

# NAVAL SCIENCE AND TECHNOLOGY FUTURE FORCE™

SUMMER 2016

JOIN EXPLORER DON  
WALSH ON HIS HISTORIC  
1960 DIVE

TALES OF DISCOVERY:  
ONR AT 70

POWDER AND  
PROPELLANTS: A CENTURY  
OF BRINGING THE BOOM



# 70 YEARS

OF  
NAVAL SCIENCE  
AND  
TECHNOLOGY





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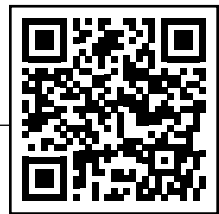
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The summer of 1946 was a time of transitions. The last week of July had brought the second of two atomic bomb tests at Bikini Atoll in the central Pacific. Violence in Palestine and British India that summer foreshadowed the soon-to-be violent births of the modern states of Israel, India, and Pakistan. And there was a new awareness of a coming conflict, when several months before former British Prime Minister Winston Churchill had declared that an “iron curtain” had descended over Europe.

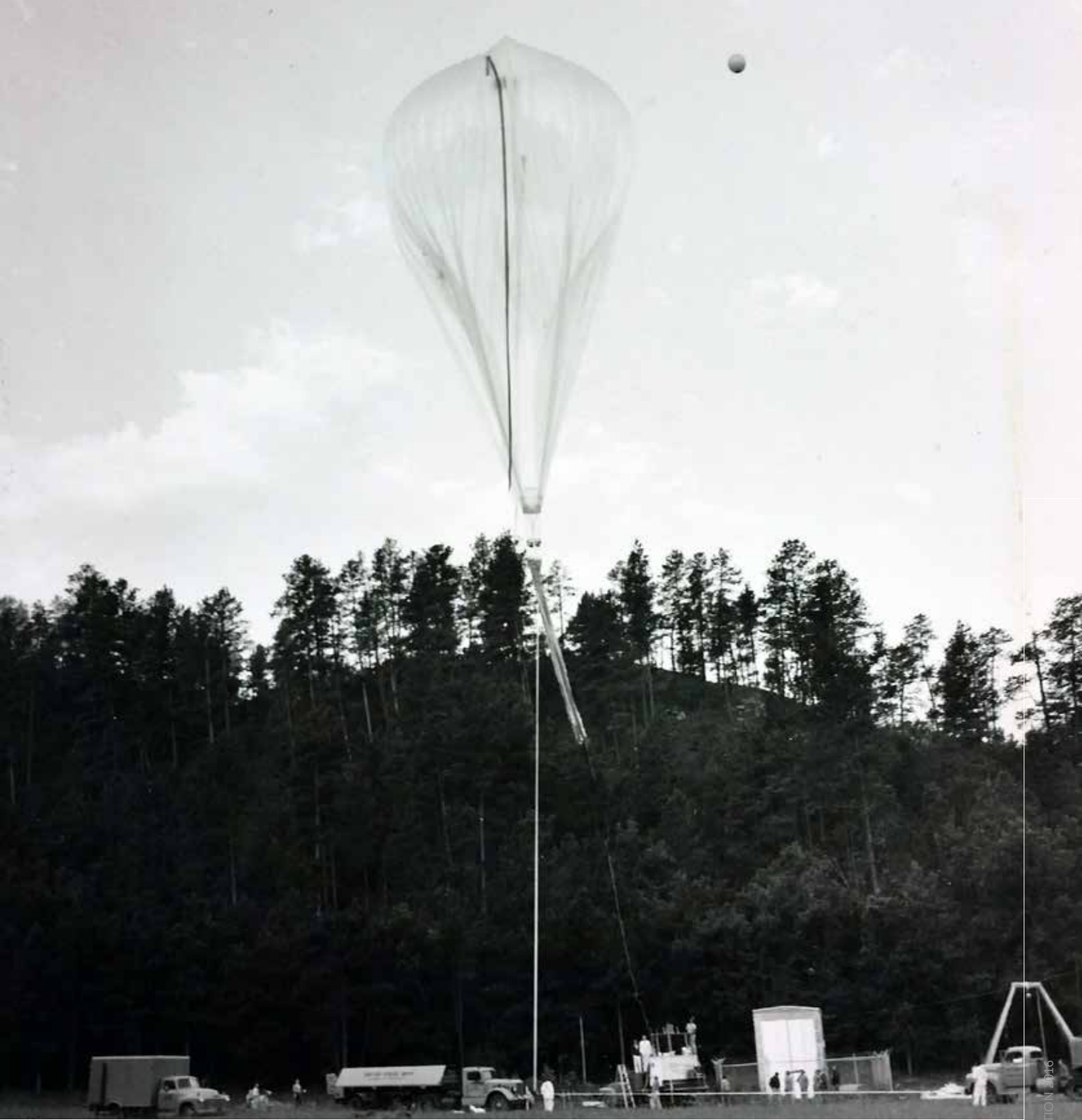
In the midst of this, on 1 August, President Harry S. Truman signed Public Law 588, establishing the Office of Naval Research (ONR). The organization was not technically new—the Navy itself had established it a year before under the title of Office of Research and Inventions—but the congressional action legitimated the office as a permanent peacetime agency. ONR also was neither the first government nor the first military science and technology organization. There was a long history of federal support for science through a number of wartime and peacetime agencies going back to the Civil War and even earlier. What was new about ONR was that it supported civilian science outside of government while working for military outcomes, in times of war or peace. The paradigm under which it operated had been pioneered during World War II by the Office of Scientific Research and Development—but Truman’s signature made this model a permanent fixture.

This year we celebrate 70 years of ONR and its contributions to the development of the modern US Navy and Marine Corps, as well as to the progress of American and global science and technology. ONR has supported countless advancements in science—from improving our understanding of how electrons behave to the development of new materials stronger than steel—as well as numerous innovations in technology—from creating one of the earliest computers to building the first atomic clocks. More than this, however, ONR has changed how science and technology get done. By acting as a channel for federal money to academia and industry, ONR has helped bring about the tremendous growth of science that has occurred since World War II. And by acting as the leader for basic research in the Department of the Navy, ONR has played a vital part in coordinating the efforts of a vast Naval Research and Development Enterprise dedicated to keeping the Navy and Marine Corps at the cutting edge of technology.

Presented in this issue of *Future Force* is a selection of articles that commemorate ONR’s achievements, as well as highlight the contributions of other naval science and technology organizations that all have been transformed in the wake of the decision 70 years ago to establish the Office of Naval Research.

EDITOR’S NOTE: The current and future issues of *Future Force* magazine will be available only online at <http://futureforce.navylive.dodlive.mil>. A print edition of the magazine occasionally may be produced in the future for certain special events.

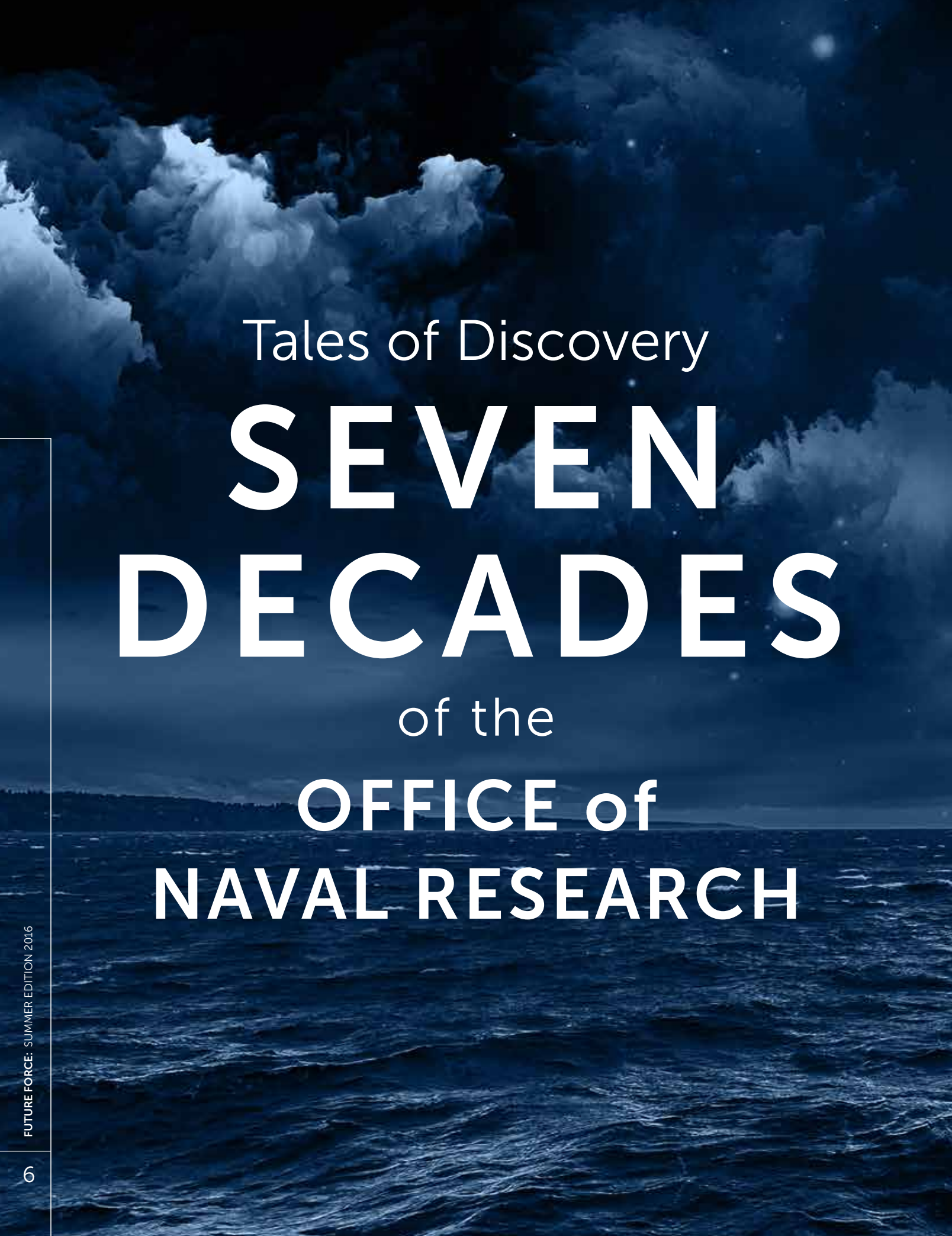
**Colin Babb is a contractor serving as the historian for the Office of Naval Research, and is the managing editor of *Future Force*.**



## 70 Years of Naval Science and Technology

An open basket tethered to a high-altitude balloon is prepared for flight at a location near Rapid City, South Dakota, on 7 August 1959 as part of Operation Strato-Lab. The flight would include a "coronagraph," used for observing the sun. This flight was one of a series in the late 1950s and early 1960s that culminated in a record-breaking ascent of 113,740 feet in May 1961.



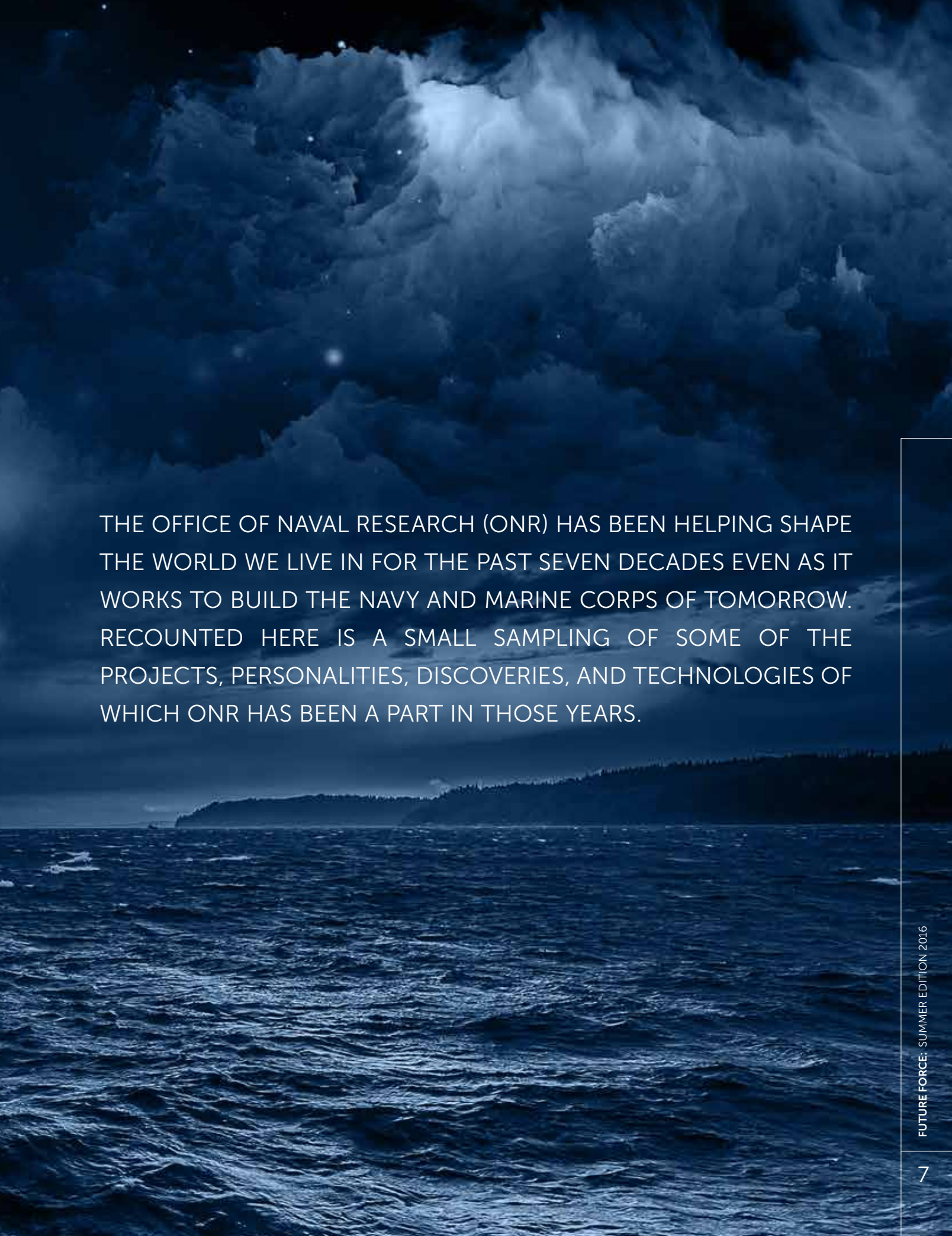


Tales of Discovery

# SEVEN DECADES

of the

# OFFICE of NAVAL RESEARCH

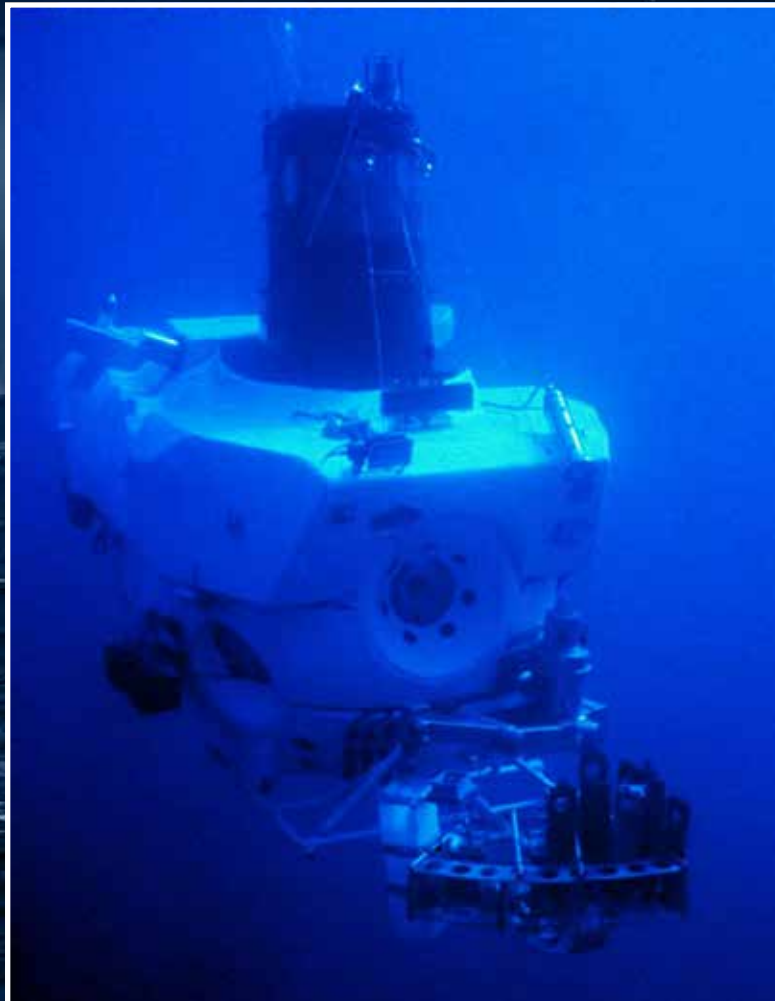


THE OFFICE OF NAVAL RESEARCH (ONR) HAS BEEN HELPING SHAPE THE WORLD WE LIVE IN FOR THE PAST SEVEN DECADES EVEN AS IT WORKS TO BUILD THE NAVY AND MARINE CORPS OF TOMORROW. RECOUNTED HERE IS A SMALL SAMPLING OF SOME OF THE PROJECTS, PERSONALITIES, DISCOVERIES, AND TECHNOLOGIES OF WHICH ONR HAS BEEN A PART IN THOSE YEARS.

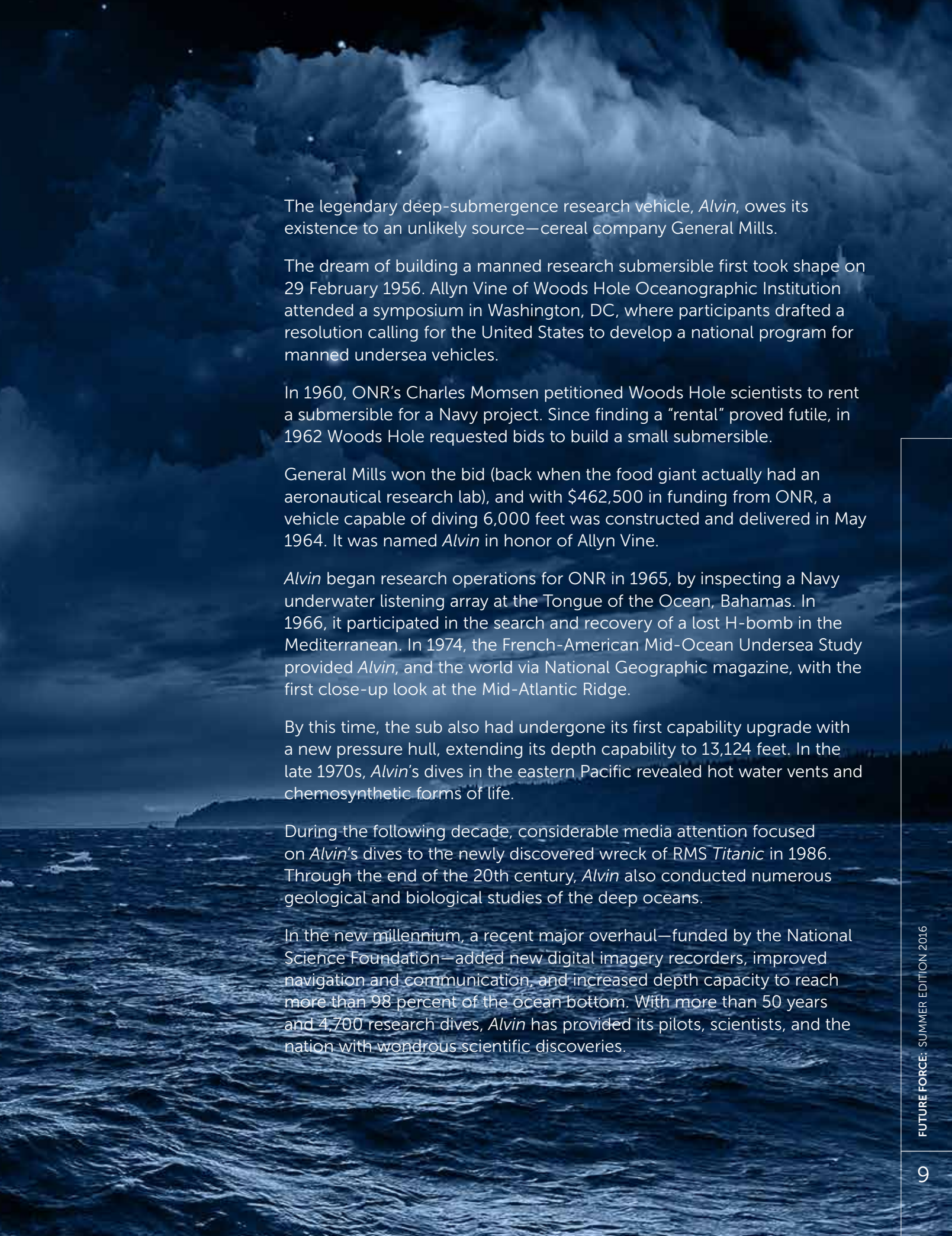


# DEEP SUBMERGENCE VEHICLE ALVIN

*Some of the most important undersea scientific discoveries of the past 50 years have been because of the little manned submersible Alvin.*







The legendary deep-submergence research vehicle, *Alvin*, owes its existence to an unlikely source—cereal company General Mills.

The dream of building a manned research submersible first took shape on 29 February 1956. Allyn Vine of Woods Hole Oceanographic Institution attended a symposium in Washington, DC, where participants drafted a resolution calling for the United States to develop a national program for manned undersea vehicles.

In 1960, ONR's Charles Momsen petitioned Woods Hole scientists to rent a submersible for a Navy project. Since finding a "rental" proved futile, in 1962 Woods Hole requested bids to build a small submersible.

General Mills won the bid (back when the food giant actually had an aeronautical research lab), and with \$462,500 in funding from ONR, a vehicle capable of diving 6,000 feet was constructed and delivered in May 1964. It was named *Alvin* in honor of Allyn Vine.

*Alvin* began research operations for ONR in 1965, by inspecting a Navy underwater listening array at the Tongue of the Ocean, Bahamas. In 1966, it participated in the search and recovery of a lost H-bomb in the Mediterranean. In 1974, the French-American Mid-Ocean Undersea Study provided *Alvin*, and the world via National Geographic magazine, with the first close-up look at the Mid-Atlantic Ridge.

By this time, the sub also had undergone its first capability upgrade with a new pressure hull, extending its depth capability to 13,124 feet. In the late 1970s, *Alvin*'s dives in the eastern Pacific revealed hot water vents and chemosynthetic forms of life.

During the following decade, considerable media attention focused on *Alvin*'s dives to the newly discovered wreck of RMS *Titanic* in 1986. Through the end of the 20th century, *Alvin* also conducted numerous geological and biological studies of the deep oceans.

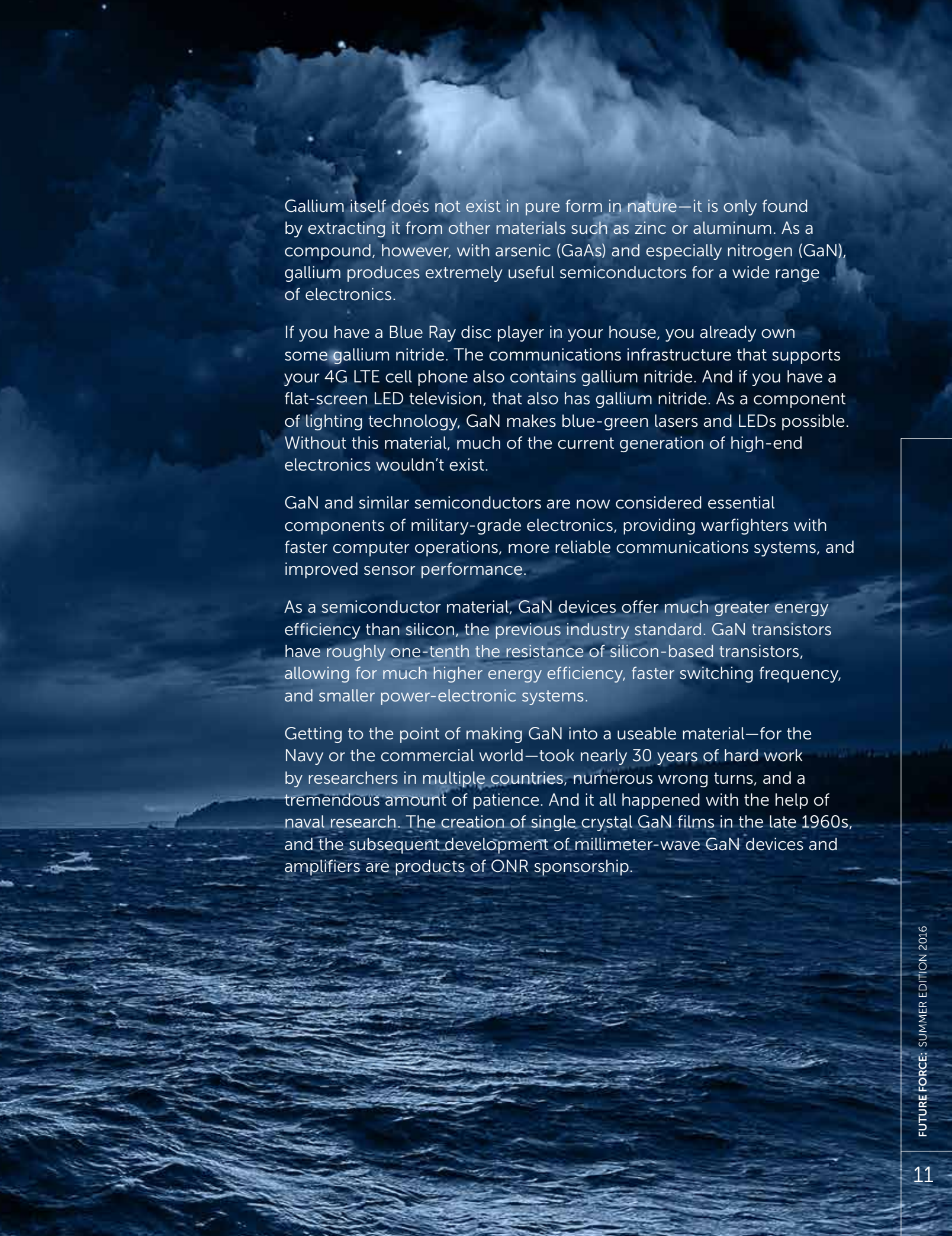
In the new millennium, a recent major overhaul—funded by the National Science Foundation—added new digital imagery recorders, improved navigation and communication, and increased depth capacity to reach more than 98 percent of the ocean bottom. With more than 50 years and 4,700 research dives, *Alvin* has provided its pilots, scientists, and the nation with wondrous scientific discoveries.

# Gallium Nitride and Seeing the World in Blue-Green

*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 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 Blue Ray disc player in your house, you already own some gallium nitride. The communications infrastructure that supports your 4G LTE 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.

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 useable material—for the Navy or the commercial world—took nearly 30 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 ONR sponsorship.

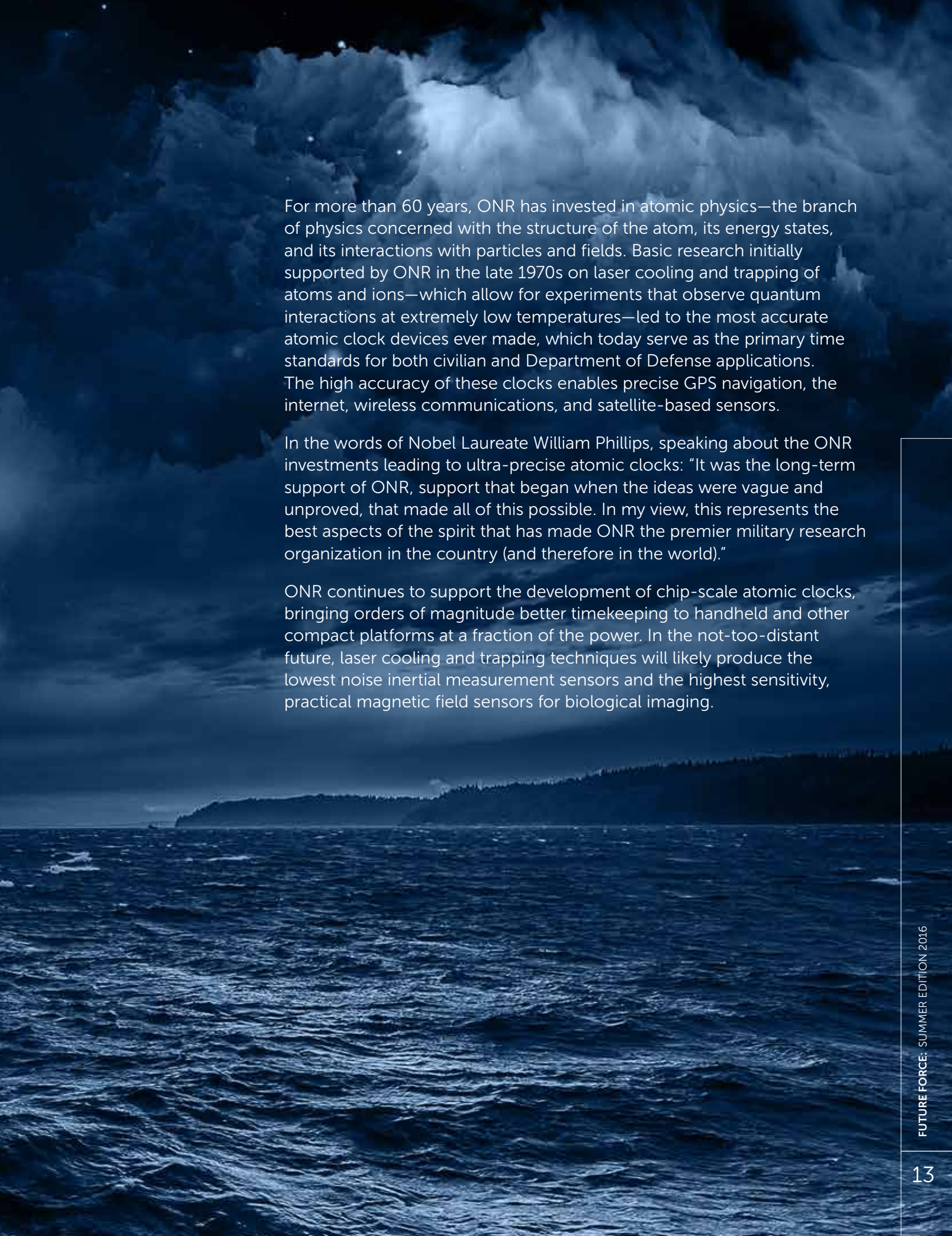


# Atomic Physics and the World's Most Accurate Timekeeping

*Greater understanding of atomic physics at the quantum level has led to the creation of our most accurate clocks—which in turn have made possible everything from satellite navigation to the internet.*







For more than 60 years, ONR 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. 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.



# SEALAB Manned Undersea Habitat

*As NASA launched its effort to reach the moon, ONR spearheaded attempts in the 1960s to show that humans could live and work at the bottom of the ocean.*







In a parallel to the “Space Race,” ONR led biomedical studies in what would become known as the SEALAB undersea habitat.

SEALAB I was lowered into the water at the US 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. American astronaut and aquanaut Scott Carpenter spent a record 30 days in this submerged world.

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 their many pioneering efforts, the team investigated the effects of nitrogen narcosis on cognition, tested diver warming with the new foam wet suit and developed a method to compensate for the high-pitched 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. ONR’s SEALAB expeditions vastly advanced the operational capabilities of saturation diving and submarine rescue. Thanks to this research, submarines such as the USS Parche (SSN 683) and USS Halibut (SSN 587) were able to tap into undersea Soviet communication cables.

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 is a direct descendent 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 technological and pharmaceutical interventions that both expand the operational envelope and increase survivability in emergency situations such as submarine rescue.



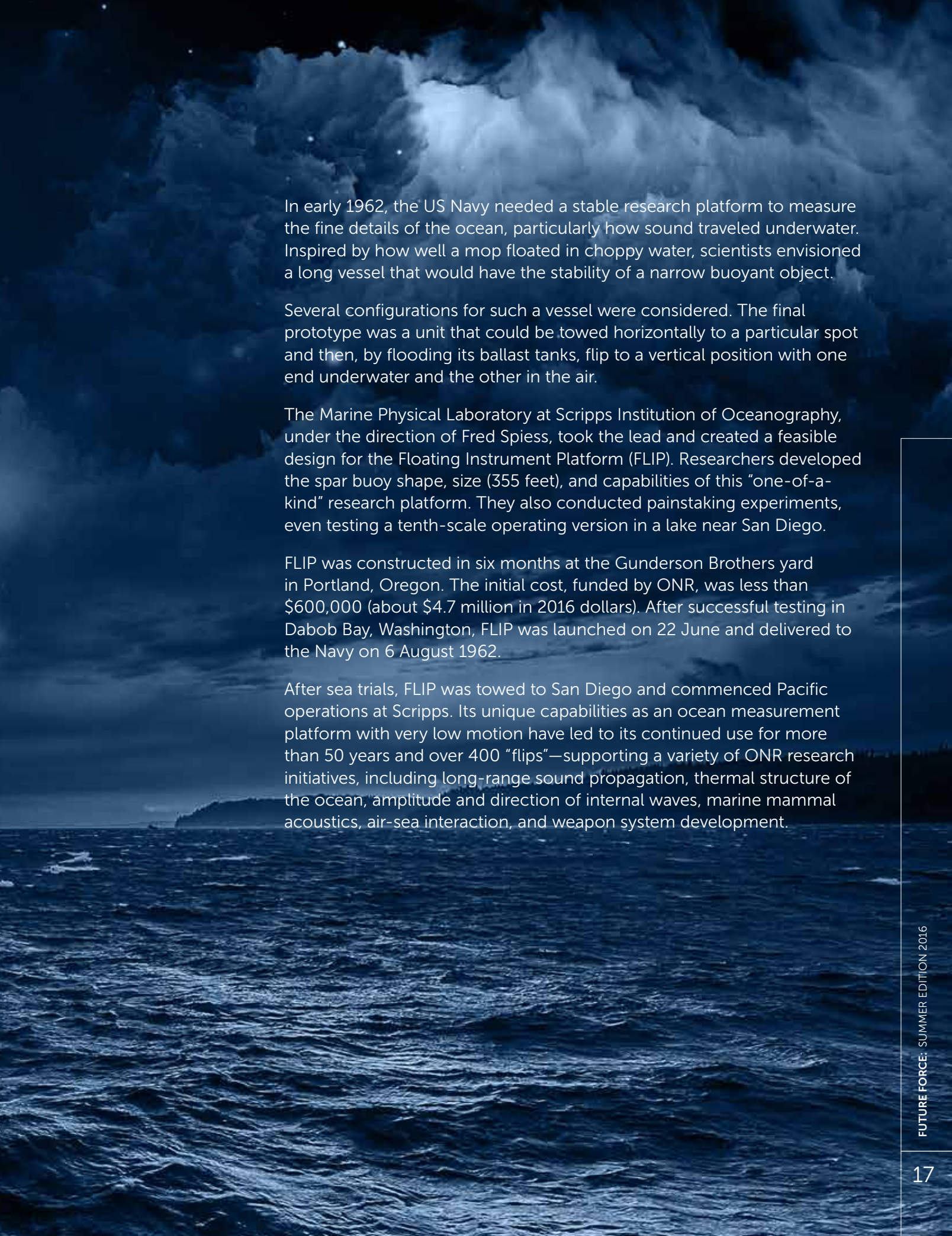
# Floating Instrument Platform—FLIP

*One of the most unusual sea-going vessels ever constructed has been helping several generations of researchers uncover the ocean's secrets for more than five decades.*

Photo by John F. Williams







In early 1962, the US Navy needed a stable research platform to measure the fine details of the ocean, particularly how sound traveled underwater. Inspired by how well a mop floated in choppy water, scientists envisioned a long vessel that would have the stability of a narrow buoyant object.

Several configurations for such a vessel were considered. The final prototype was a unit that could be towed horizontally to a particular spot and then, by flooding its ballast tanks, flip to a vertical position with one end underwater and the other in the air.

The Marine Physical Laboratory at Scripps Institution of Oceanography, under the direction of Fred Spiess, took the lead and created a feasible design for the Floating Instrument Platform (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.

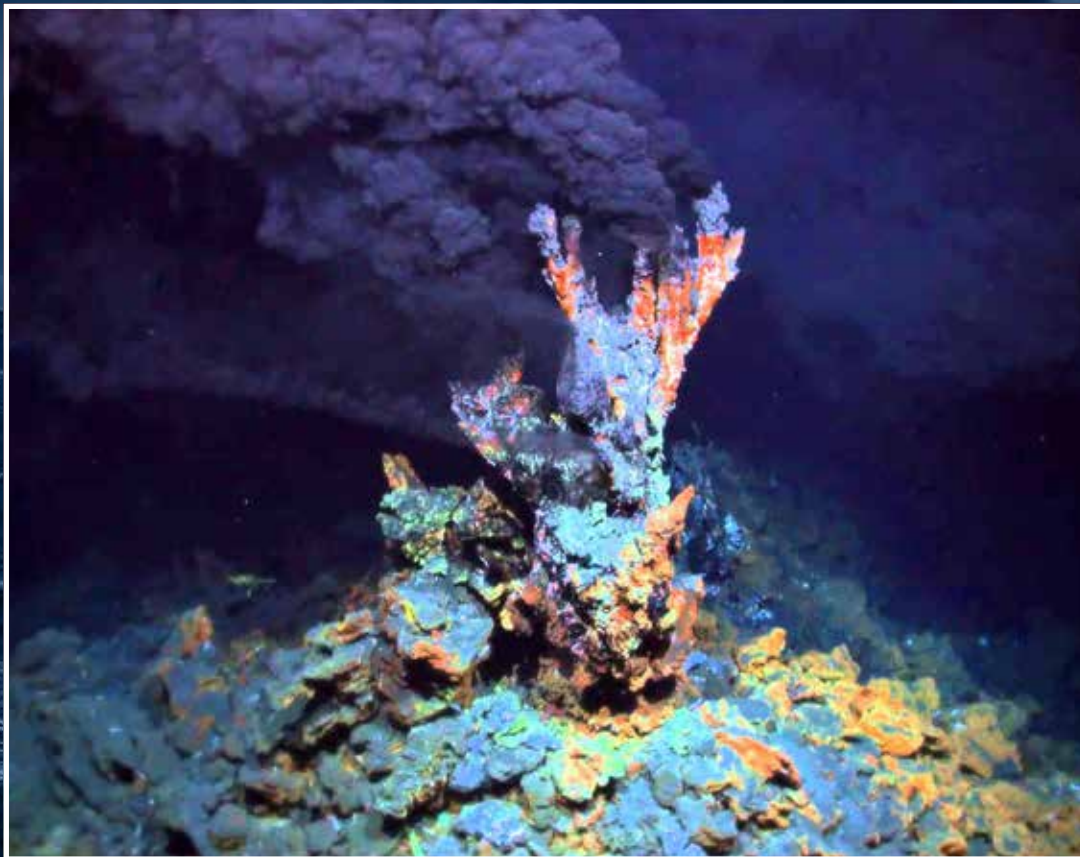
FLIP was constructed in six months at the Gunderson Brothers yard in Portland, Oregon. The initial cost, funded by ONR, was less than \$600,000 (about \$4.7 million in 2016 dollars). After successful testing in Dabob Bay, Washington, FLIP was launched on 22 June and delivered to the Navy on 6 August 1962.

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 have led to its continued use for more than 50 years and over 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.

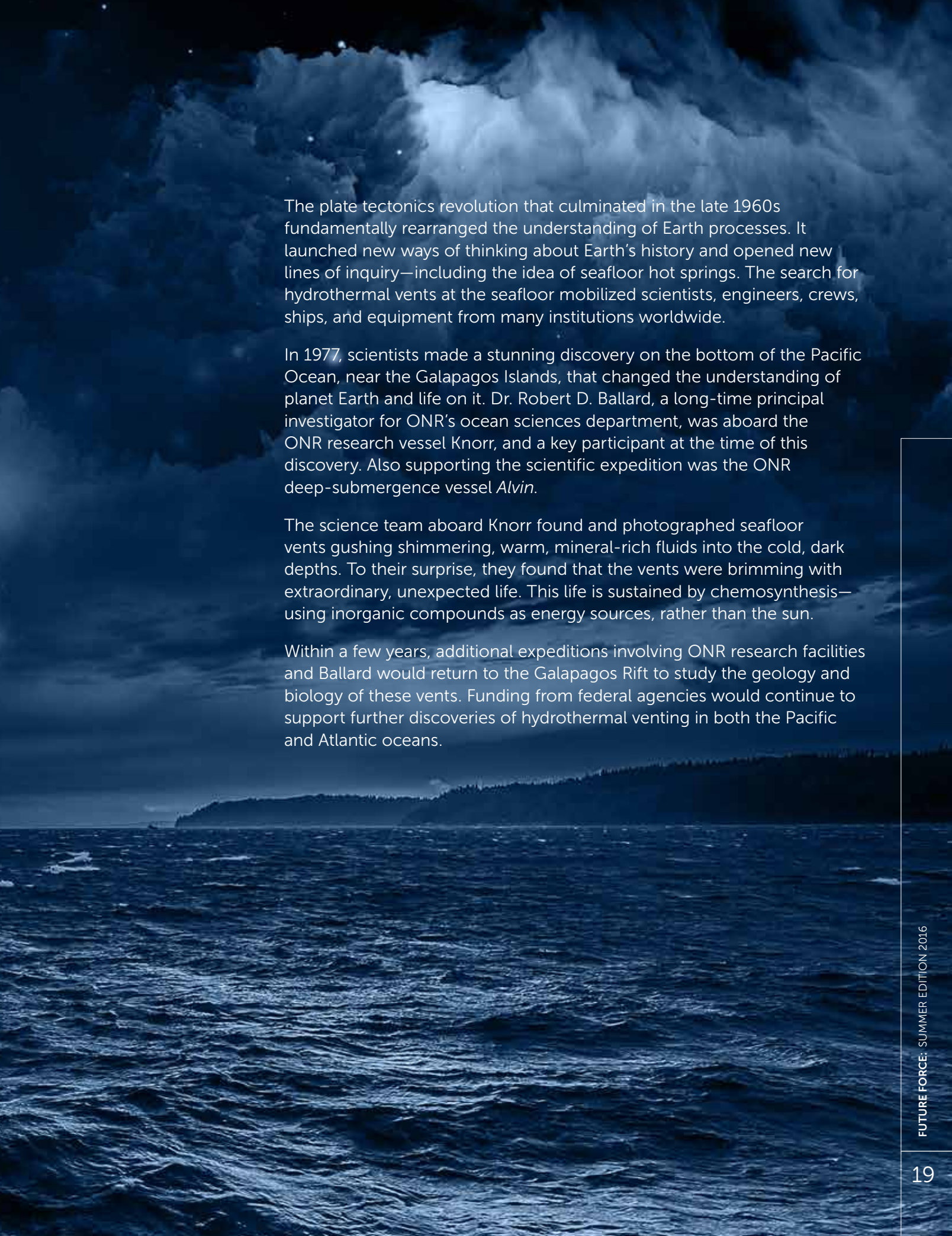


# The Discovery of Hydrothermal Vents

*The idea that life could be sustained by inorganic compounds, rather than through photosynthesis, was a 90-year-old theory until researchers discovered unique life at the bottom of the ocean.*







The plate tectonics revolution that culminated in the late 1960s fundamentally rearranged the understanding of Earth processes. It launched new ways of thinking about Earth's history and opened new lines of inquiry—including the idea of seafloor hot springs. The search for hydrothermal vents at the seafloor mobilized scientists, engineers, crews, ships, and equipment from many institutions worldwide.

In 1977, scientists made a stunning discovery on the bottom of the Pacific Ocean, near the Galapagos Islands, that changed the understanding of planet Earth and life on it. Dr. Robert D. Ballard, a long-time principal investigator for ONR's ocean sciences department, was aboard the ONR research vessel *Knorr*, and a key participant at the time of this discovery. Also supporting the scientific expedition was the ONR deep-submergence vessel *Alvin*.

The science team aboard *Knorr* found and photographed seafloor vents gushing shimmering, warm, mineral-rich fluids into the cold, dark depths. To their surprise, they found that the vents were brimming with extraordinary, unexpected life. This life is sustained by chemosynthesis—using inorganic compounds as energy sources, rather than the sun.

Within a few years, additional expeditions involving ONR research facilities and Ballard would return to the Galapagos Rift to study the geology and biology of these vents. Funding from federal agencies would continue to support further discoveries of hydrothermal venting in both the Pacific and Atlantic oceans.




# Project Whirlwind and the Dawn of Digital 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.*







Up to the 1940s, mechanical—or analog—computers were incorporated in a number of calculating devices, most especially in military equipment such as naval fire control systems on 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 accurately portray the precise movements of modern aircraft. Project managers began exploring the possibility of using faster digital computers to control the system—but they would have to build their own computer from scratch.

Beginning at the Massachusetts Institute of Technology in late 1944, Whirlwind became one of the earliest projects of the Navy's Office of Research and Inventions—what would soon become ONR. While the more famous “first” computers—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, Whirlwind was among the first attempts to apply digital computing directly to the 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.

Faced with the prospect of developing a computer without an apparent 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 would become by the end of the 1950s the world's first strategic defense network. SAGE integrated global early warning radar data into a single system, becoming the digital heart of NORAD based at Cheyenne Mountain, Colorado.

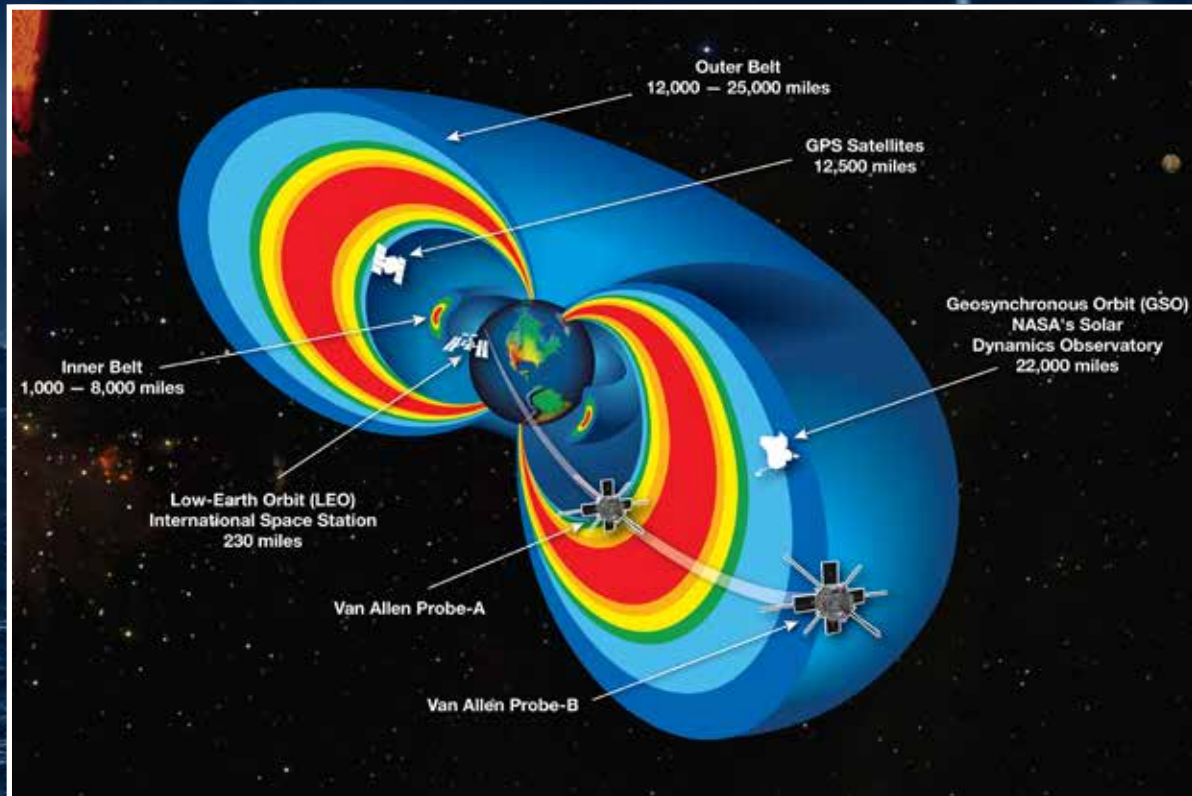
Whirlwind advanced the state of the art of digital computers so far in the 1950s and 1960s that much of current digital computing owes a debt to this early project.



# The Van Allen Radiation Belts and Spaceflight

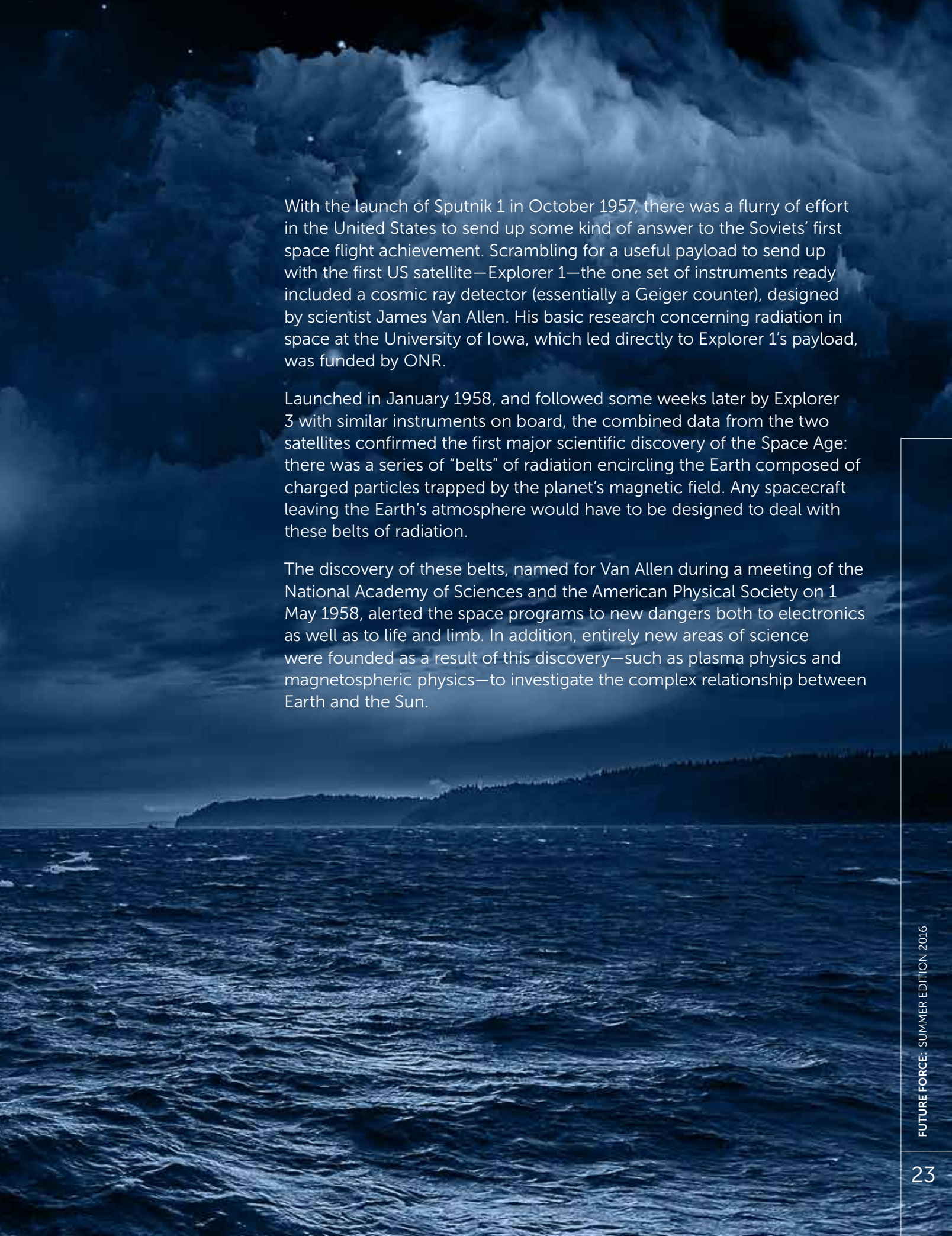
*Discovered by some of the earliest spacecraft in the late 1950s, knowledge of these belts of charged particles surrounding the earth helped in the design of safe manned craft and satellites.*

Photo by NASA



This shows a general view of the Van Allen belts around the earth, as well the positions of several satellites and probes within the belts.





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 US satellite—Explorer 1—the one set of instruments ready included a cosmic ray detector (essentially a Geiger counter), designed by scientist 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 ONR.

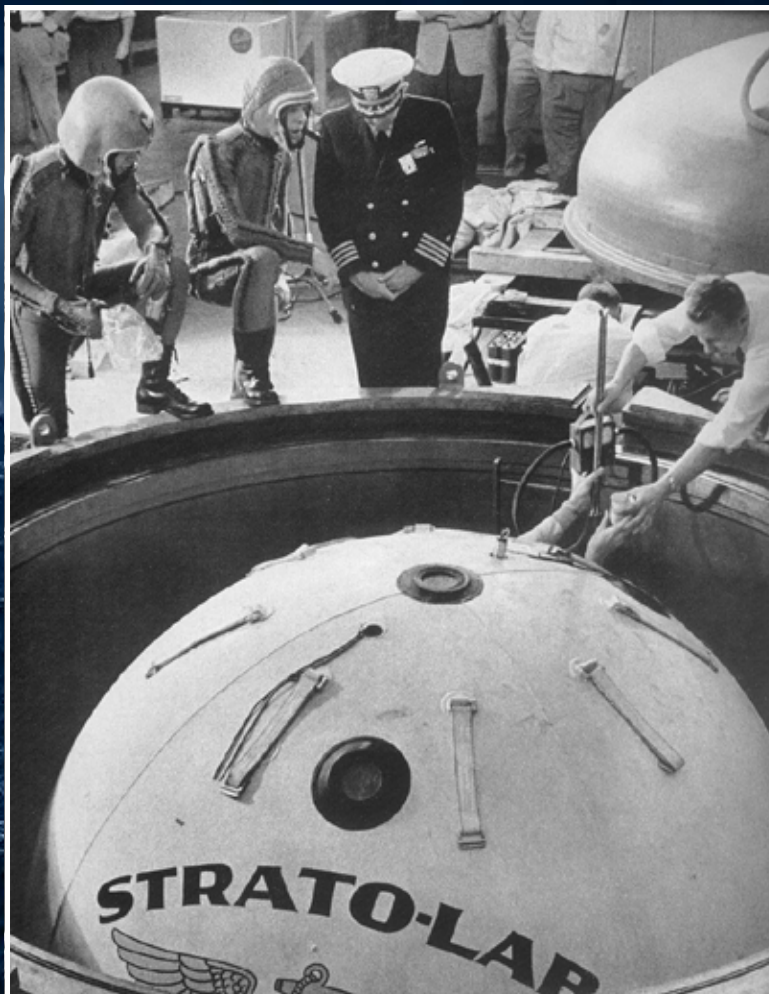
Launched in January 1958, and followed some weeks later by Explorer 3 with similar instruments on board, the combined data from the two satellites confirmed the first major scientific discovery of the Space Age: there was a series of "belts" of radiation encircling the Earth composed of charged particles 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.

The discovery of these belts, named for Van Allen during a meeting of the National Academy of Sciences and the American Physical Society on 1 May 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 Earth and the Sun.

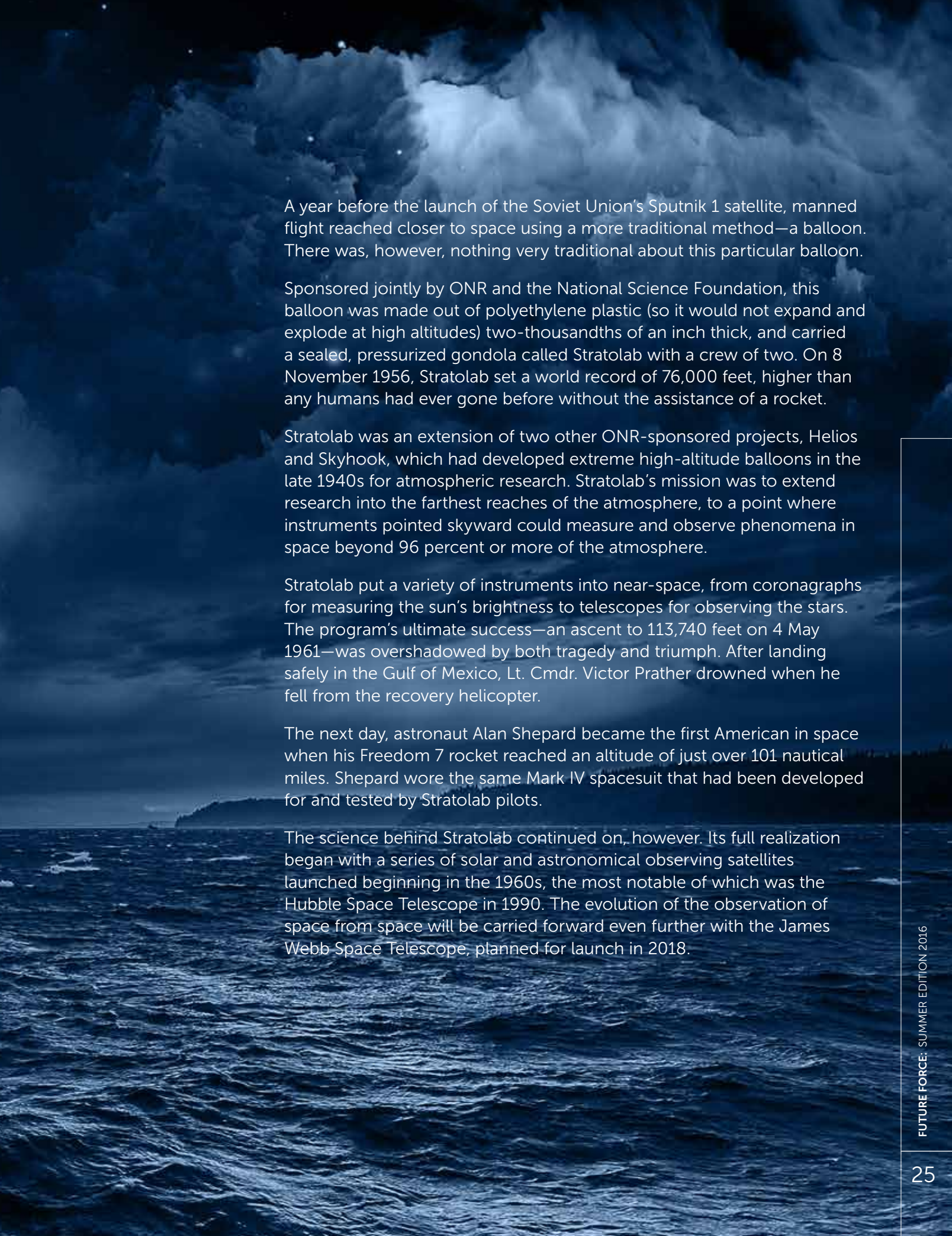


# High-Altitude Balloons Take First Steps toward Space

*Experiments with balloons in the 1940s and 1950s took human beings higher than ever, bringing with them space-observing scientific instruments.*







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.

Sponsored jointly by ONR 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 8 November 1956, Stratolab set a world record of 76,000 feet, higher than any humans had ever gone before without the assistance of a rocket.

Stratolab was an extension of two other ONR-sponsored 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 coronagraphs 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.

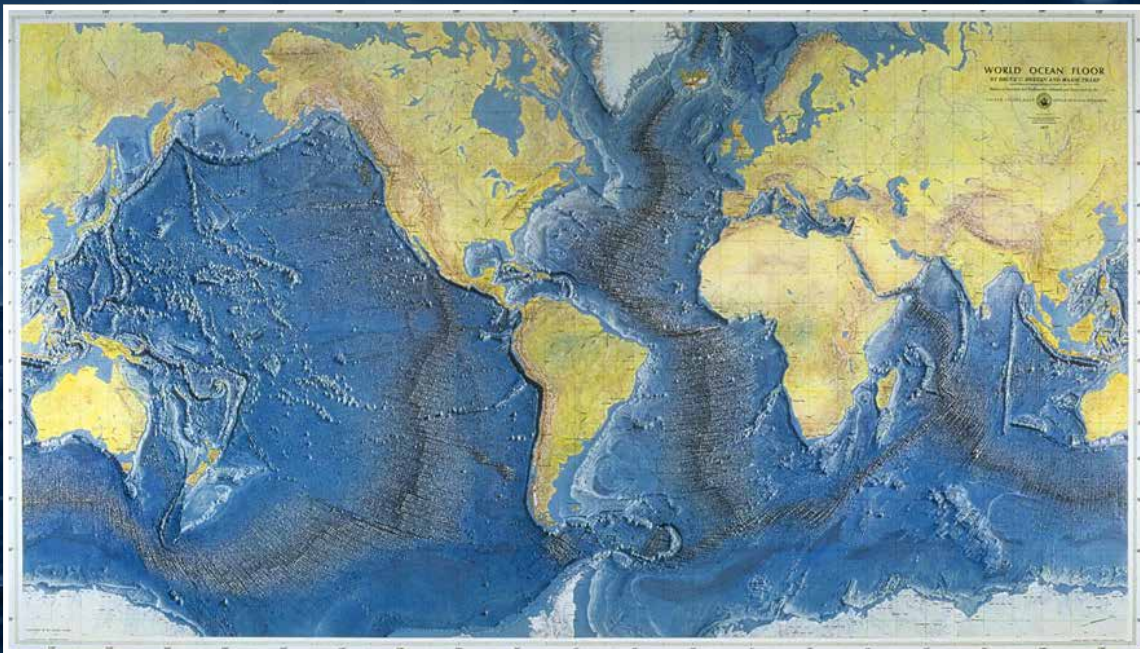
The science behind Stratolab continued on, however. Its full realization began with a series of solar and astronomical observing satellites launched beginning in the 1960s, the most notable of which was the Hubble Space Telescope in 1990. The evolution of the observation of space from space will be carried forward even further with the James Webb Space Telescope, planned for launch in 2018.



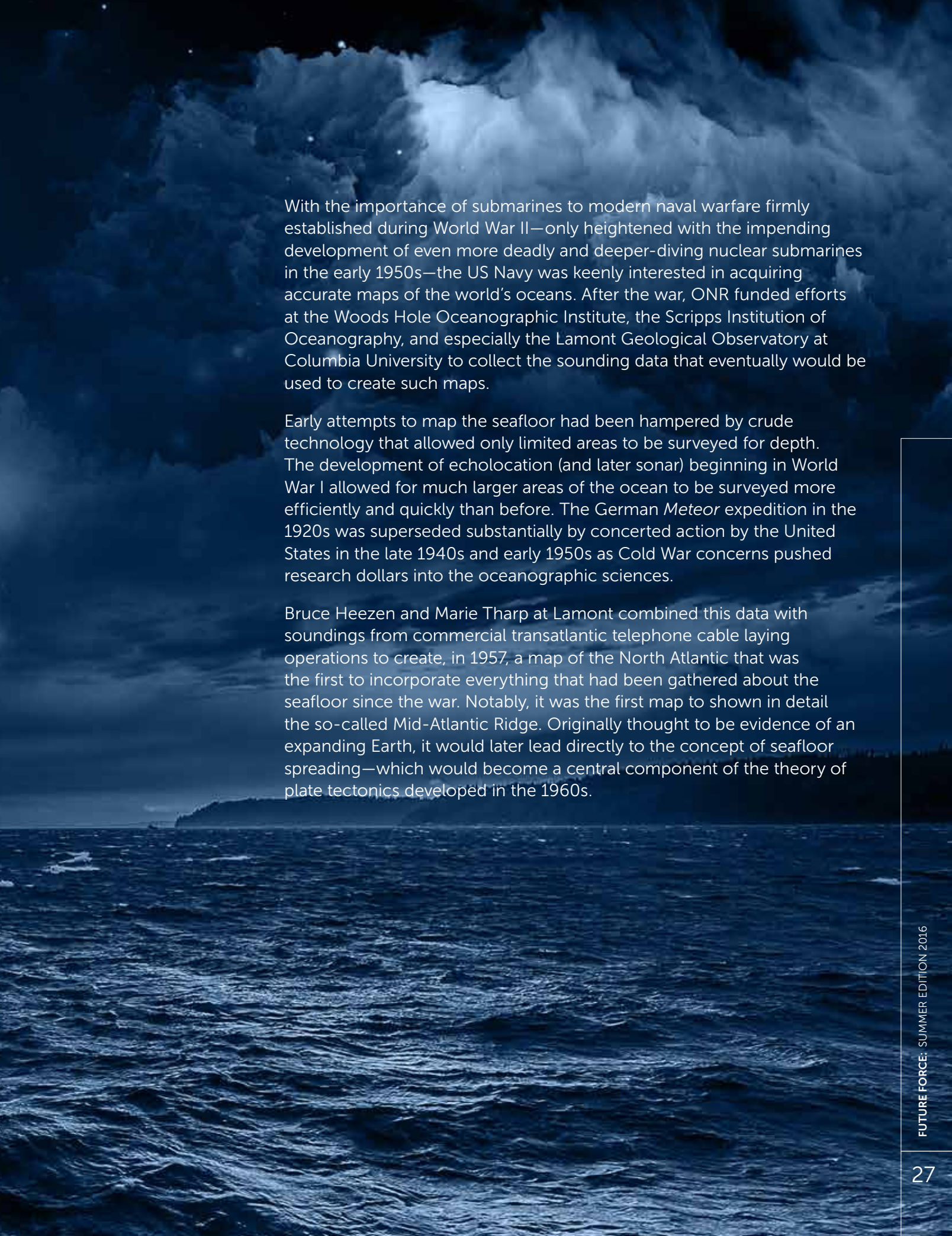
# Seafloor Mapping and the Rise of Plate Tectonics

*The first detailed map of the ocean's bottom in 1957 helped revolutionize our understanding of the geology of the seafloor—and contributed directly to the development of the theory of plate tectonics.*

Photo by Columbia University







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

Early attempts to map the seafloor had been hampered by crude technology that allowed only limited areas to be surveyed for depth. The development of echolocation (and later sonar) beginning in World War I allowed for much larger areas of the ocean to be surveyed more efficiently and quickly than before. The German *Meteor* expedition in the 1920s was superseded substantially by concerted action by the United States in the late 1940s and early 1950s as Cold War concerns pushed research dollars into the oceanographic sciences.

Bruce Heezen and Marie Tharp at Lamont combined this data with soundings from commercial transatlantic telephone cable laying operations to create, in 1957, 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 shown in detail the so-called Mid-Atlantic Ridge. Originally thought to be evidence of an expanding Earth, it would later lead directly to the concept of seafloor spreading—which would become a central component of the theory of plate tectonics developed in the 1960s.





**“IT WAS JUST A  
LONGER DAY AT  
THE OFFICE”:**

# **AN ORAL HISTORY WITH DON WALSH**



On 23 January 1960, while aboard the bathyscaphe *Trieste*, Navy Lt. Don Walsh and Swiss engineer Jacques Piccard descended to the deepest depths of the world ocean in the Challenger Deep several hundred miles from the Pacific island of Guam. An important watershed event in the history of the then nearly 14-year-old Office of Naval Research (ONR), *Trieste's* record-setting dive of more than 35,800 feet epitomized the organization's approach of fostering the creation of cutting-edge technology while also making advancements in science.

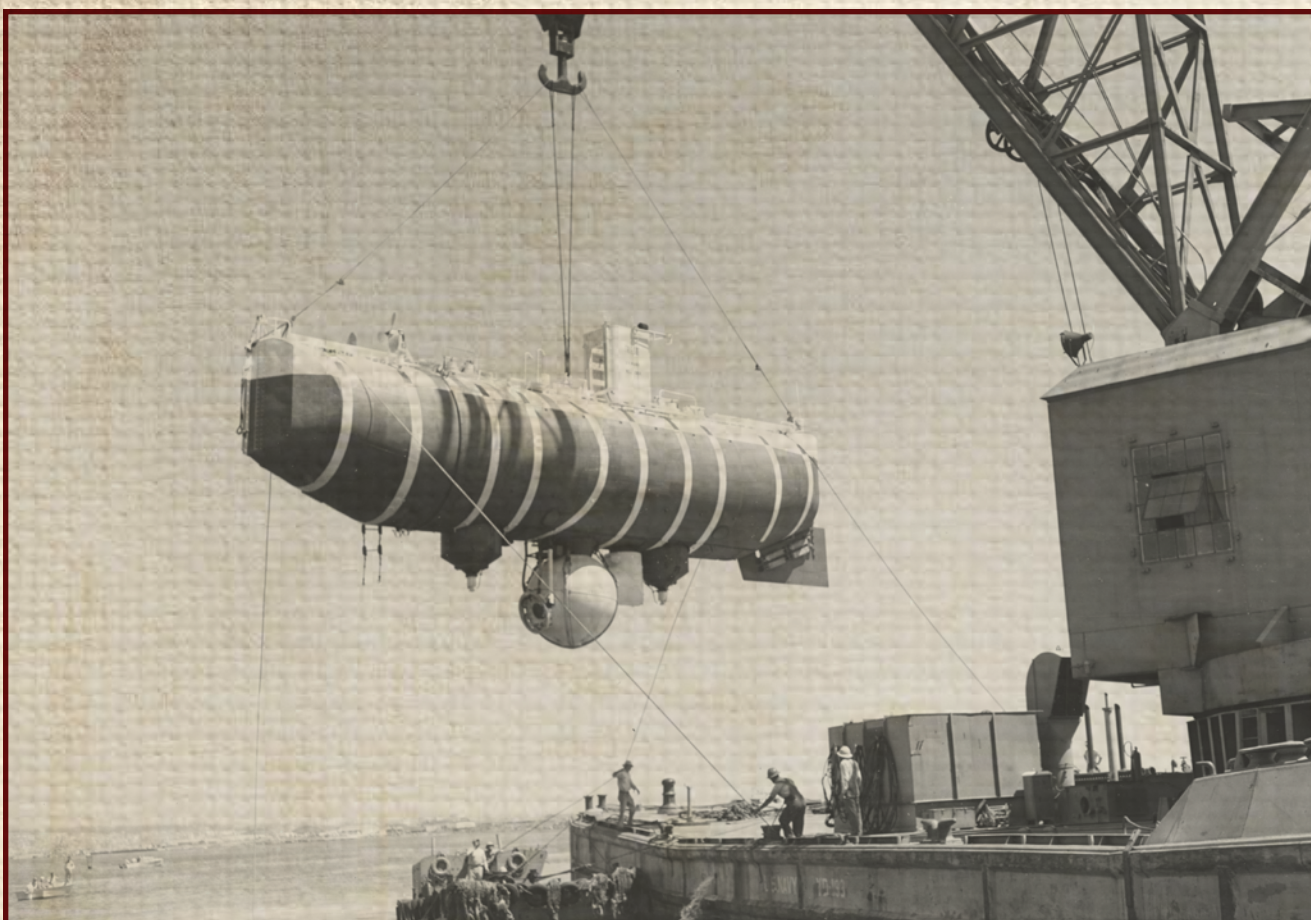
The project was several years in the making. *Trieste* was designed by Piccard's father, Auguste, in the early 1950s to continue the Piccard family's experiments in deep diving after many years of record-breaking work with high-altitude balloons. After meeting with Jacques Piccard in 1955, a scientist associated with ONR's London office, Robert Dietz, took an interest in the *Trieste* and later arranged for the purchase of the deep-diving craft for the US Navy in 1958. Originally designed for the relatively modest depths of the Mediterranean, a special crew sphere was constructed for *Trieste* by Krupp Steel Works in Germany, which would allow the craft to dive much deeper in the descents planned for it in the Pacific with the Navy. Codenamed Project Nekton, the dives at the end of 1959 and early 1960 that culminated at the Challenger Deep were meant to test the viability of using manned craft at extreme depths to study marine life, the propagation of sound, and other scientific questions.

Presented below is a partial transcript of the more than six-hour oral history of Don Walsh conducted by ONR historian Colin Babb in November 2014. This excerpt recounts Walsh's famous dive more than 55 years ago. It begins with Navy leaders attempting to keep the news of the impending deep dive from the public until success had been achieved. In addition to Walsh and Piccard, the team also included Walsh's assistant, Lt. Lawrence Shumaker, and Dr. Andreas "Andy" Rechnitzer, a scientist with the Navy Electronics Laboratory in San Diego, the *Trieste's* home base.



After their record-setting dive, Lt. Don Walsh and Jacques Piccard went to the White House, where they received awards from President Dwight Eisenhower.





On 2 October 1959, *Trieste* was loaded on the freighter *Santa Maria* at the Naval Electronics Laboratory in San Diego, California, for the trip to the mid-Pacific.

**Don Walsh:** We went out in January [1960] then, our next dive was off of Guam to a depth of 24,000 feet. Everything seemed to be working well. So then after that why don't we go out and do the deepest dive? But the story was too good not to tell around the old water cooler back at the lab, because the civilians were rotating in and out—you couldn't expect them to stay out there for seven months. So they would come out for two or three months, then go home and be replaced by [...] from the lab. And it was just a really great story—you know brag on and on. So nobody ratted us out, but eventually the story got up to topside from the waterfront to the topside, the main office. And of course there was a lot constantly, 'why weren't we told this....?' But they didn't say anything. But the day of the deep dive we get a radio message from the Navy lab, saying 'project canceled, come home.' We're at sea, I'm on board the *Trieste* with Piccard, we're just getting ready to start the dive. The radioman brings this message to Andy Rechnitzer, and he's sitting there

with [Chief] Jon Michel, and he puts it in his pocket, and he says, 'Jon, let's go have a cup of coffee.' So they went to the wardroom, and drank some coffee, and they've reported that the sub has begun the dive. And he said, 'Well, I guess we better go up and return the message.' So he said, 'Unable to comply, *Trieste* passing 10,000 feet.' What happened is they had found out about this and they lost their nerve. But it was too late, because Andy sequestered the radio message in his pocket for a while.

**Colin Babb:** Right, well talking about Nelson's eye [at the Battle of Copenhagen in 1801], that is exactly....

**DW:** The same thing. But you know we got back after the deep dive, back to San Diego, we couldn't find anybody that said we told you not to do this. Because we were going to do a second dive, and Bob Dietz would be going. The first dive would be myself and Andy, and then it turns out that Piccard had a contract with ONR, which



we had not seen, which guaranteed him the right to be on board the *Trieste* for any dive that was unusual. Well every dive in a bathyscaphe is unusual, what are you talking about? There's no routine.

**CB:** Well, he intended it that way, he wanted to be on it.

**DW:** I know, but it would've been nice if we'd known about it. Now the lab claimed that they didn't even know about this, our lab. Remember, the Naval Electronics Laboratory in San Diego would say it belonged to the Bureau of Ships, BuShips, it was not an ONR lab. ONR only has one lab, that's the NRL. But all our funding flowed through NEL to where we were.

**CB:** Right. Now is NEL the predecessor of what is now SPAWAR, or was it something...

**DW:** Yeah, it became the Naval Undersea Center, Naval something-else center, and then it was folded into SPAWAR San Diego. Anyway, so we were going to do the first dive with Andy and myself; I pilot, Andy would be the science on board. Second dive we would have Bob Dietz and probably Larry Shumaker. But that didn't work. First of all we found out you can't recycle the bathyscaphe at

sea, it was just too rough, because you have to put more ballast shot in and a little bit of gas to make up for what it's lost during the dive. And your air-scrubber canisters, CO<sup>2</sup> absorbent and all of that, and charging the batteries, all takes time and a fairly stable situation. We had gone back into port, done all that, come back out. When we got back into port...well, before we even got back into port we were ordered to come to Washington to brief people on what we had done. Because now it's a pretty big deal. For a brief period of time it's very newsworthy and all of that. So clearly we had to go back and explain to our masters what we did, testified at hearings at the House and the Senate, and a whole lot of admirals, and one very relieved Arleigh Burke. Because he'd rolled the dice with us, just like ONR rolled the dice with us. He figured, well these guys are yelling...but they could probably do it. And we did it. And so he was pretty happy about that. In fact ten years later we had a tenth anniversary luncheon celebrating the deep dive at the Navy Yard, Washington Navy Yard, in the officers' club. And he had since retired, of course, and I sat next to him at lunch. And I said, 'Admiral, remember what you told me in your office about Shumaker? ('I'm going to have his balls if you don't come up') And he looked at me and said, 'I didn't say that.' I said, 'Admiral, when a four-star admiral tells a lieutenant something like that, it is tattooed on my brain.' He smiled and he said, 'I guess I did.' He was a great man.

Anyway, one day when they sent a Navy car, CHINFO was kind of running all this stuff and sent a Navy car around to take us to another place, another briefing, rewind the tape, hit the on switch, 'Well congressman, this is what...' We stopped at the White House. Well I thought that's pretty nice. So we went in, they put us in some room, door opens, here comes President Eisenhower. We were all given medals, the four of us—Larry, myself, Andy, and Jacques—by the President of the United States. That was kind of an interesting day. A better day than average. That's a long drive from Guam in the days of propeller airplanes to Washington, DC. A long drive. But we had our own airplane from Guam to San Diego, this kind of private DC-6. And that helped me a bit in my naval career, because I was not a nuke submariner. That had been decided when I was still on the *Rasher* [SSR 269] in '56 to '58, that I was not of the intellectual attainment and quality to be in the nuclear power program, the varsity team, because of my class standing at Annapolis. So I was a very disposable diesel submariner at that point because the future was clear: they're putting nukes into the fleet as fast as they



Lt. Don Walsh (right) with his Operation Nekton team member Lt. Larry Shumaker. Shumaker had previously served with Walsh on the submarine *USS Rasher* (SSR 269), and the two had been classmates at the US Naval Academy.



could, people like me had a limited shelf life. 'Use before...' like they say on a meat package. So I knew I was not going to get a very good assignment my next job in the Navy, except for the fact that I'm the only lieutenant in the Navy that's wearing the Legion of Merit which the President of the United States had personally put on my chest. So I had a blot of my copy book, and so that opened a lot of doors metaphorically for me for the future. Anyway, that was just a footnote to this.

While we were in DC, the Navy decided, BuShips decided that we'd be restricted to 20,000 feet, that we couldn't dive any deeper anymore. So there goes our second dive. We're going to go back out to Guam and resume our operations, and Bob and Larry would do this. Now Larry and Andy had made a dive to 20,000 feet on the second part of our expedition, because that would have been, oh, like March or April through late summer of '60, and then we packed everything up and came home to San Diego. That's too bad, because Bob Dietz really deserved, I don't think he ever got any kind of substantial dive. He did in Capri earlier in '57, but Bob never got a...he was a key man, a key player. And one of the great marine geologists. He was the kind of guy that would develop a theory of something, and he'd get poo-pooed by everybody in the community, and sometimes he was right. He was a pathfinder. That's a shame, he deserved better.

**CB:** How did you...there was some issue of who would go on that first, the record-setting dive.

**DW:** On deciding the crewing for the deepest dive, it was clear to us that Piccard was going to make the dive, because he had contractual agreement with ONR, which we didn't know about. So who's the other person going to be? Well I wanted to step aside because Andy Rechnitzer was a commander in the naval reserve, and he's a marine scientist, he's an oceanographer. So you get both a Navy guy, put him on active duty, you got a Navy guy and you get a scientist on board. And I'm a new boy, I've only been on the project at that time well, just about a year, 12 months. I don't have any standing, like I had been with this project.... Bob Dietz had a better call on that other seat than I did. And certainly Andy met all the requirements: naval officer, scientist. But we got an email from the CNO...not email, radio message...that said Walsh will be, will make the dive. I think that's right from Burke, I never asked him about it.

**CB:** He obviously knew you, because you came in his office and talked to about it, so I guess he had you envisioned?

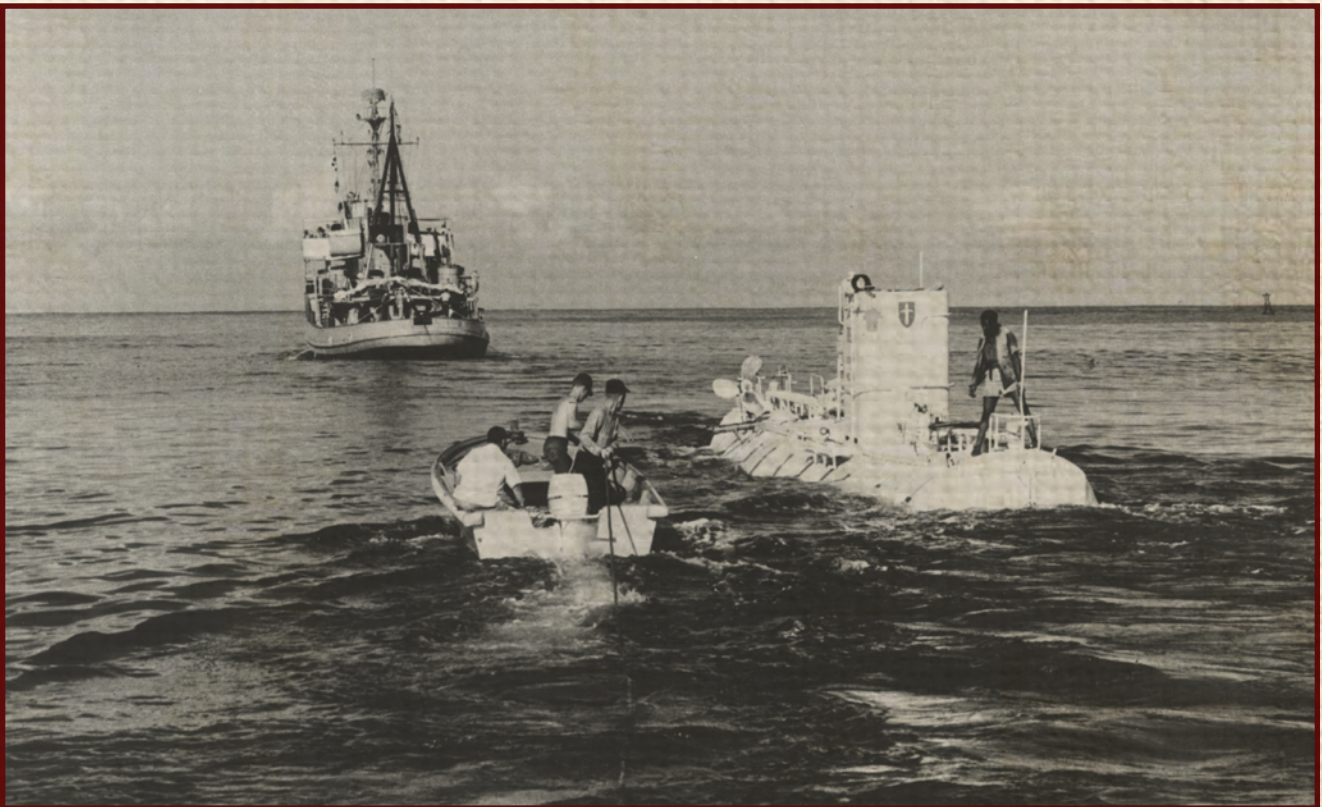
**DW:** I don't know the reason because I was least qualified of several people. And it wouldn't have bothered me at all, I mean I had a hell of an adventure and something I could talk about the camp fire for the rest of my life. I didn't have any knowledge of all that other stuff out there. It was what was right, was Andy make it. And he was of course profoundly disappointed. He had a major role putting this whole program together, bring it to San Diego, structure the program, recruiting me in basically through my commodore. He had standing. As it happened we didn't have an oceanographer on the first dive, but I've told people that Piccard and myself were really test pilots of an experimental device. It's like when Boeing rolls a new airplane out of their factory, they don't send it right over to the airline terminal and load passengers for St. Louis. You test it. That was the whole idea. The whole idea of the dive series at Guam was to test the program, the platform, and find out what it could do and how reliable it was, how safe it was, and really learn all about it before we start putting a scientist in there. Because they don't want adventure, they want data. You're not wearing the little red hat, you get to the bottom, and you drink champagne and say we've overcome suspicion or whatever. They don't like that, they don't want adventure. It's just another tool—you put a guy in there who knows it's reliable, it'll perform, it's safe, and that's what we were doing. Doing all that testing, fixing what wasn't too good and so on, over a period of seven months. Increasingly deeper test dives; we started in the harbor at Guam with a hundred feet, and by the end of November we were at 16,000 feet. By January we were at 35,814 feet, at maximum depth. So we put it to the full depth test, so we were test pilots, not scientists. So I'm not apologetic about that, we were just trying to, as an engineer and submarine officer, and Jacques who grew up and helped build the thing, we were probably the best people qualified to look at it from an operational engineering point of view. But still wrong that Andy didn't make the dive. He was technically competent, no question about that. But that's the way it happens, I don't know why. It's too late now to find out what went wrong. Andy's dead, Arleigh Burke's dead, they're all gone, Larry's dead, Jacques' dead—I'm the only survivor.

**CB:** So take me through that record-setting dive, your experience of doing that.



**DW:** Well I'm going something that may seem a bit [...] 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 sole, 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....



Jacques Piccard and his assistants make final checks prior to *Trieste's* first Project Nekton deep dive in the Marianas Trench on 15 November 1959, diving to 18,600 feet and breaking the previous record of 13,000 feet. The tug USS *Wandank* (ATA 204) is in the distance. The final record-setting dive on 23 January 1960 would be the project's eighth dive.



**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 in the nets and all that. They were expected and nothing new. If we had been real marine biologists, captured stuff, looked at them, we probably passed through all kinds of species that had never been seen. So we have to use the generic "invertebrates," worms, jellies, things like that.

**CB:** Now subsequently there's been some question about whether that fish that you saw, that there were fish there.

**DW:** Oh, right from the beginning, yeah: we weren't ichthyologists, we weren't scientists, we didn't know what we were seeing.

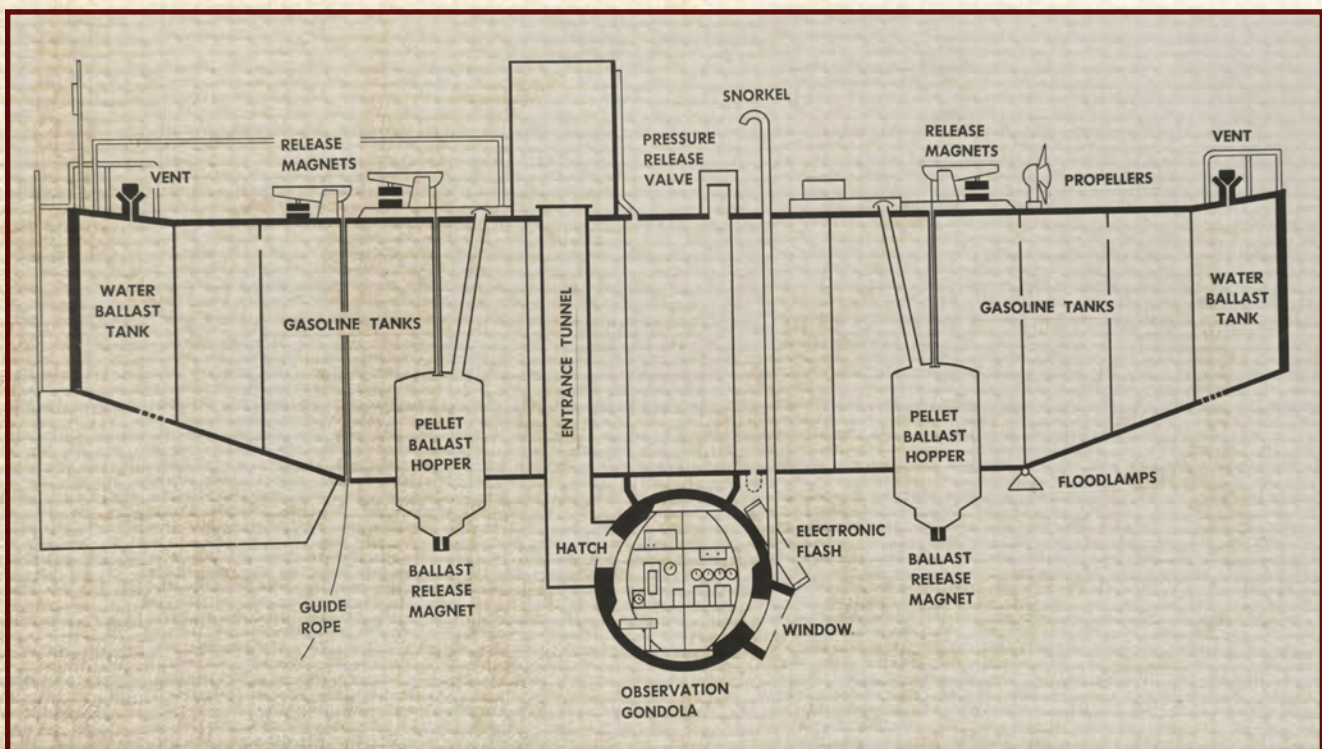
**CB:** But it was something that was moving?

**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 were looking at a sea cucumber rather than a flat fish. You know before Jim Cameron made his deep dive I was on his expedition in March of 2012, he very graciously invited me to join the expedition. So I was there when he made his deep dive, and I was the last person to talk to him when he shut the hatch on his sub, and I said, 'Have fun, and find that damn fish.' And I was the first person to talk to him when he came back up, and he didn't see anything. He had his hands full and had some technical problems. But that was nice, 50-plus years later, to see somebody else do it. It was kind of neat.

But back to the day of the dive, that was pretty much it. The reason that we kind of allocated nine hours, this is wintertime so the days are a bit shorter, even though we were closer to the equator. So we had to unhook, once the.... We had two vessels: we had the tug, an auxiliary tug called the *Wandank* [ATA 204], which lived at Guam, part of the few ships that actually reported to ComNavForce Marianas; and our mother ship was a DE, a destroyer



This general arrangement drawing of *Trieste* shows the bathyscaphe's main features at the time of the dive at the Challenger Deep in January 1960. The craft was filled with aviation gas to provide buoyancy at the extremely cold temperatures and high pressure found at the bottom of the ocean, and also used iron shot pellets for ballast that would be released to return *Trieste* to the surface.



escort [USS *Lewis* (DE 535)], which was faster. And so when our tug was coming out at five knots, we went out on the destroyer escort at a good rate of speed, 15-20 knots, and tried to locate the Challenger Deep. Because we didn't have a precision depth recorder, we had no way.... The fathometer of the ship, of course, could measure the seafloor 100-200 feet below the keel of the ship and that was it. That wasn't good enough for our needs. The oceanographic ships that had been out there, the *Challenger* in 1950, the Soviet research ship *Vityaz*, and a Scripps ship (I don't know which one it was), they all had these precision depth recorders that could actually could get something, not very good—approximate. All three of them agreed that this was the deepest place in the world ocean, and this was sort of '50 to maybe '53, in that time frame. So the Soviets, the Brits, and Americans all agree, that's the deepest place. But how do we find it? Because our navigation wasn't all that good. We were on a, we used LORAN in those days—they didn't have GPS. And in LORAN there's something called the baseline, and that's with respect to the transmissions of the signals from the LORAN station. When you get on the baseline, your navigation's not very accurate, you have to get off of that. We were sitting right on a baseline, so we couldn't get very good, except really approximate. So what did we do? Andy figured out, Andy Rechnitzer figured out, well look that transducer for that fathometer could probably hear a return echo from the seafloor if you put enough energy in the water. It's not a function of that transducer's design specifically, it's that the fathometer can't put out enough energy to bounce off the seafloor. So he ordered up a whole bunch of one-pound blocks of TNT. We actually had a harbor tug come out 200 miles and deliver this TNT to us. I think we even had a resupply. And so we'd just poke a hole in the top of these things and put in the detonator, light a match, and throw them in the water, and when it went off you started your stopwatch and then listen for the return echo. Seven seconds was not as deep as 12 seconds. That's how we mapped it. It was all relative to time, and not to depth. We had no idea what the accurate depth was except what those earlier expeditions had found. But we finally mapped out something, I think it was about a mile wide and seven miles long on the bottom of the Challenger Deep, the Mariana Trench, and so when the tug came out we said put it there and launch it. So you've got this tug with a one-inch cable towing wire and what we call a pelican hook that was hooked to a little towing bridle on the *Trieste*. The only way to unhook that is with hands, so someone's got to get down in there and

take this apart with this thousand-ton tug boat on one end and the *Trieste* on the other—and that can be pretty hazardous.

**CB:** So this had to be a diver, in other words?

**DW:** No, no, we were all divers....

**CB:** I mean you had to have somebody in the water.

**DW:** Somebody in the water. There's Larry Shumaker hanging over the front of this thing and unhooking it. So you want to take your time and do it full daylight, didn't want somebody to lose a hand just because we were in a hurry. So we kind of scheduled the day length of daylight and how long it took to unhook the tow and 'preflight' the *Trieste* for the dive, and after it came back up to hook up the tow again. The sea state was pretty heavy, it was like six when we came back up. It was tough, and we had to take the bridle in the front of the Trieste and the towing wire on the tugboat and hook them together at the end of the day. Again, you want lots of daylight. So that kind of determined how long we could actually be diving and have a safe cushion on each end of the day. That was it. They towed it back to Guam, and the principals, Larry, Andy, Jacques, and myself rode the destroyer escort back into Guam at high speed. A plane was waiting for us and flew us east, then Hawaii. Of course SubPac greeted us, and then on to DC. Well we were at the Navy lab—that's where we couldn't find anybody who told us not to make the dive.



An aerial photograph of a large body of water, likely a reservoir or a large lake, with numerous islands and peninsulas. The water is a light brownish-grey color. The surrounding land is mostly green with trees, but there are some developed areas with buildings and roads visible in the foreground and middle ground. The sky is a pale blue-grey.

# Powder and Propellants for the Navy: **A HISTORY OF AN ENERGETICS LEADER**

By Josh Phillips





## THE NAVAL SURFACE WARFARE CENTER AT INDIAN HEAD HAS BEEN AT THE FOREFRONT OF ENERGETICS PRODUCTION, TESTING, AND RESEARCH FOR MORE THAN 125 YEARS.

**T**he Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division isn't the easiest place to find on a map. Founded in 1890 as the Naval Proving Ground Indian Head, the command is buried deep in the countryside of Charles County, Maryland, along the Potomac River—a place known for bass tournaments, scenic country lanes, roadside produce stands, and cutting-edge naval technology.

One hundred years ago, however, the Cornwallis Neck Peninsula of Indian Head thundered with cannon fire during weapons proofing, while scientists and chemists focused on developing reliable propellants for the nation's emerging naval forces. While initially founded to test the Navy's shipboard armaments because of its proximity to the lower Potomac, that mission would shift and give way to the command becoming the Navy's leader in energetics research and development.

### Black Powder's Last Hurrah

Black powder was on the way out in the mid-1800s, as dense smoke created after firing left the guns unable to be operated for several minutes afterwards. To shorten the firing delay, navies and industry began experimenting with cordite to develop a smokeless powder with the same firing properties as black powder. Smokeless powder also allowed for quicker reloading and re-firing, an immediate clear shot at the target, and did not require a sponge-out of residue as needed with black powder.

The last hurrah for black powder would come in 1898 during the Spanish-American War, when Commodore George Dewey ordered the protected cruisers USS *Olympia*, USS *Boston*, USS *Baltimore*, and USS *Raleigh* to navigate into Manila Bay to surprise the remaining Spanish fleet. Dewey's fleet sank eight Spanish ships without losing any of their own. Most of the damage to the Spanish fleet is believed to be caused by Dashiell 5-inch rapid fire guns developed at Indian Head. According to Lt. C.G. Calkins navigation officer, while the 5-inch guns performed well above expectation, the smoke from the black powder obscured vision and hindered the accuracy of the ship's main 8-inch batteries.



Three days after the battle, Congress authorized the Navy to construct a smokeless powder factory at Indian Head to serve as a full-time production line to meet the needs of the fleet and to remain level with other global navies that were producing smokeless powders of their own.

## A New Era: Smokeless Powder

On 16 June 1900, Indian Head produced its first batch of smokeless powder, ushering in a new century and a new era of capabilities for the U.S. Navy. Because smokeless powder burned slower than black powder, the Navy required a longer barreled gun to ensure the powder released all its energy before the shell left the muzzle.

The results of the combined upgrades were significant. The new powder and longer barrels generated higher muzzle velocities—and hence longer ranges—for shells. In addition, according to Rodney Carlisle in his book, “Powder and Propellants: Energetic Materials at Indian Head, Maryland, 1890-2001,” the 1890 model 12-inch gun, with the shorter barrel, could only penetrate 13.79 inches of steel, while “a 12-inch gun with a smokeless powder charge could fire an 850 pound uncapped projectile that would penetrate 17.92 of nickel-steel at 3,000 yards.”

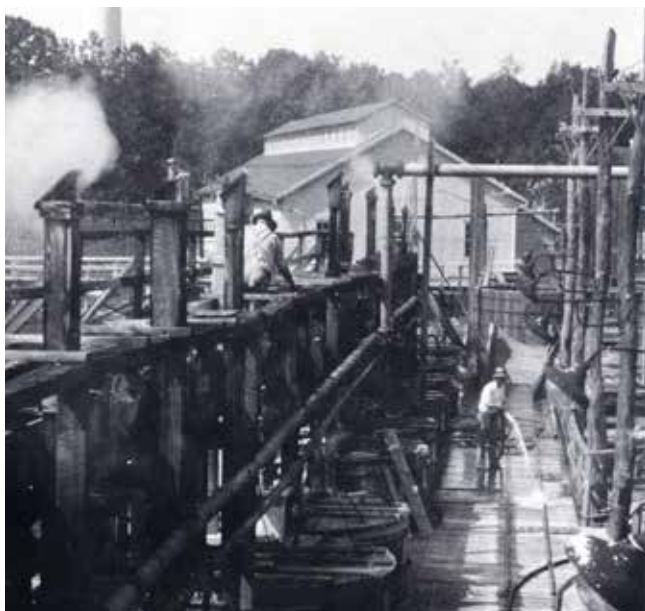
Smokeless powder had been experimented on and used for approximately 50 years before Indian Head began its large scale production operation. Swedish chemist, inventor of

dynamite, and namesake of the Nobel Prize, Alfred Nobel, developed an early formulation of smokeless powder in 1888, although his version was deemed too unstable for naval usage due to it being 40 percent nitroglycerine.

The Navy experimented with small-scale powder production facilities before 1900, but realized they needed an area of considerable size to meet growing fleet requirements. The Navy’s torpedo factory in Newport, Rhode Island, provided testing and small-batch production of smokeless powder before 1900, but it was deemed untenable for any sustained production because of its small size and potential for disaster due to the proximity of the station’s infrastructure if the powder were to explode.

What Newport did have was a young chemist named Dr. George Patterson. Patterson would leave Newport in 1900 to become the chief chemist at Indian Head, where he tested smokeless powder compounds for more than 40 years and became the nation’s foremost expert on smokeless powder.

With a newfound mission to develop and deliver smokeless powder to meet the Navy’s needs, Indian Head produced more than 250,000 pounds in its first year of operation. That number would grow as the site expanded to accommodate the experimentation and production of smokeless powder. Such experiments dealt with the effects of electric light, salt water, and stabilizing agents in the powder.



Workers tend to the facilities at the Naval Proving Ground’s smokeless powder production plant.  
(Photo courtesy of the Coster/Parran Collection)

In 1911, the French battleship *Liberté* suffered a magazine explosion while moored in Toulon on the Mediterranean coast. The resulting explosion killed approximately 250 people and destroyed the ship. Because of similarities of the US smokeless powder’s formula with the French version, officials were concerned about a similar occurrence on US naval vessels. Patterson’s research and experimentation with smokeless powder, however, found that adding a diphenylamine stabilizer during manufacturing lessened the volatility of the powder.

“By 1912, the specifications for smokeless powder included the stabilizer,” wrote Carlisle. “Thus, when reports of the *Liberté* disaster alerted line officers to the danger of unstable smokeless powder stored in shipboard magazines, the Bureau of Ordnance could report that, thanks to Indian Head research, American stabilized powder was far safer in magazine storage.”

By the time the United States entered World War I in 1917, Indian Head had become one of the country’s foremost





An Indian Head worker extracts powder from the finishing press. (Photo courtesy of the Coster/Parran Collection)

producer of smokeless powder to the good fortune of the US Navy. Demand for smokeless powder had never been higher and to meet the wartime need, Indian Head produced more than 831,000 pounds of smokeless powder from 1918–1919, compared to 297,000 pounds in 1915.

## World War II and the Extrusion

The post-World War I years brought significant changes and mission shifts to the staff at Indian Head. The command's lower station, located at Dahlgren, Virginia, became independent and responsible for gun testing in 1921. Indian Head shifted its full-time focus to the production of smokeless powder and other explosives, such as ammonium picrate. To reflect the changes in these duties, Indian Head formally changed its name from the Naval Proving Ground to the Naval Powder Factory (NPF) in 1923.

Indian Head would also undergo a dramatic pivot shortly before World War II, as the command established a facility to produce rocket propellant grains for experimental air-to-air rocket systems to better engage jet-powered aircraft. This double-base powder was composed of nitrocellulose—a highly flammable material composed of wood pulp used in gunpowder—and nitroglycerine that were rolled into a sheet and passed through a press into the necessary length and diameter, resulting in a product aptly named “extruded grains.” The grains were then shipped to other facilities that would load them into 1.75-inch and 2.75-inch folding fin aircraft rockets.

“By mid-1943, the first Indian Head [extrusion] presses were at work,” wrote Carlisle. “Two presses were put in operation by August, with three more ready to go if sufficient staff could be hired to run them.”

By 1944, NPF Indian Head began production of extruded grains for rockets, bazookas, and air-to-ground anti-tank weapons such as the Mighty Mouse folding-fin aircraft rocket. The American-Japanese naval engagements in the Pacific demanded the need for more of these weapons produced at a faster pace. To that extent, Indian Head was asked to step up its production to more than 900,000 pounds of extruded grains per month.

The pivot from smokeless powder production to the manufacture of extruded grains received little attention until after the war. F.C. Thames, the civilian chemist in charge of production and supervisor for extrusion work, was asked to describe what contributions were made by his extrusion division in support of the war.

“In the hectic pace to meet production goals and in the generally classified environment of World War II production, there had been no opportunity to develop a public relations presentation of achievements, and by the time Thames had offered his assessment, the work was no longer news,” said Carlisle. “Like much of the incremental technological work done by Indian Head in the 1920s, the rapid and quiet innovation essential to progress in a new area, got little public attention compared to the more spectacular innovations in armament elsewhere during the war.”





Old meets new: The oldest battleship in the fleet at the time, the World War I-era USS *Mississippi* (EAG 128), fires the Navy's first surface-to-air missile, a RIM-2 Terrier, during at-sea tests in 1955. Indian Head began producing booster grains for the Terrier in 1954.

## Mission Shift

Following the end of World War II, NPF Indian Head saw the need of smokeless powder dwindle, resulting in a workforce reduction and questions about Indian Head's future role with the Navy and joint forces community.

Work at Indian Head would dramatically pick back up in 1950, however, as the nation's entry into the Korean War resulted in increased demand for Mk-31 2.75-inch rocket grains. Production of these grains required the expansion of the station's extrusion plant facility as the then-current limitation of the facility allowed for the production of 25,000 individual rocket grains monthly. Following expansion, the plant's monthly grain production capability grew to more than 80,000 rocket grains.

"The development of large, cast-propellant rockets, in which the propellant would be cast directly into the casings suggested the need for technical changes," said Carlisle. "Indian Head's background in extruded rockets in the 1940s and the addition of a casting plant in the mid-

1950s suggested that it could lay claim to a solid role in these new developments."

Among these changes was Indian Head's selection to produce propellant for the Polaris missile – the nation's first surface-to-surface, intermediate-range ballistic missile designed to be launched from submarines—as well as the Terrier surface-to-air missile. The production of the Polaris propellant facility in 1954, as well as a casting plan and the expansion of the command's research and development program showed that Indian Head could be looked on to lead the way in propellant manufacturing for their new ordnance technologies. By 1958, Indian Head's role as a propellant plant overcame its previous duties as the Navy's premier producer of smokeless powder, facilitating the change of designations to the Naval Propellant Plant.

## Otto Fuel II

In the late 1960s, Indian Head began its involvement in the developing of a new torpedo fuel to replace a propyl nitrate monopropellant thought to be too unstable



and dangerous for continued use. Dr. Otto Reitlinger, a manager with the Bureau of Weapons, visited Indian Head to discuss with personnel the formulation of a new, safer torpedo propellant.

"Even though [Indian Head] was not 'tasked' with torpedo work and its evolving mission focused on rocket and gun propellant, he sought advice from the Indian Head chemists," said Carlisle. "In spelling out the torpedo fuel requirements, Reitlinger made it clear that a torpedo monopropellant had to run clean and not produce a lot of carbon to foul the torpedo engine."

Through trial and error, what the team eventually designed and produced was a torpedo propellant that met all requirements for torpedo fuel production. The fuel was dubbed "Otto Fuel II" and was quickly brought to production at Indian Head for initial use in Mk-46 air-dropped antisubmarine torpedoes and in the antisubmarine rocket-launched shipboard torpedo. By 1967, Otto Fuel was regularly produced at the station's Biazzi Nitration Facility—a continuous flow facility originally used to produce nitroglycerine, but with small modifications also allowed for the development of Otto Fuel II.

Indian Head is the sole manufacturer of this fuel, which is still used by the fleet and other allied countries.

## Cook-Offs and the Dawn of Insensitive Munitions

USS *Forrestal* (CVA 59) was deployed to the Gulf of Tonkin in 1967 when a 5-inch Zuni rocket attached to an F-4 Phantom on the flight deck was accidentally discharged, striking an A-4 Skyhawk and rupturing its fuel tank. The fire caused by the explosion engulfed nearly a dozen other Skyhawks. A domino-effect of explosions occurred as ordnance cooked off, resulting in 134 deaths, 21 aircraft destroyed, and \$15 million in damage.

Less than two years later on 14 January 1969, an F-4 Phantom aboard USS *Enterprise* (CVN 65) had a Zuni rocket explode after being overheated by an aircraft start unit. Again, a domino-effect of cooked-off ordnance across the flight deck resulted in the death of 27 Sailors and the destruction of 15 aircraft.

The Navy had been working to improve insensitive munitions (IMs) characteristics for their shipboard ordnance and to find a safer alternative for TNT. IMs

minimize the response of a munition to unplanned stimuli, while ensuring it still functions as intended. With the tragedies aboard *Enterprise* and *Forrestal* as motivators, the search for ways to maintain lethality while developing IMs for fleet usage took a more earnest approach in the next several decades.

"Making insensitive munitions that would not detonate from external heat and also stand up under electromagnetic and static electrical environment aboard aircraft carriers and other ships became and even higher priority item in 1992, when the Navy issued IM as a requirement," said Carlisle.

Scientists and chemists at Indian Head, Dahlgren, and China Lake, California, cooperated under the Navy's Insensitive Munitions Advanced Development-High Explosives program in 1999 to find applications for plastic bonded explosives (PBXs)—a newly qualified explosive substance with a high mechanical strength and excellent chemical stability and that is impervious to shock. Multiple PBX formulations were developed and tested, including PBXN-109, which eventually replaced older warhead payloads on Mk-84 2,000 pound bombs. Indian Head also served as the lead laboratory in the development on a PBX grenade fill substitute to be used in antipersonnel obstacle breaching systems.

"[By 2001,] more than a dozen new explosives with insensitive qualities had been introduced and developed in over 43 new weapons using IM developed at Indian Head," said Carlisle.

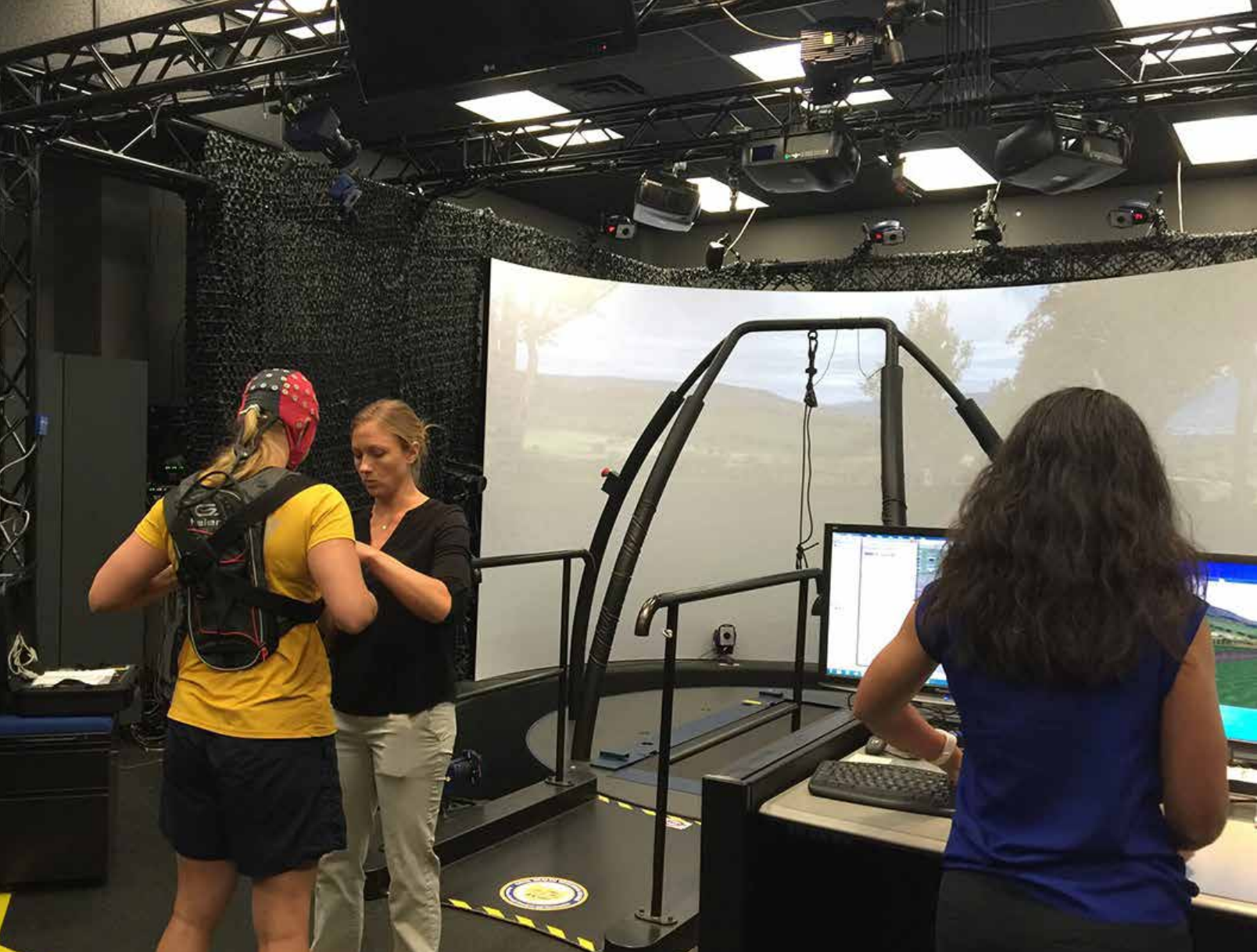
## Conclusion

It has been more than 125 years since Ens. Robert Dashiell traveled from the District of Columbia to construct a proving ground on an agrarian parcel of land known by locals as Indian Head. Since then, the command has adapted and evolved to meet the ever-shifting requirements of the fleet and services. While the names and requirements have oft changed, Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division has stood tall as the Navy's true leader in the development of energetics.

### About the author:

**Josh Phillips** is a writer with Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division corporate communications.





Researchers from the warfighter performance department at the Naval Health Research Center prepare a test subject to enter the Computer Assisted Rehabilitation Environment (CAREN). CAREN is a high-tech tool, originally designed for rehabilitation and clinical research, which has been enhanced by NHRC scientists to study injury prevention, test equipment, and evaluate cognitive performance in a virtual environment.

# THE EVOLUTION OF **MEDICAL RESEARCH** **AT THE NAVAL HEALTH** **RESEARCH CENTER**

By Capt. Rita Simmons, USN



## FROM SMALL BEGINNINGS AS A “NEUROPSYCHIATRY” RESEARCH UNIT, THE NAVAL HEALTH RESEARCH CENTER HAS BECOME A MAJOR PLAYER IN ADVANCING NAVAL MEDICAL RESEARCH.

**A**fter World War II, most of the Navy’s psychiatric and psychological research was contracted out to universities through the Office of Naval Research (ONR). In the mid-1950s, however, the Navy’s Bureau of Medicine and Surgery (BUMED) decided that an in-service psychiatric research program would better meet the Navy’s needs.

A panel of leading experts in psychiatry and psychology was assembled to develop the program. The members, all of whom had experience with Navy neuropsychiatry programs during World War II, were influential in shaping the early stages of the program’s research.

Early in the planning process, the panel decided that research should be conducted programmatically and not distinguish between basic and applied research, as both would be necessary for the advancement of military medicine. In addition, the research conducted by the new program was to be both directed and nondirected, allowing the researchers to be responsive to the needs of the Navy.

On 1 June 1959, the Navy Medical Neuropsychiatric Research Unit (NMNPRU) was established with the mission “to conduct research in neuropsychiatry as it applies to the naval service.”

San Diego was selected as the ideal site for the new unit as it was close to Navy and Marine Corps recruit training centers, a large confinement facility, a major military hospital, air units and the Pacific Fleet. It was perfect for conducting medical research to meet the needs of most operational units.

Navy Medicine gave the new research laboratory a budget of \$30,000 for its first year. Furniture and office equipment were acquired from the excess supplies of a nearby Navy confinement facility and other local units, thanks to the ingenuity of a Navy chief petty officer, William Wright. When an additional \$5,000 was needed, BUMED provided it from their janitorial supply budget.

The original leadership team at NMNPRU was composed of Dr. Walter Wilkins, a psychologist and consultant to the Surgeon General, and Cmdr. Ransom Arthur, a former World War II intelligence officer with the Marine Corps and a Harvard-educated physician.

### Early Research

One of the first tasks assigned to NMNPRU was developing empirically supported guidelines for selecting Navy and civilian personnel for Operation Deep Freeze, an ongoing research program led by the National Science Foundation to conduct diverse scientific studies in Antarctica. Groups of approximately 20 men (and later women) were to be completely isolated and confined to small living and working spaces for 12 months. Anecdotal reports indicated the harsh Antarctic conditions could cause some personnel to develop moderate to severe psychological dysfunction.

Dr. Eric Gunderson, a researcher with NMNPRU, was tasked with designing a series of studies that would help identify personnel who could adjust to Operation Deep Freeze’s challenging environment. Using preliminary data from an earlier study of one group assigned to the South Pole Station in 1959, Gunderson developed a five-year program to test and interview all applicants for Antarctic duty.

Ultimately, Gunderson and his collaborators studied more than 1,000 Operation Deep Freeze personnel and identified useful predictors that were incorporated into a screening program. The knowledge gained from this research not only benefited the Navy and the National



British Dr. Gordon de Q Robin and Norwegian Dr. Tore Gjelsuik present a plaque to US Lt. Philip K. Swartz during a commemoration marking the 50th anniversary of the Amundsen-Scott South Pole expeditions.  
(Photo by PHC F. Kazukaitis)





British, American, and Norwegian personnel at the South Pole Station commemorate the first expeditions to the South Pole. (Photo by PHC F. Kazukaitis)

Science Foundation, it also eventually led to Gunderson serving as a consultant to NASA.

Another important aspect of NHRC's early research included establishing the Center for Prisoner of War Studies, near the end of the Vietnam War. Aware of the potential medical and psychological consequences of being held captive and subjected to inhumane conditions and torture, NMNPRU proposed a plan to evaluate the effects of captivity on American prisoners of war (POWs).

BUMED and the Department of Defense (DoD) supported the proposal and the Center for Prisoner of War Studies was established in 1971 in San Diego. The immediate goal of the center was to develop a comprehensive, long-term plan for the medical care and related support of released American prisoners and add to the knowledge of relationships between psychological and physical health. Eventually, the center transitioned to the Naval Aerospace Medical Institute in Pensacola, Florida, where evaluation of POWs and data collection continues.

## Expanding the Research Mission

In September 1974, NMNPRU was redesignated the Naval Health Research Center (NHRC) with the mission, "To conduct research and development on the medical and psychological aspects of health and performance of naval service personnel; and to perform such other functions or tasks as may be directed by the Chief, Bureau of Medicine and Surgery."

Over the years, NHRC's scientists have delved into several areas of research that have direct relevance to the physical and psychological health and readiness of our military, including:

- Clinical and preventive psychiatry
- Neurology
- Occupational medicine
- Psychophysiology
- Sleep
- Exercise physiology
- Health and social psychology
- Infectious diseases
- Chronic diseases
- Medical informatics



An image from the archives of the Naval Health Research Center of Navy hospital corps personnel attached to the command in the 1960s.





Aerial view of the Naval Health Research Center located in Point Loma, California.

NHRC has spearheaded numerous important studies for the Navy and DoD over the years, and has accomplished much in support of the health and readiness of our military members and their families. A few of those achievements include:

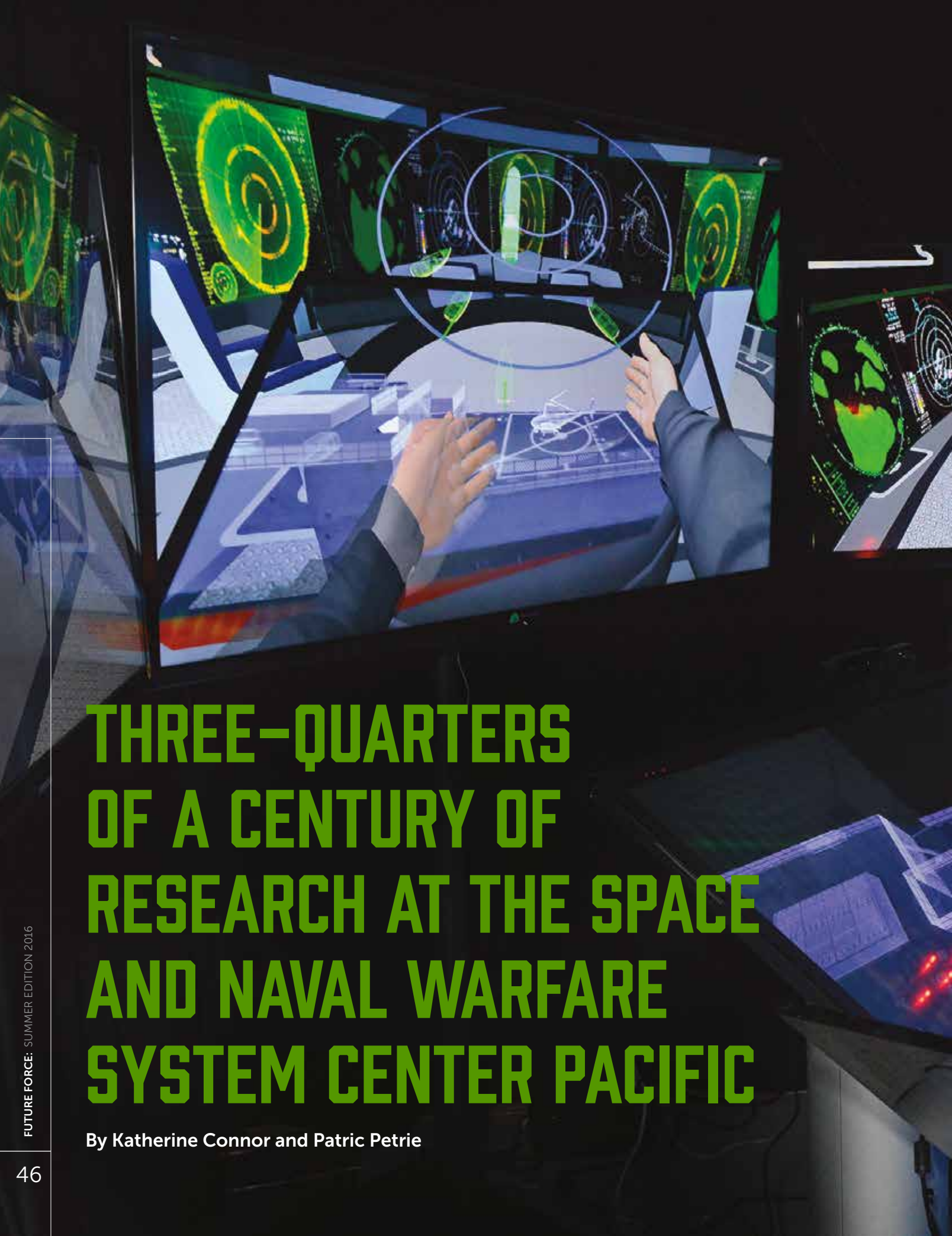
- Navy Family Service Centers: Research conducted at NHRC was instrumental in documenting the need to provide a comprehensive information and referral service on programs and services available in both military and civilian communities.
- HIV Serum Repository: Established at NHRC in 1985, this marked the first in-depth investigation of HIV-positive U.S. Navy and Marine Corps personnel and resulted in the DoD Serum Repository being established in Silver Spring, Maryland.
- Physical Readiness Test (PRT): In 2002, NHRC researchers developed new PRT standards based on five-year age groups. In 2010, NHRC created performance specifications for elliptical trainers and stationary bikes to be included into PRT cardiovascular testing.
- Millennium Cohort Study: After the Gulf War in 1991, the DoD launched the Millennium Cohort Study to collect data on the long-term health effect of military service on members. This is the largest prospective study in military history.
- H1N1: Researchers at NHRC discovered the first two cases of H1N1 influenza virus in the United States and received the Centers for Disease Control and Prevention 2010 Excellence in Public Health Response award.
- Birth and Infant Health Registry (BIHR): In 1998, the DoD established BIHR at NHRC to increase the understanding of the reproductive health effects of military service.

While the mental health of our service members is still a top priority at NHRC, our research portfolio has evolved far beyond our neuropsychiatric roots. Some of our recent innovations include the Computer Assisted Rehabilitation Environment to study injury prevention and test gear and equipment in a virtual environment, mobile application development capabilities designed to empower patients and extend provider information, and high-tech, handheld devices that can be used by forward-deployed Marines or Sailors to detect the presence of dangerous pathogens. NHRC has always been on the cutting-edge of science and we will continue to build and expand our research capabilities to make certain our warfighters are the most medically ready and fit military force of the 21st century.

### About the author:

**Capt. Simmons** is the commanding officer of the Naval Health Research Center.





# THREE-QUARTERS OF A CENTURY OF RESEARCH AT THE SPACE AND NAVAL WARFARE SYSTEM CENTER PACIFIC

By Katherine Connor and Patric Petrie





The Battlespace Exploitation of Mixed Reality (BEMR) lab uses virtual and mixed reality in the full spectrum of naval operations, from training to platform configuration to use in the field.



For the first 76 years of its existence, the Navy's Space and Naval Warfare Systems Center (SSC) Pacific was quiet about the high-level technical advancements in warfare communications, sensors, weapons, and platforms made at its facility on the tip of Point Loma, San Diego. But that doesn't mean major breakthroughs were not being made.

SSC Pacific got its start in 1940 as the Navy Radio and Sound Laboratory with a single radio antenna, and by the end of World War II was fully engaged with sonar and radio innovation.

Today, the center employs a highly educated, diverse, multidisciplinary workforce of more than 4,500 scientists, engineers, technical specialists, and civilian support staff who hold more than 170 PhD and JD degrees, and almost 1,000 master's degrees.

The lab is ranked as a top generator of patents and license agreements and has a new focus on virtual reality—thanks to a directive from the chief of naval operations. SSC Pacific is a key developer of unmanned and autonomous robots for land and sea, microbial fuel cells, photonics, novel materials, and is investing heavily in solving the data analytics and communications link challenges created by the many new sensors deployed in the fleet.

"We're involved in cyber, computers, communications, command and control and networks, and that is a force enabler, a force multiplier for the military," said Carmela Keeney, executive director of SSC Pacific. "While platforms may be reducing budgets, the space we're in is vital to the Navy and continuing to grow significantly."

Commanding officer Capt. Kurt Rothenhaus firmly believes the diversity of the workforce is what makes the organization so important to the Navy and the nation.

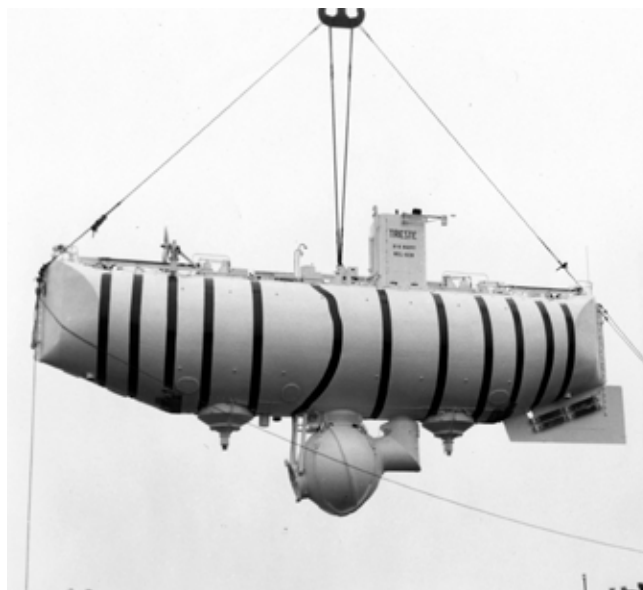
"Nowhere else but here at SSC Pacific does a cyber engineer sit next to a quantum scientist, an undersea autonomous system developer, and an in-service engineering expert in order to come up with the best solutions to make it all work for our Sailors and Marines," said Rothenhaus.

Collaboration like that leads to innovative ways of solving fleet challenges, like these handful of examples from the thousands of projects spearheaded by the center over the past 76 years. The name of the lab may have changed—from the Navy Radio and Sound Laboratory to

Naval Electronics Laboratory Center and the Naval Ocean Systems Center (NOSC), to name a few—but the quality of work has remained the same.

## Autonomous Vehicles

The center has played a pivotal role in advancing the Navy's use of autonomous systems, from the extreme depths of the ocean to terrestrial and air vehicles. Take the manned submersible *Trieste*, for example, which set the stage for later work in unmanned and autonomous systems.



The Office of Naval Research purchased the manned submersible *Trieste* and had it sent to the Navy Electronics Laboratory to study potential naval applications of the technology.

Designed and built by Swiss oceanographer Auguste Piccard in 1956, it was assigned to the lab as part of the Office of Naval Research's Project Nekton's goal to locate the deepest trough in the world's oceans and determine if *Trieste* could reach the bottom. Lab scientists and researchers successfully led *Trieste*'s 1960 mission to the bottom of Challenger Deep in the Mariana Trench at 35,800 feet below the surface. If Mt. Everest were lifted from its base and placed at the bottom of Challenger Deep, its summit would be more than one mile underwater. It would be half a century before another underwater vehicle arrived in Challenger Deep, and this time no people were on board.

In 1963, following the tragic loss of the submarine USS *Thresher* (SSN 593), the center was directed to send *Trieste* to the suspected wreck site to investigate. In August, crew members used *Trieste*'s mechanical arm to recover



a length of copper piping and a fitting positively identified as wreckage from *Thresher* at 8,400 feet. The crew was awarded the Navy Unit Commendation.

Building off this work, the center developed the Cable-controlled Underwater Recovery Vehicle (CURV) class of undersea vehicles, which was originally built to recover torpedoes fired during testing at the center's sea ranges at Long Beach and San Clemente Island, and had a design depth of about 2,000 feet.

The CURV platform proved its worth in 1966 after a U.S. Air Force B-52 bomber collided with its KC-135 refueling plane in the skies over Spain. Most of the two flight crews died, and three hydrogen bombs rained down on the Spanish countryside. A fourth hydrogen bomb fell into the Mediterranean Sea.

The Navy assembled a task force of 20 ships to search for it, and after more than two months of searching, the Naval Ordnance Test Station Pasadena Annex was requested to send CURV to assist. The depth was almost 1,000 feet beyond CURV's design at the time, but with 1,000 additional feet of 55-connector control cable quickly assembled, CURV made three dives to 2,850 feet and attached three recovery lines, then became entangled in the bomb's parachute. The support ship hauled the entire mass of bomb, parachute and undersea vehicle safely to the surface.

On the land side of things, the Mobile Detection and Response System (MDARS), developed in 1989, was one of the center's first developments in autonomous vehicles. The security robot could make random patrols to detect fires, flooding or intruders, and conduct inventory checks.

This has evolved into today's work on the Reconnaissance and Detection Expendable Rover for the U.S. Marine Corps. The autonomous route reconnaissance and clearance platform will provide remote standoff capability and increase the operational speed for route clearance personnel while removing them from the extremely dangerous task of driving vehicles over improvised explosive devices.

## Arctic Submarine Warfare

The lab also has been a leader in submarine research, particularly in how undersea platforms function in arctic environments. As early as 1946, shortly after his arrival at the laboratory, Dr. Waldo Lyon perceived the significance of enabling the US Navy to operate its submarines safely

and effectively in the Arctic. Though he was virtually alone in that conviction at the time, he and a group of scientists and engineers built a lab at the center to provide data for the crews of these vessels. He acquired a World War I coast defense mortar emplacement and had a 15,000-pound capacity bridge crane installed. He arranged for super-pressure chambers to be manufactured from 12- and 16-inch battleship gun barrels, and obtained a 22-million-electron-volt betatron, anticipating the requirement to X-ray sonar projectors.

Brief, tentative forays under the ice led to hours of careful navigation to avoid striking ice keels and icebergs port, starboard and straight ahead. A presidential citation summarized that Lyon and his staff had "made it possible for a submarine to navigate under the ice cap in the Arctic."



The Trieste, with two people on board, descended 35,800 feet to the bottom of Challenger Deep in the Mariana Trench.





The development of the Cable-controlled Underwater Recovery Vehicle (CURV) class of undersea vehicles began at the Pasadena Lab and its Long Beach sea range.

In the late 1970s, three lab personnel invented a Color Sonar for Underwater Object Collision Avoidance device. No US submarine went to the Arctic after 1983 without these inventors' patented device to avoid collisions with ice keels and similar dangers.

Fast forward to today, and SSC Pacific's work on the Enhanced Polar System Gateway project, which will provide continuous 24-hour, extremely-high-frequency (EHF) protected satellite communications (SATCOM) to forces operating in the North Polar Region, above 65 degrees north latitude. SSC Pacific essentially created a 3,000-mile extension cord between Clear Air Force Station in Alaska, where the terminals enabling users to connect to the system are located, and Camp Roberts in California, where the existing infrastructure is located.

This technology allows submarines to communicate with each other and back to shore, using services such as NIPRnet and SIPRnet as if they were connected into terrestrial infrastructure. In the future, as more naval communities and services such as the Coast Guard are tasked with Arctic missions, they will be able to hook into the terminals at Clear Air Force Station as well, providing their platforms with protected EHF satellite communications.

## Command and Control

From the development of the first digital command and control (C2) system through work on maritime C2 systems and fielding of mixed and augmented reality systems, the center has been at the core of Navy communications and electronics since its inception.

The Navy Tactical Data System (NTDS), developed in 1959 and first deployed in the early 1960s, was a computerized

information processing system for use in combat ships. Two decades later, NOSC upgraded the NTDS technology with liquid crystal displays.

Building on that innovation, the Global Command and Control System - Maritime (GCCS-M) was developed and fielded in 1986 as the Joint Operational Tactical System. GCCS-M is installed on all US Navy ships and many shore facilities globally. GCCS-M provides US and partner maritime commanders at all echelons with a single interoperable, integrated, scalable command and control system that fuses, correlates, filters, maintains and displays location and attributes information on friendly, hostile and neutral land, sea, and air forces.

These early information gathering, surveillance, and reconnaissance systems laid the foundation for ongoing work in the center's Battlespace Exploitation of Mixed Reality lab, which aims to provide warfighters with more effective and cost-efficient means of training.

## Satellite Communications

As the Navy Electronics Laboratory/Navy Electronics Laboratory Center, the organization was on the cutting edge of SATCOM technology in the mid-to-late 1960s. Employing satellites such as the Echo I communications satellite, the lab demonstrated the potential for fleet use of such innovative technology. Echo I was the first shipboard SATCOM terminal, and was installed on USS *Providence* (CLG 6) in 1968.

Echo I led to improved SATCOM systems, including the center's Navy Multiband Terminal (NMT), which debuted in 1997 and provides secure, protected and survivable



Progress is made in transforming a former World War I mortar emplacement site into the submarine facility, with the arctic pool built and filling with water.



connectivity. NMT is the next-generation maritime military satellite communications terminal for the Navy and coalition partners.

The center also assisted with engineering and fleet support for the Multi User Objective System (MUOS) satellite program, which successfully launched its fifth and final satellite into orbit in June 2016.

## Mine Countermeasures

Since 1972, the center has fielded several marine mammal systems, beginning with Mark 5 in the early 1970s. It employed California sea lions to attach recovery lines to objects of interest, initially antisubmarine rocket quality assurance rounds. The Mark 6 dolphin swimmer defense system was deployed to Vietnam in 1970 for the first operational deployment of marine mammals, which have been used frequently since. In the first days of Operation Iraqi Freedom, mine-hunting dolphins and their SSC San Diego trainers went to the combat zone with Navy handlers to work alongside divers and unmanned vehicles to clear the harbor of Umm Qasr of mines. The center maintains facilities in Bangor, Washington, and Kings Bay, Georgia, with upgraded swimmer defense system dolphins and sea lions supporting base security.

In an example of biomimicry, lab personnel developed the Mark 18 unmanned underwater vehicle to use side-scan sonar and video cameras to locate, detect and identify underwater mines and explosive ordnance. The Mark 18 units are small and easily portable by two people, making them ideal for deployments. In 2014, an SSC Pacific team responded to an urgent operational need to rapidly field the Mark 18, and responded with the state-of-the-art autonomous mine-hunting system.

## Advanced Materials

One of the premier facilities on Point Loma beginning in the 1970s was the Integrated Circuits Fabrication Facility. The facility produced both state-of-the-art circuits and limited runs of DoD-required electronics that were no longer commercially available. Early in 1988, there was a major upgrade that installed a new wafer implantation system, which increased silicon-on-sapphire wafer-size capacity to four inches.

The intellectual property associated with these circuit advances was the foundation of San Diego-based



The Mobile Detection and Response System (MDARS) interior vehicle, one of the center's first autonomous vehicles, is pictured patrolling the interior of a warehouse at Camp Elliot.

Peregrine Semiconductor, co-founded by two former NOSC employees who entered into a cooperative research and development agreement with NOSC in 1991. The agreement enabled the development of integrated circuits using thin-film silicon-on-sapphire submicron device technology, which was foundational for the company's UltraCMOS technology, an advanced form of silicon-on-insulator that used sapphire as the substrate. In October 2013, Peregrine announced it had shipped its two billionth UltraCMOS chip. The company was acquired by Murata in December 2014 for a total value of \$471 million.

With upwards of 600 projects underway at any given time and a 76-year history to account for, it would take a whole book to explain all of the advances made for the Navy and the nation courtesy of SSC Pacific researchers. Here's to many more years of naval innovation!

### About the authors:

**Katherine Connor** and **Patric Petrie** are staff writers at the Space and Naval Warfare Systems Center Pacific.



# A LOOK AHEAD

## PLATFORM DESIGN AND SURVIVABILITY

►► By Dr. Thomas Fu

**T**he next issue of *Future Force* will focus on the varied and diverse range of technologies that contribute to platform design and survivability. Future roles, future capabilities, and future threats are changing the way the Navy looks at ship design and platform survivability. US naval superiority in surface and undersea missions will continue to depend on the advanced capabilities of its ships, submarines, and small craft. The United States' strategic swing to the Pacific and increased focus on polar regions are creating ever-changing operational requirements for naval platforms. The development and fielding of advanced sensor systems and directed energy weapon systems not only is increasing but changing the nature of power and energy requirements—"power and energy are now in the kill chain." This increased capability also is impacting our shipboard thermal cooling and management systems. The use of new materials, including engineered composites, new hull designs (multihulls), and the advent of electronic maneuver warfare is changing the way the platform designers address survivability. The increased use of unmanned systems and advanced autonomy also are fundamentally changing how the Navy approaches the design and use of its maritime platforms.

The development of set-based design tools for surface ships and submarines is changing the way the Navy performs analysis of alternatives and develops platform design requirements. The development of shipboard power and energy design tools is well under way, enabling the design of these next generation platforms which will utilize the advanced power and energy generation, storage, distribution, and control technologies currently being developed. In addition, the development of state-of-the-art design environments that leverage optimization techniques, including multidiscipline optimization, is enabling platform design to enter a new era characterized by the use of high-fidelity numerical modeling and simulation tools. Using the DoD high-performance computing (HPC) centers resources and the HPC Modernization Program CREATE program, this integrated design environment has allowed for increased hydrodynamics, seakeeping, and structural loads information to enter the design spiral earlier and earlier, saving time and money while providing increased platform capability and survivability.

**Dr. Fu is the director of the ship systems and engineering research division at the Office of Naval Research.**

Photo by General Dynamics Bath Iron Works







Designing and building modern warships—such as the newly commissioned USS *Zumwalt* (DD 1000), show here under construction in Bath, Maine—is more than just building a hull and filling it with various technologies and expecting them to work together. Many of *Zumwalt*'s systems, such as its AN/SPY-3 radar, its electric propulsion system, and its advanced gun system, were invented for this ship—integrating them together brings new challenges.





The Office of Naval Research held its Technology Innovation Display at the Pentagon in Arlington, Va., on 24 June 2016 to showcase its past and future technologies and innovations as part of its celebration of its 70th anniversary. Photo by Austin Rooney.

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