective in developing certain important skills as well as helping students to learn to drive simulated ships. The school plans to implement a learning system developed from COVE-ITS for regular instructional use. The effect of COVE-ITS at the school has been impressive. It has lowered the cost of training by reducing instructor time by as much as 50 percent, and improved the ability of instructors to assess performance, provide instruction and remediation, and develop skill sets.

The Surface Warfare Officers School plans to transition to an operational version of COVE-ITS for classroom use, as well as deploy the system to other fleet concentration areas and five Naval Reserve Officer Training Corps units.

Another example of ONR-sponsored training systems is Live, Virtual, Constructive (LVC) training, a result of more than 20 years of sustained investments in virtual reality, artificial intelligence, and computing technology research. LVC training prepares Sailors for naval deployments with scalable, integrated, cost-efficient, immersive, realistic, higher-repetition training, and it allows participants at shore-based installations and on ships in port and at sea to work together as they would during operations.

ONR led a virtual reality head-mounted display effort, as part of Small Business Technology Transfer project that drove research toward phone-type displays, simple magnifying optics, and open-source designs, and ultimately influenced the commercial sector. The end product was the WideS, a fully immersive, lightweight, and comfortable head-mounted display. Palmer Lucky worked as a technician at the Mixed Reality Lab at the University of Southern California’s Institute for Creative Technologies, a partner on the project. He went on to launch Oculus VR, through a Kickstarter campaign, and ultimately sold the company to Facebook for $2 billion.

ONR has invested in augmented reality for more than 20 years. Early research in the 1990s through the Young Investigator Award supported a Columbia University professor, Steve Feiner, who developed early augmented reality systems to the Marine Corps. More recently, ONR has conducted research and transitioned augmented reality systems to the Marine Corps. The Augmented Immersive Team Trainer (AITT) displays virtual effects, such as smoke, aircraft, vehicles, and/or role players onto the real world. This technology transitioned to the Marine Corps at the end of 2015, and included a Deployable system that fits into a single Pelican case.
The Office of Naval Research has supported basic research in the study of the human brain and mind for decades, pioneering work that has impacted multiple fields, including artificial intelligence, machine learning, training, combat medical care, and the study of post-traumatic stress disorder.

Professor Michael Posner of the University of Oregon, a long-time ONR performer, was awarded the National Medal of Science, the U.S. government’s highest scientific honor, in 2009. The award was for pioneering work, much of it funded by ONR in the 1990s, in the field of cognitive neuroscience—the study of the brain mechanisms underlying cognition and perception. Posner’s contributions have led to a deep understanding of the fundamental mechanisms of attention, skill acquisition, and word recognition. The experimental techniques developed and refined by Posner and his colleagues are now used in hundreds of laboratories throughout the world to understand the relationship between the brain and the mind.

MIT professor Ann Graybiel’s ground-breaking work, a portion of which has been supported by ONR, has unraveled the modular architecture of the striatum, a subcortical part of the forebrain that coordinates motivation with action. Her research has shown how neural interactions between the cortex and the striatum are altered when animals learn new skills and reveals for the first time how neuronal circuits organize familiar motor patterns into action sequences. She received the Kavli Prize, awarded for outstanding contributions in astrophysics, nanoscience, and neuroscience by the Norwegian Academy of Science and Letters, the Norwegian government, and the Kavli Foundation, in 2012, for her ONR-supported research.

ONR has supported work in the laboratories of Arthur Kramer at the University of Illinois and Daphne Bavelier at Rochester University that has demonstrated for the first time that a three-to-four week period of training on certain fast-paced computer-based games produces reliable increases in measured perceptual and cognitive function among young adults. The observed improvements include attention span, working memory capacity, short-term memory, and multitasking. These results document the capacity of the adult brain to improve its fundamental information processing capacity in response to targeted training.

In 2009, University of Oregon professor Michael Posner received the National Medal of Science for his ground-breaking work in cognitive neuroscience from President Barack Obama. White House Photo

In 2012, MIT professor Ann Graybiel (third from left) received the prestigious Kavli Prize, awarded for her contributions to the field of neuroscience. Norwegian Academy of Science and Letters Photo

Jose Principe’s work in computational neuroscience at the University of Florida has led to significant advances in the ability of synthetic, autonomous agents to distinguish underwater objects. Coast Guard Photo

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Jose Principe’s work in computational neuroscience at the University of Florida has led to significant advances in the ability of synthetic, autonomous agents to distinguish underwater objects. Coast Guard Photo
As NASA launched its effort to reach the Moon, the Office of Naval Research spearheaded attempts to show that humans could live and work at the bottom of the ocean. In a parallel to the Space Race during the 1960s, ONR led a series of biomedical studies in what would become known as the SEALAB undersea habitat. Although each iteration of the habitat involved multiple experiments, the fundamental purpose of SEALAB was to prove the viability of humans living for extended periods in a saturated atmosphere environment—also known as saturation diving—where humans breathe a mixture of oxygen, nitrogen, and helium.

SEALAB I was lowered into the water at the U.S. Naval Station Bermuda in July 1964. It housed four researchers for 11 days at 192 feet. SEALAB II was lowered off of La Jolla, California, to 203 feet in 1965. Scott Carpenter, one of the original Mercury Seven astronauts, was transferred to the program and spent a record 30 days in this submerged world. SEALAB III, the final habitat used in the program, was lowered to a more than 600-foot depth off California’s San Clemente Island in February 1969. During an attempt to repair a leak in the habitat, aquanaut Berry Cannon died as a result of a faulty rebreather. The program ended soon after.

The principal investigator was Navy Capt. George Bond, the “Father of Saturation Diving.” His experiments explored the extreme physiological and psychological exposures of undersea habitation. Among many pioneering efforts, his team investigated the effects of nitrogen narcosis on cognition, tested diver warming with the new “neoprene” foam wet suit, and developed a method to compensate for the high-pitched “chipmunk” speech experienced when breathing helium.

SEALAB was primarily a habitability study, but the experiments also enabled covert missions that played a key role in the undersea Cold War of the 1970s. Another major SEALAB challenge was developing safe decompression procedures for saturation diving. These experiments aided in the creation of the decompression tables used today.

Today’s ONR Undersea Medicine program has grown since the time of SEALAB and seeks to understand the human challenges of undersea exploration in the modern age of biomedical science and technology. The goal is to develop innovative technological and biomedical approaches to reduce the threats of operating in the hostile undersea environment, expanding undersea mission flexibility and decreasing the medical logistic burden of undersea operations.

Decades of research in the Undersea Medicine has led to the emergence of an alternate theory for the cause of decompression sickness (DCS), which could lead to improved prevention and treatment. The research has characterized specific biomarkers involved in the inflammatory response associated with DCS. Recent results culminating from these insights have demonstrated in mice that the inflammatory response can almost be completely abrogated with treatment of a naturally occurring anti-inflammatory protein called Gelsolin. Phase 1 clinical studies have demonstrated that intravenous Gelsolin supplementation is safe and can be an effective treatment in other inflammatory disorders. Since this is a naturally occurring protein, altered levels of Gelsolin may explain individual DCS susceptibility and could therefore be used to supplement those who do not have sufficient supply.

Additionally recent investments through the Future Naval Capability mechanism has resulted in the successful development of the Divers Augmented Vision Display (DAVD) system. DAVD is a heads up display (HUD) placed in different dive platforms (helmets or masks) with the ability to integrate live sonar feeds, text messaging, photo and video display, dive telemetry data, and positioning information. DAVD 1.0 and 2.0 have been produced and fielded to the fleet. The third generation is currently under development along with a closed-circuit rebreather version of the DAVD HUD. The DAVD program continues to add capabilities thru a collaborative agreement with NASA with planned use in training activities as well as missions on the dark side of the moon.
The U.S. Navy is legally required to assess the potential effects of all training and testing activities on marine life, but definitive studies on the response of marine mammals to sonar are hampered by the short surface time and deep-diving lifestyle of many species.

In the past two decades, rapid advances in the transmitters, receivers and data storage tags that are attached to animals have made it possible to collect high-quality biological and oceanographic observations on timescales varying from days to years. Since the early 2000s, ONR has capitalized on these improvements by sponsoring the creation of what would become known as the “DTAG,” or digital recording tag, which to this day—now in its third generation—is the most sophisticated tag available for marine mammals.

The DTAG is noninvasive (attached to the whales with suction cups) and contains solid-state memory. It records continuously from a built-in hydrophone and a suite of sensors. The sensors sample the orientation of the animal with sufficient speed and resolution to capture individual fluke strokes. Audio and sensor recording is synchronous, so the relative timing of sounds and motion can be determined precisely.
With the modern military experience louder than ever—whether it involves training or actual combat, small-arms fire or the roar of jet engines—protecting against hearing loss is essential. For more than 70 years, the Office of Naval Research supported research aimed at reducing and preventing two of the highest long-term disabilities facing Sailors and Marines—tinnitus (ringing in the ears) and hearing loss, which occurs when inner ear hair and nerve cells are damaged by exposure to high noise levels.

The foundation of this work started with one of ONR’s earliest contracts (beginning in fact under the Office of Research and Invention), with Harvard University’s Psycho-Acoustic Laboratory, which was established during World War II to investigate issues related to noise problems and aviators. A notable principal investigator at the lab was Georg von Békésy, whose work in bone conduction and maximal sound protection by ear plugs was sponsored by ONR while he was at the laboratory beginning in the late 1940s. His research laid the groundwork for understanding cochlear mechanics, the inner workings of the ear, for which he would receive a Nobel Prize in medicine in 1961.

ONR’s Noise Induced Hearing Loss (NIHL) program continues to build on von Békésy’s work—addressing challenges associated with operational performance in noisy environments and the hearing loss faced by warfighters.

The NIHL portfolio included four major research areas: reduce noise on ships and aircraft and around other equipment; evaluate and assess hearing loss and tinnitus incidence, susceptibility, and risk factors; prevent and treat tinnitus and hearing loss; and improve personal protective equipment, hearing protection devices, and underwater communications and hearing protection.
OFFICE OF NAVAL RESEARCH: 75+ YEARS OF TECHNOLOGICAL ADVANTAGE

Founded just after World War II, the Office of Naval Research has consistently advanced key technologies that led to war-winning capabilities for the Department of the Navy. Its ongoing efforts will be key to U.S. success in 21st-century strategic competition.

Rear Adm. Lorin Selby, USN
As the long conflicts of World War II at last came to an end in 1945, Fleet Adm. Chester Nimitz—one of the greatest naval strategists this nation has ever known—commanded the largest naval armada the world had ever seen. With the United States now the unquestioned leader of the free world (actually coming out of the war with far greater strength than going in), it would have been reasonable for Nimitz, and the rest of the world, to believe the United States was holding all the right cards to ensure continued dominance.

Yet Adm. Nimitz knew resting on laurels would not win tomorrow’s battles. The United States had seen dark days during the war—times when the enemy’s technological capabilities had surprised the Allies and led to significant losses in battle. Those surprises started with the attack on Pearl Harbor, when not only the attack itself was a surprise, but the accuracy and power of Japanese torpedoes caught the U.S. Navy off guard. (It would take us a year to catch up on them at a scale never seen before. Crucial new materials, such as synthetic rubber, while lacking the star-power of new carriers or bombers, nonetheless played key roles—as did new medical technologies, advances in computers, and even duct tape.

Adm. Nimitz and other key leaders knew that the recent past underscored the importance of imagining the future. And that would extend to the Navy itself. ‘There will always be a Navy,’ he said, ‘Not necessarily a Navy of battleships, or submarines, or carriers, but a Navy in the sense of what the word Navy truly means . . . what the future Navy will be like, we cannot say as yet.’

Against this backdrop, in 1946, Congress created the Office of Naval Research (ONR). President Harry Truman signed the bill into law in August 1946—a little over 75 years ago. The bill’s instruction for the new organization: “to plan, foster and encourage scientific research in recognition of its paramount importance as related to the maintenance of future naval power, and the preservation of national security.”

Since its founding, ONR has produced incredible results. ONR sponsored research has played a key role in the development of GPS, radar, computers, new uses for gallium nitride, new autonomous surface, sub-surface, and airborne platforms, virtual training, tropical cyclone prediction, directed-energy weapons, stealth capabilities, and so much more. The raw knowledge coming out of ONR over the years has been astounding: More than 70 Nobel Prize winners have been sponsored by ONR; in many cases, they have thanked ONR directly for pivotal guidance and partnership.

Impressive as its history is, and as exciting as today’s technologies are, the people of ONR cannot be satisfied with what we have already accomplished. We must continue to forge ahead with an ongoing call to intellectual arms. Today, the Department of the Navy and the nation require us to reimagine naval power, and recognize that, across the Navy and Marine Corps, we must change to maintain naval dominance. Monumental efforts are needed, in the spirit of people like Adm. Hyman Rickover, whose singular focus brought about the nuclear-powered Navy, despite entrenched bureaucracy seemingly designed to slow down dramatic change. I recently introduced the concept of a new “hedge strategy” for the Navy, where newly developed, autonomous platforms and sensors on thousands of unmanned vehicles—the small, the agile, and the many—will complement the Navy’s powerful carriers, aircraft, and submarines. Noted entrepreneur Steve Blank wrote about this strategy in Proceedings earlier this year.

Our nation and the Navy are the better for ONR’s first 75 years of research and development. We must act just as boldly today because what happens in the next 10 years of science and technology may well determine the next 100 years of history. We are at a pivotal moment—and technologies being developed now are going to be akin to James Watt’s steam engine and the subsequent Industrial Revolution that changed the world. Artificial intelligence; autonomous and unmanned capabilities; quantum computing; directed energy; materials science; and biotechnology are today’s equivalents. And, too often-overlooked, the workforce development and STEM educational efforts that drive those advances are what will ensure the U.S. Navy and Marine Corps maintain their edge and ensure a safe and secure nation and global commons.

1946—PRESENT
Eight months before Winston Churchill declared at Westminster College in Missouri that an “Iron curtain has descended across” Europe, U.S. naval officers ensured that the postwar Navy would have the services of the first military organization dedicated to advancing civilian science and technology for future readiness. Originally founded on a temporary basis in July 1945 as the Office of Research and Invention on the authority of the Secretary of the Navy and the War Powers Act, the new organization was the product of what had been learned from the national mobilization of science for the war. Soon renamed the Office of Naval Research, the command had a revolutionary mission: to support science in the interest of national security, in peacetime as well as wartime. As had Nimitz, Vice
Adm. Harold Bowen, the first Chief of Naval Research, championed the argument that readiness was no longer something that could happen after a conflict had begun. Enduring technological advantage was a national security imperative.

As the Naval STEM Executive, I believe that maxim has never been truer. To maintain that technical advantage, we need to view our naval STEM workforce as a matter of national security. Our edge will continue to come from great ideas; the great ideas will come from a unique, diverse workforce; but that STEM-inspired workforce will not just magically appear—it must be supported and nurtured. Holistically, if we are to succeed in a rapidly-changing technological landscape, we need to support the institutions and networks that will develop the vehicles, sensors, and remote vehicles, originally developed with ONR support to study ocean dynamics and climate change, provides the means for real-time maritime domain awareness today.

In addition to discoveries in the oceans, ONR continues to lead in developing the vehicles, sensors, platforms, and ships that make all these discoveries possible. These efforts include everything from building submersibles such as Alvin, launched in 1964, and unique vessels such as the Floating Instrument Platform (FLIP), to providing many of the nation’s largest ocean-going research ships such as the venerable R/V Melville (AGOR 14) and R/V Knorr (AGOR 15), each of which provided more than 40 years of service, and the current R/V Sally Ride (AGOR 28) and R/V Neil Armstrong (AGOR 27).

ONR’s impact goes beyond marine sciences. One of its earliest projects in the 1940s, Project Whirlwind, resulted in the first digital computer capable of real-time computing. Originally intended to control a next-generation flight simulator, Whirlwind would eventually be incorporated as the heart of the first strategic air defense early-warning system. Today, nearly every device that contains a real-time computing device—from the computer in your car to the servers that monitor daily shipping traffic—owes something to ONR’s early work in digital computing.

ONR-sponsored research aided in the development and enhancement of the atomic clock, an essential and necessary component to the satellite navigation systems upon which so much of modern life depends. Early investments in directed energy supported the research of Charles Townes, who invented the microwave amplification by simulated emission of radiation (maser) in the 1950s and contributed to later development of the light amplification by simulated emission of radiation (laser). Those investments came full circle in 2014, as ONR deployed the first laser weapon system on a warship, the USS Ponce (AFSB(I) 15)—and today has put a far more powerful laser aboard USS Portland (LPD 27). ONR-sponsored research in railguns over the past decade resulted in a series of record-breaking kinetic milestones with this next-generation technology. And, ONR has long been at the forefront of new materials for nearly every environment, from explosive-resistant coatings for vehicles and ships, to highly conductive materials such as gallium nitride—found in nearly anything with full-color LED lighting and, more significantly, in high-power radars and electronics.

Warfighter protection efforts have been front and center as well, with significant military and societal significance. Medical research sponsored by ONR has included everything from the Sealab underwater habitats that helped us understand human interactions underwater, to more recent automated trauma monitoring systems, virtual reality PTSD treatments, and QuikClot, a wound dressing that accelerates blood clotting. Indeed over the years, ONR has supported an array of technologies that have directly benefited Marines, from wearable tactical energy systems, mobile power and logistics systems, to next-generation tactical ground vehicles.

Our work in unmanned systems has led to enormous success and...
even greater promise ahead—but it is worth noting it took decades to get to the point of such groundbreaking autonomy exercises as the Integrated Battle Problem 21 (IBP21), where over 30 autonomous platforms were successfully tested in blue water operations. Beginning with some of the earliest investments in artificial intelligence that resulted in the first autonomous robot, Shakey, at Stanford University in the 1960s, ONR has been a leader in building and improving autonomous vehicles, automated decision-making, and human-robotic teaming and interactions. This year, our new SCOUT initiative—a novel partnership with the Joint Interagency Task Force—South—will provide impressive new autonomous capabilities to support narcotics interdiction efforts.

ONR’s importance to American science and technology extends beyond research and new capabilities—indeed, the organizational infrastructure that ONR uses to support research and innovation has been replicated across the Department of Defense and beyond. The first deputy chief of ONR, Alan T. Waterman, and beyond. The first deputy chief of ONR, Alan T. Waterman, would become the first director of the National Science Foundation when it was founded in 1950. Our peer organizations—the Army Research Office, the Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency—were founded during the Cold War using the same S&T management principles pioneered by ONR.

Over the decades, a wide range of warfare centers, laboratories, and university-affiliated research centers, have been established and grown into a diverse S&T network, dedicated to advancing innovation. Of all ONR’s many legacies, collaboration between institutions and organizations—military, industrial, and academic—is perhaps the most profound and longest-lasting. Fostering an environment of partnership, from the Naval Research Laboratory and ONR Global, to our sister organizations throughout DoD and beyond, has proven time and again to be essential to advancing modern science and technology.

MOVING FORWARD

As impressive as the organization’s history is, we will not rest on our laurels. The challenges facing our Nation today are grave. To ensure continued deterrent-level dominance over increasingly sophisticated state and non-state actors, we must in this decade overcome our own well-intentioned bureaucratic hurdles, which may have once been useful but are no longer. As happens periodically, there come tipping points where what has worked well in the past—how we operate both internally as well as externally with our partners—is no longer effective.

In that spirit, ONR has expanded its paradigms and vision. In the early decades, ONR was optimized as a basic research organization focused on discovery in universities and basic research institutions. In the 1980s and early 1990s, though, as the Cold War was ending, ONR took on more applied research and advanced technology development. In the past 30 years, we have added new ways to approach innovation. Examples include: TechSolutions, which takes ideas from Sailors and Marines to swiftly produce working prototypes; Future Naval Capabilities, which accelerate cutting-edge technologies into the fleet and force; and Innovative Naval Prototypes, which take seemingly “over the top” ideas, technologically, and explores finding the next game-changing capability.

Innovation is not only about platforms or technologies. We must also rethink how we do business. For some programs, it will take decades to “get there.” But for others, our research is so close to maturity that we simply cannot accept slow contracting processes, constrained funding lines, and inability to get on ship modernization schedules. Our Sailors and Marines need capabilities now. We can better utilize tools that already exist to get things done—including newer forms of funding, such as Partnership Intermediary Agreements (PIAs), Other Transactional Authorities (OTAs), hackathons and prize challenges, new internships, and creative academic programs such as multidisciplinary university research initiatives (MURI), and more, all of which can accelerate innovation deliveries.

One of the key ways we’re doing this is through our Naval X program, with its associated Tech Bridges. At its essence, Naval X is a new way of inspiring collaboration and fostering new paths for new ideas. The Tech Bridges, envisioned as a new kind of collaborative workspace and uninhibited idea factory, have taken off around the country and now, around the world, with new ones in London, U.K., and Yokosuka, Japan.

Too often, projects fail to move from advanced technology development to component development and prototyping. Bureaucracy and complacency are powerful and omnipresent, poised to grab onto promising projects and stymy them. We must overcome these obstacles—go around them, over them, and do whatever it takes to defeat them. I do not have all the answers on how to do that, but we are making progress and eagerly looking to new ways of doing business. If you have a great idea, the Naval Research Enterprise wants to talk with you.

As I meet with thought leaders around the country, including author and entrepreneur Safi Bahcall, MIT lecturer and author Steven Spear, process guru Steve Blank at Stanford, and other brilliant folks from government, industry and academia, I am hearing excitement about what ONR is trying to do and agreement that the time to act is now.

As it has for 75 years, ONR is pursuing the future with a sense of determination, and optimism. Yes, our adversaries are moving quickly, fielding new technologies and weapons faster than they have ever been. But ONR is answering the challenge with a sense of optimism. Working with civilian universities, industry large and small, other government labs, and our allies, we will continue to provide the technological edge that allows the U.S. Navy and Marine Corps to adapt, survive, and win.