Powered by Naval Research, from Discovery to Deployment

‘America’s Sea Services - her Navy and her Corps of Marines - have understood from the earliest days of the Republic that scientific knowledge of the unforgiving ocean, and ingenuity applied to the implements of their profession, would always be the indispensable servants of their valor’.

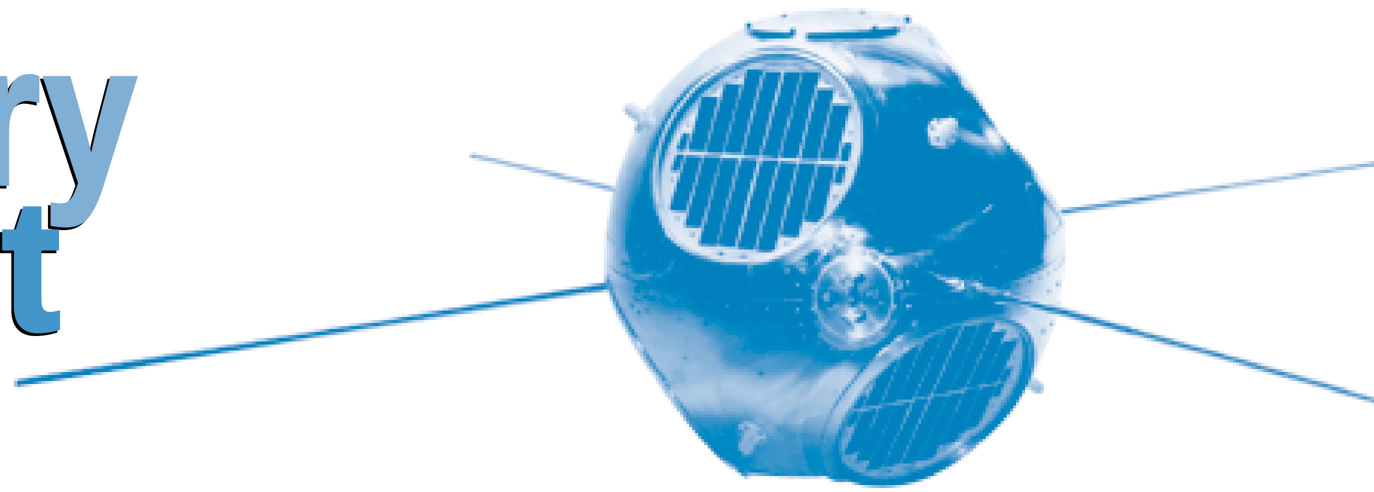
Today the Office of Naval Research leads the Department of the Navy’s science and technology community, but the Navy’s involvement with science and technology dates, of course, to its earliest years, long before the Office of Naval Research was created in 1946. This has been true since science was called ‘natural philosophy,’ and engineering was hardly mentioned at all. The Navy’s earliest systematic involvement in science and technology came, naturally enough, in the related fields of shipbuilding, oceanography, charting, mapping and navigation.

Early investment in Naval technology

One of the government’s first investments in Naval technology came in 1794, when Commodore John Barry was appointed Superintendent overseeing construction of a 44-gun frigate. Barry’s charge was to ensure ‘that all parts of the business harmonize and are conformed to the public interest‘. Barry was actually appointed by the War Department - the Navy Department was only established by Congress four years later when tensions with Algeria (and subsequently revolutionary France) reminded the country of why it needed a Navy. The Navy had acquired ships before, but Barry’s appointment marked a new determination to design and construct them systematically, with a view to getting the most value for public money.[2]

Four years after Barry set to work, the new Navy Department opened the Portsmouth Naval Shipyard near the mouth of the Piscataqua River on the Maine - New Hampshire border. Portsmouth was to give the Navy the ability to construct the newest class of frigates, which required more dock and warehouse space than was available in the private yards that had built the Navy’s older warships.[3] Naval construction continued to advance throughout the Nineteenth century and the Department of the Navy worked hard - often with the familiar handicap of severely constrained budgets - to keep pace in its shipyards and arsenals. Between the War of 1812 and the Civil War, the Navy would experiment with steam propulsion, breech-loading and shell-firing guns (advanced for the day), iron construction and telegraphy. Naval technological advance was of a piece with the general move toward industrialization of the time.

The Navy’s first steam warship - the ‘steam battery’ *Fulton* was built experimentally during the War of 1812. Although Congress would in 1816 authorize three more steam batteries, *Fulton* would remain the only example of her type until 1837. She spent most of her career laid up at the Brooklyn Navy Yard until her accidental destruction in 1829. The launch of a second *Fulton* in 1837 (during President Martin Van Buren’s first year in office) began in earnest the Navy’s transition from sail to steam propulsion. Related contemporary developments included improvements to ordnance and increased use of iron in construction. The latter in particular would contribute to the growth of American metallurgical industries.[4]

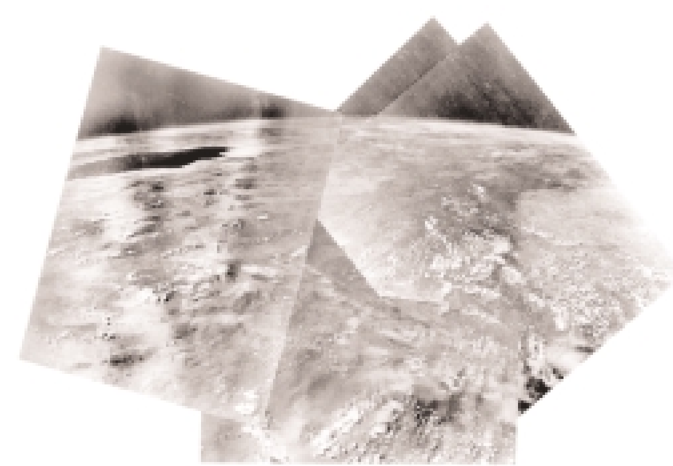


Solrad - Science and Naval capabilities. NRL’s SolRad I satellite, launched in 1960, studied the Sun’s radiant energy. Recently, it was revealed that SolRad I also had a classified mission, called GRAB, to identify and assess Soviet air-defense radar capabilities.
(US Navy photo - Naval Research Laboratory)

Oceanography and exploration

In 1829 the Secretary of the Navy asked his advisors on the Navy Board of Commissioners to give him some recommendations concerning the systematic provision of charts and instruments to the Fleet. Their report to him resulted in the formation of the Depot of Charts and Instruments on December 6, 1830 - the Navy’s first organization devoted to what we would now call science and technology. The Depot’s most famous director was Commander Matthew Fontaine Maury, who served from July 1842 until April 1861, when he went South to offer his services to his native Virginia. Maury organized methods of meticulously charting the oceans with a view to issuing sailing instructions. His pioneering work in hydrography led him to initiate studies of weather, the effect of the environment on ship routing and even marine biology. The results were published to the tremendous benefit of American commerce and, of course, to the American Navy. Maury stood firmly in the even-then old American tradition of pursuing science for its utility, and his example is instructive. It foreshadows the close relationship that has grown up among science, technology, prosperity and security.

Maury was a Naval officer and a scientist. His work was used to great advantage by American traders and Maury himself never lost sight of the importance the oceans held for the nation’s security. Maury’s work also foreshadows some current work in surface wave forecasting now yielding improved tools for optimal ship routing. Wave modeling and prediction have advanced beyond Maury’s imagination, but the practical purposes to which we put them are not far removed from the uses clipper captains found for Maury’s ocean current charts. ▸



The Navy's 1947 V-2 launch achieved a milestone in high altitude photography. These composite pictures cover over 500,000 square miles of the southwestern United States and northern Mexico from greater than 100 miles above the earth’s surface.
(US Navy photo-Naval Research Laboratory)

Lieutenant Charles Wilkes led his scientific flotilla from USS Vincennes. Wilkes sailed on August 18, 1838; it would take him almost four years to complete his mission.

Ocean science and technology, of course, were not the preserve of any single nation - certainly not the exclusive property of the United States - any more than they are today. But if an interest in the oceans was not exclusively American, it was certainly distinctively American. We have always been a seafaring nation. One expedition nicely captures the early history of ocean science and the United States Navy's commitment to the field.

On May 14, 1836, Congress passed its first appropriation for an oceanographic expedition. The bill's language authorized the Navy 'to send our a surveying and exploring expedition to the Pacific Ocean and South Seas; and for that purpose to employ a sloop of war and to purchase or provide such smaller vessels as may be necessary and proper to render said expedition efficient and useful'. President Andrew Jackson's Navy received the then-considerable sum of $300,000 to make it so.

This 'United States Exploring Expedition' would eventually be commanded by Lieutenant Charles Wilkes, who led his scientific flotilla from *USS Vincennes*. Wilkes sailed on August 18, 1838; it would take him almost four years to complete his mission. The scientific staff was appropriately varied - mineralogists, botanists, mathematical instrument maker, naturalists, taxidermists, artist, philologist and interpreter. Wilkes' charter and staff foreshadowed the synoptic, interdisciplinary character ocean science increasingly assumed as it matured. His expedition's most famous achievement was the demonstration that there was indeed an Antarctic continent, as opposed to mere fields of floating ice among a scattered archipelago. The region of Antarctica that lies between latitude 66° to 70° South and longitude 102° to 142° 20' East is known today as Wilkes Land, in the lieutenant's honor.[5]

Timekeeping and astronomy

The Depot of Charts and Instruments soon evolved beyond its original charter. In 1844 it moved to the Foggy Bottom neighborhood of the District of Columbia (setting up on a hill north of where the Lincoln Memorial now stands) and was reorganized as the United States Naval Observatory. This was a natural development. Open ocean navigation depended upon accurate timekeeping and astronomical observation and the Observatory provided standard time and astrometric information to the fleet. Ships in the Potomac could synchronize their chronometers to the regular dropping of the time ball - a large sphere that would be run down a pole precisely at noon each day. (The Naval Observatory marked the new millenium by ceremoniously lowering the old time ball as December 31, 1999 ticked over into January 1, 2000.)

Maury's interests were principally oceanographic, but he also occupied himself and his staff with astronomic observations. He made a notable discovery himself in 1846 when he observed Biela's Comet break up into two pieces. In 1854 Maury's establishment became the United States Naval Observatory and Hydrographic Office. It began publishing astronomical and nautical almanacs in 1855 (as it still does today); its scientific studies included measurements of the speed of light, astrometrics and telescopic observation. The Observatory's big 26-inch refracting telescope - called the 'Great Equatorial,' still useful and in use today - is the instrument Naval astronomer Asaph Hall used to discover the moons of Mars, Phobos and Deimos in August 1877. The Great Equatorial was the world's largest telescope when it was installed in 1873 and it kept this distinction for more than a decade.[6]

A technical education for Naval service

Any productive research community needs a way of refreshing itself. The young Navy needed Sailors who knew their trade and technically proficient officers to lead them. It was at first of a divided mind, however, as to how it could best train its personnel. John Paul Jones, who admired the French system of naval academies, advocated the establishment of a shore-based school for aspiring officers in imitation of the French model. He was unsuccessful. Most senior officers were comfortable with the practice, inherited from Britain's Royal Navy, of assigning 'young gentlemen' as 'midshipmen' aboard warships. The young gentlemen would learn their profession as apprentices to the ship's officers, sometimes with the assistance of an embarked schoolmaster.

The National Academy of Science continues to enjoy a close relationship with the Department of the Navy today: its Naval Studies Board is instrumental in evaluating and validating National Naval Responsibilities in science and technology.

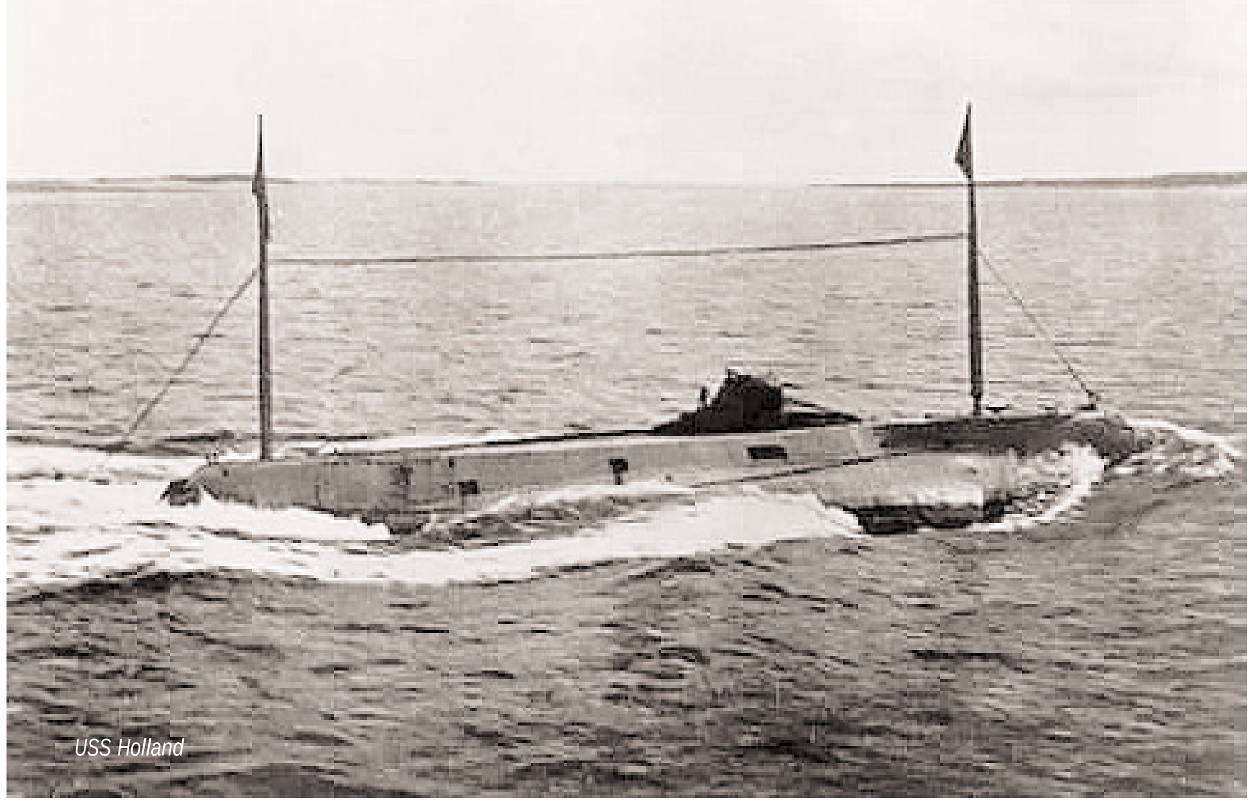
In 1802 President John Adams assigned schoolmaster's duties to the ships' chaplains. The results were predictably indifferent. Qualified as they were to give instruction in subjects like English and history, they were not prepared to teach the technical fields a young Naval officer needed to master. This was particularly true of mathematics, essential to any navigator. When Congress passed the appropriations for the first American ships of the line at the beginning of the War of 1812, the legislation specifically directed that a schoolmaster be attached to each new ship. This reform also proved inadequate. Maury, who found while a midshipman that he basically had to teach himself by working trignometric problems on round shot with a piece of chalk, later observed that, 'the duties of the school-room... are subordinate to every other duty aboard ship. There the midshipman is practically taught to consider his attendance at school as the matter of least importance in his routine'. Low pay, low status and generally poor treatment made the Navy unattractive to able teachers, and the formation of midshipmen suffered accordingly. Many found it difficult to pass the examination required for promotion to lieutenant.[7]

'Cram schools' - which did exactly what their name implies - were established at four locations between 1821 and 1838. These hardly offered a serious education, but sought rather to drill the principles of navigation into the midshipmen's poorly prepared heads. One of the schools, however, the one on the grounds of a sailor's retirement home in Philadelphia, was fortunate in attracting the services of a remarkably talented, Yale-trained mathematician. William Chauvenet not only made the best of his unpromising circumstances, but devised a plan of organizing an effective naval school within the scope of existing appropriations and legislation. Chauvenet's plan slowly gathered support until Secretary of the Navy George Bancroft persuaded the Secretary of War to transfer some surplus property in Maryland. Bancroft also combined the salaries of the 25 naval schoolmasters Congress had authorized into a budget. He ordered Commander Franklin Buchanan to open a proper academy at old Fort Severn, and on August 15, 1845, the United States Naval Academy opened for instruction. Bancroft charged Commander Buchanan with giving the midshipmen instruction in 'mathematics, nautical astronomy, theory of morals, international law, use of steam, the Spanish and French languages, and other branches essential... to the accomplishment of a naval officer'.[8]

The star of Bancroft's faculty was William Chauvenet. He remained at Annapolis for 18 years, leaving in 1859 to accept a professorship at Washington University in St. Louis. Chauvenet continued a pattern set by Maury - that of marshalling science for the public good - when he co-founded the National Academy of Sciences at President Lincoln's request in 1862.[9] The National Academy of Science continues to enjoy a close relationship with the Department of the Navy today: its Naval Studies Board is instrumental in evaluating and validating National Naval Responsibilities in science and technology. His legacy may also be seen in the legislation that established the Office of Naval Research in 1947. Along with a charge to foster research necessary to the Naval services, it authorized the Secretary of the Navy to promote science education.

Scientific education

In the post-Civil War years the education Annapolis provided one midshipman, Albert Abraham Michelson, prepared him to become a leader of American science in the late Nineteenth and early Twentieth Centuries. With his colleague E.W. Morley, Michelson conducted a famous experiment designed to determine an absolute, Newtonian frame of reference against which the motion of astronomical bodies could be measured. His intention was to observe relative variations in the speed of light through a hypothesized 'aether' thought to permeate space. Since light was known to behave in some respects as a wave, and since waves - like ocean waves - are energy moving through a medium - like the ocean's water - it was thought that light must require some analogous medium for its transmission.



USS Holland

And the speed of a wave relative to, say, a ship travelling in the same direction as the wave is lower than the speed of that same wave relative to a ship travelling in the opposite direction. Michelson expected to see a similar difference in relative speed when he measured light waves travelling in the direction of the earth's motion around the sun against waves travelling perpendicular to that motion. What he found when he and Morley did their experiment in 1887 was precisely no difference: light waves travelling in opposite directions had the same speed. This surprising result was one of the principal anomalies Einstein's Theory of Relativity would explain in 1905. In a sense we are still drawing on Michelson's work 113 years later, something it's good to bear in mind when we grow impatient with long horizons of basic research. And Michelson's great contribution was a null result, too, which should encourage all scientific risk-takers. Michelson would win the 1907 Nobel prize in physics, the first American to win a scientific Nobel. Many Naval scientists would follow in his footsteps in the second half of the Twentieth Century.

Technology in the Nineteenth Century

Naval technology advanced rapidly in the middle decades of the Nineteenth Century. Steam replaced sail, and iron hulls replaced wooden ones. The Navy again suffered from disuse and inattention until renewed appreciation for the nation's global interests prompted a modernization program in the 1880s. By the time the Spanish-American War broke out in 1898, the United States Navy had re-established itself with modern, steam-driven warships capable of operating anywhere from Havana to Manila Bay. Wireless telegraphy - radio - and shipboard electrical systems like searchlights opened up new fields of technology and lent a new interest to the fundamental sciences of physics and chemistry.

Two developments at century's end are particularly noteworthy. In 1898 Assistant Secretary of the Navy Theodore Roosevelt secured the appointment of two officers 'of scientific attainments and practical ability' to a joint Army-Navy commission convened to investigate the military potential of Professor Samuel P. Langley's powered heavier-than-air flying machine.[10] Langley's model was too small to carry a pilot (it had a wingspan of only 12 feet) but it indicated the arrival of a new field that in a few decades would prove vital to the Navy's and Marine Corps' combat capabilities.

One of Langley's contemporaries, schoolteacher and inventor John P. Holland, had been experimenting with submarines on New Jersey's Passaic River. Holland built his first steam-powered submarine in 1875. He would develop this into the world's first practical submarine. (Earlier efforts had been suggestive but ultimately unsuccessful. They included David Bushnell's *Revolutionary Turtle* and an 1801 effort by Robert Fulton.) The Navy bought Holland's sixth submersible on 12 October 1900 for $160,000. The 53.3-foot-long, 63-ton submarine, which the Navy called *USS Holland* (SS-1) (above), could dive to 75 feet. On the surface, a 45-horsepower internal combustion engine drove *Holland* at speed of up to six knots. Submerged, the vessel was powered by an electric motor run from storage batteries.

Holland, the Navy's first operational submarine, had a crew of six. It carried three torpedoes and a topside gun.

The legacy of these and other Nineteenth Century advances would be to make the Naval services increasingly proficient in - and dependent on - the leading technologies of their day.

The First World War

The United States Exploring Expedition and Asaph Hall's planetary studies belonged to the Nineteenth century's heroic age of scientific exploration. The Twentieth century's Great War interrupted, diverted and then in some ways hastened the course of scientific progress. The navies that fought that war - steel-hulled, steam-turbine - driven, and controlled by wireless - represented a great investment in military technology. The submarine and the airplane extended combat above and below the ocean's surface, and in doing so exerted their own pressure on technology. Much of this pressure would force the Naval sciences into new and often surprising problem sets. Ocean acoustics, for example, was born with great urgency as a scientific discipline that seemed to offer a counter to the submarine threat. Its present importance to geophysical science and marine biology were to emerge only much later.

The National Research Council catalyzed work in acoustics on the eve of American entry into the war when it persuaded the University of Chicago's Robert A. Millikan to mobilize its Physics Division for wartime service. Although serving as a major in the United States Army, Millikan's first project was a submarine detection system. He had no hesitation in pitching it to the Navy, rousting that service's Engineer in Chief, Admiral Robert Griffin, at his quarters early one morning in February 1917. Griffin received the reserve major (and Nobel laureate) in his robe and slippers, remonstrated good-naturedly about the early hour, but immediately saw the importance of Milliken's proposal. Griffin assured Millikan that the Navy would fund the project.[11]

Millikan put together an industry group in Nahant, Massachusetts. General Electric, Western Electric and the Submarine Signal Company were represented. He supplemented their in-house talent with university scientists and engineers who would work out of a Naval Experimental Station at New London, Connecticut, which Admiral Griffin established for their use. This collaboration between government, industry, and universities would produce the practical hydrophone, an indispensable tool of both oceanographic research and undersea warfare ever since.

Interwar years - the Naval Research Laboratory and cooperation with universities

After the war a certain residual military momentum continued to propel ocean science. The Naval Research Laboratory (NRL), for example, was planned during the war - Thomas Edison pushed the Navy to establish a modern research institute, and today a large bust of Edison at the entrance of NRL commemorates his role in the laboratory's founding - but it opened only in 1923. The laboratory made its mark quickly. Its first contribution was radar.

In 1922 two scientists at Naval Air Station Anacostia's Aircraft Radio Laboratory made an ▶

Roger Revelle, who at various times worked for the Navy's Hydrographic Office, Scripps, and the Office of Naval Research, was a pioneering oceanographer and one of the research administrators who set the pattern for modern federal support of scientific research.
(Photo courtesy Scripps Institution of Oceanography)

Harald Sverdrup aboard an old sail research vessel. Norway's Harald Sverdrup, one of the greatest oceanographers in history, came to America to work at the Scripps Institution of Oceanography, where he did valuable work on projects vital to the United States Navy.
(Photo courtesy Scripps Institution of Oceanography)

interesting discovery. Albert Hoyt Taylor - who would subsequently lead NRL's early radio research program - and Leo Young detected a ship moving in the Potomac River from a station at the confluence of the Potomac and the Anacostia Rivers, in what is now West Potomac Park. From the time it opened in 1923 NRL would remain deeply involved in radio research. By 1930 Young and Lawrence Hyland would be working to extend radar's usefulness to aircraft detection.[12]

But worsening economic conditions were unfriendly to large and expensive scientific projects. A remarkable series of opportunistic collaborations between individuals and institutions interested in oceanography, however, set a pattern for Naval support of scientific research in universities. Scripps, Woods Hole, and the University of Washington all became important centers of ocean science at about this time. Columbus Iselin of Woods Hole was one of the most prescient leaders of academic collaboration with the Navy in ocean research. The Navy gave vital assistance to these institutions. During and after the Second World War such collaboration would become common in other sciences as well.

Interwar years - development of Naval aviation

Naval aviation antedated the First World War. Naval observers had watched public demonstrations staged by the Wright brothers in 1908, and on December 2 of that year Rear Admiral W.S. Cowles, Chief of the Bureau of Equipment, submitted a report on aviation that outlined specifications for a craft capable of operating from naval vessels on scouting and observation missions. The report also discussed the tactical advantages that capability would bring and recommended that aircraft be purchased and 'placed in the hands of the personnel of the Navy to further develop special features adapted to naval uses'. In August 1909 the Secretary of the Navy disapproved a request to purchase two flying machines on the grounds that the technology was still too immature, but the Navy continued to follow developments in the field. On November 3, 1909 Lieutenant George C. Sweet rode as a passenger in an Army Wright at College Park, Maryland, becoming the first Naval officer to go aloft in an airplane. In 1910 Captain Washington I. Chambers arranged for Glenn Curtiss and Eugene Ely to demonstrate the Naval potential of aviation. The first Naval officer began flight training in 1911. That year also saw the Navy's first appropriation for aviation.

At the end of the First World War Naval aviation was still in its infancy. On March 7, 1921, it received its first great leader when Captain William A. Moffett became Director of Naval Aviation. On August 10 of that year, Moffett, by then a Rear Admiral, would take command of the newly established Bureau of Aeronautics. He would prove an effective and visionary advocate of Naval aviation and technological advance until his tragic death on April 4, 1933, in the crash of the rigid airship *Akron* (ZRS-4) off Barnegat Light, New Jersey.[13]

The course of aeronautical development was powerfully affected by Congressional action. The Morrow Commission of 1925 and the Morrow Act of 1926 set Naval aviation on a firm foundation. Experiments with *USS Langley*, a converted collier that served as the Navy's first aircraft carrier, greatly advanced the state of the art and the Navy continued to evolve carrier doctrine and technology throughout the 1930s.

Naval aviation would continue the tradition of exploration begun in the Nineteenth Century by Lieutenant Wilkes. On November 29, 1929, Admiral Richard Byrd became the first person to fly over the South Pole - one of the great aeronautical achievements of the age.[14]

The Second World War

As is unfortunately so often the case in the modern history of science, war again gave decisive impetus to research. Between 1941 and 1945, pursuit of victory on the world ocean led to rapid advances in basic disciplines like ocean acoustics and in basic tools like the bathythermograph. Athelstan Spillhaus of M.I.T. had invented the bathythermograph between the wars as a scientific instrument. While a clever device, in its original form the bathythermograph was an awkward, clumsy cage. At Woods Hole in 1940 Allyn Vine and Maurice Ewing refined Spillhaus' conception into an instrument resembling those that remain in use today - the streamlined projectile that can be shot rapidly to great depths. It would prove its worth to the Navy during the war.

The Navy understood very well during the Second World War that science had become essential to victory. This understanding reached from the Chief of Naval Operations to the sailors whose lives were daily on the line. One tribute is memorable for the way it captures a scientist's direct, personal contribution to one ship's crew. On November 6, 1944, the commanding officer of the submarine *USS Guitarro* (SS 363) sent a bathythermograph trace to the staff of the Woods Hole Oceanographic Institute. He accompanied it with this letter:

The Engineering Officer is happy to be able to forward this card because it means we were able to 'walk away' from this one. This card was made following a successful attack on a heavy cruiser. As we hit 300 feet the countermeasures started which severely damaged this sub. We were able to ▸

In August 1909 the Secretary of the Navy disapproved a request to purchase two flying machines on the grounds that the technology was still too immature.

stay under the sharp (temperature) gradient at 240 feet and gradually pull away from the scene of the attack licking our wounds. The seven [enemy] escorts continued to harass us, but their efforts became less and less fruitful as we moved away under the layer. My sincere thanks to Allyn Vine of Woods Hole Institute for the time he spent explaining the value of BT (Bathythermograph) observations to me. When we were finally able to come to periscope depth, the escorts were still getting an echo back at the scene of attack and dropping sporadic charges. We on the SS363 have always believed in the BT, but this attack made a salesman for BT out of us.

Other scientists made their own wartime contributions, far too many to enumerate here. I will note only two more, and I believe both are notable because they prompted the creation of new oceanographic sub-disciplines. Walter Munk, a protégé of Harald Sverdrup at Scripps, was asked by the Navy in 1942 to study the problem of predicting surf conditions. Work along these lines would be needed to support Operation Torch, the trans-Atlantic invasion of Vichy French North Africa, planned for October of that year. Munk began with the results of amphibious exercises in North Carolina and continued to some of the first systematic work on what we would eventually call coastal processes. The value of these inquiries to the Marine Corps is obvious. Marines paid with their blood in the dodging tides at Tarawa for the gaps in our understanding of littoral processes. The immediate response was the formation of Underwater Demolition Teams (UDTs) for pre-invasion reconnaissance and obstacle clearing, but the problems of amphibious warfare also prompted Naval investment in physical oceanography that would provide better understanding of conditions in the littorals.

Another team, established by Roger Revelle of Scripps and led by the extraordinary Mary Sears of Woods Hole, worked out of the Navy's Hydrographic Office. 'Hydro' coordinated the collection of a vast quantity of environmental data and analyzed it into products the Navy and Marine Corps used to their great advantage. We have honored both Revelle and Sears today by naming two of our most modern oceanographic vessels for them.

Wartime organization of science - the Office of Scientific Research and Development

It became clear to President Franklin Roosevelt that the nation's scientific talent would be indispensable to victory in the Second World War. He appointed Dr. Vannevar Bush of the Carnegie Institution (and before that a professor at M.I.T.) to mobilize this talent. Bush became head of the Office of Scientific Research and Development, and in that capacity organized university scientists in particular to address matters of pressing technical importance.

The Navy cooperated with OSRD and continued its own research through the Bureaus. (Today's Systems Commands are the descendants of the old Bureaus, and like the Bureaus they continue to sponsor high-quality science and engineering. Their Warfare Centers remain important, powerful centers of research and development.) Naval work involved the same partnership between universities, industry and government laboratories that prevailed elsewhere during the war. Research administration as we know it today was basically invented in the late 1940s by the same small group of Navy scientists - some regulars, others wartime reservists who went on to distinguished civilian careers. They called themselves the 'Bird Dogs' because their wartime duties included making inspection visits to Naval research facilities on behalf of the Secretary of the Navy's Coordinator of Research and Development (first Dr. Jerome Hunsaker, then Admiral Julius Furer) - 'bird-dogging' the labs for the Coordinator. They were all relatively junior officers with a lot of talent and a lot of energy: James Wakelin, Bruce Old, John Burwell, Ralph Krause, Thomas Wilson, James Parker and Gordon Dyke. Their leader was the remarkable Captain Robert Dexter Conrad, after whom the Navy named its top award for scientific achievement.

The Navy did not forget the value of science when the war ended. The first permanent federal agency dedicated to the support of scientific research was of course ONR.

The Organization of Science in the Postwar Era

The Navy did not forget the value of science when the war ended. The first permanent federal agency dedicated to the support of scientific research was of course ONR. The Navy understood that a robust scientific community was vital to the national security and so directed much of its support to individual scientists and the institutions - mostly universities - where they worked.

We were fortunate as well in having some visionary political leaders who understood what science and technology meant to America. When Vannevar Bush, the intellectual father of American science policy, needed a Congressional champion, he found one in Washington's Senator Warren Magnuson. Magnuson introduced legislation incorporating Bush's ideas on the very same day President Truman's White House released Bush's famous report, Science, the Endless Frontier. Magnuson would remain a strong friend of science throughout his long career. He provided ONR with crucial legislative support; he gave that support also to ONR's younger sister, the National Science Foundation, and its cousin, the National Aeronautics and Space Administration. The legislation that effectively created our exclusive economic zone is also named, rightly, in his honor: the Magnuson Fishery Conservation and Management Act. Warren Magnuson can stand as an example of the enlightened political leadership that has so benefited the ocean sciences.

The founding of the Office of Naval Research and the postwar scientific establishment

Back in February of 1949 Scientific American predicted that temporary building T-3 on Constitution Avenue's Navy Row would be in use for another generation or so.[15] T-3 seems not to have lasted the full traditional 30 years and is now long gone, along with the rest of Navy Row. Its tenant, the Office of Naval Research (ONR), years ago moved from the government-owned temporary quarters of its founding into rented commercial office suites across the Potomac in Arlington.

As the conditions of its tenancy have modernized, so have its relationships with its various constituencies - the university scientists it undertook to support in 1946, the Fleet it exists to serve, the Congress and the Defense establishment it answers to, and the industrial concerns that have been its occasional partners for more than half a century. ONR set the pattern for the federal government's long-term commitment to scientific and technological research. It served as the model for the National Science Foundation, and much that we now take for granted in the government-university-industry relationship worked itself out between Constitution Avenue and the Ballston district of Arlington. The history is worth some reflection, because it is remarkable that, as one scientist put it, Santa Claus should have worn a blue suit.[16]

Pioneering the support of basic research

The Second World War saw, of course, a vast increase in federal support for scientific research. University and industrial researchers received funds administered by the Department of the Navy, the War Department and OSRD. Their work was driven by the urgency of such problems as antisubmarine warfare, air defense and, most prominently, the development of nuclear explosives. OSRD was very much a wartime improvisation unlikely to survive into peace, and by early 1944 officials concerned with public support of science had begun to think about the architecture of a permanent federal establishment that would support scientific work.

The master design of postwar research investment appears in Vannevar Bush's famous study Science, the Endless Frontier, in which he outlined the national importance of basic research and proposed that a National Research Foundation be established. Issued in July 1945 in response to a request President Roosevelt had made the previous November, Bush's report outlined 'five fundamentals'.

There are certain basic principles which must underlie the program of Government support for scientific research and education if such support is to be effective and if it is to avoid impairing the very things we seek to foster. These principles are as follows:

(1) Whatever the extent of support may be, there must be stability of funds over a period of years so that long-range programs may be undertaken.

(2) The agency to administer such funds should be composed of citizens selected only on the basis of their interest in and capacity to promote the work of the agency. They should be persons of broad interest in and understanding of the peculiarities of scientific research and education.

(3) The agency should promote research through contracts or grants to organizations outside the Federal Government. It should not operate any laboratories of its own.

(4) Support of basic research in the public and private colleges, universities, and research institutes must leave the internal control of policy, personnel, and the method and scope of the research to the institutions themselves. This is of the utmost importance.

(5) While assuring complete independence and freedom for the nature, scope, and methodology of research carried on in the institutions receiving public funds, and while retaining discretion in the allocation funds among such institutions, the Foundation proposed herein must be responsible to the President and the Congress. Only through such responsibility can we maintain the proper relationship between science and other aspects of a democratic system.[17]

Bush did not, as many people believe, argue that basic science ought to be pursued for its own sake only. He certainly believed that science was an inherently fulfilling human activity, but that was not why he thought the federal government should support it. Good engineer that he was, Bush understood very clearly that basic science eventually enriched human life in directly practical ways. (His three examples of this for his 1945 audience were radar, penicillin, and pay envelopes.) He also understood that the specific benefits of basic research were imperfectly predictable at best, and that they were realized only in the relatively long term.

Bush also had the ruins of totalitarian science in Germany to provide a lurid example of what happens when you let ideologues and demagogues tell scientists and engineers what to think. That kind of political involvement strangles science. Totalitarian regimes by their nature eliminate alternative sources of power, of organization, of legitimacy - those parts of civil society we recognize as universities, foundations, professional societies, even informal teams of like-minded investigators. These are the very things that keep science and engineering alive and vital.

The national science policy Bush proposed was open and institutionally pluralistic. It was a way of doing business that suited both science and democracy. The federal government would support scientists in a variety of institutions. It would choose whom to support mainly on the basis of the scientific merit of their work and the results would enrich the life of the nation.

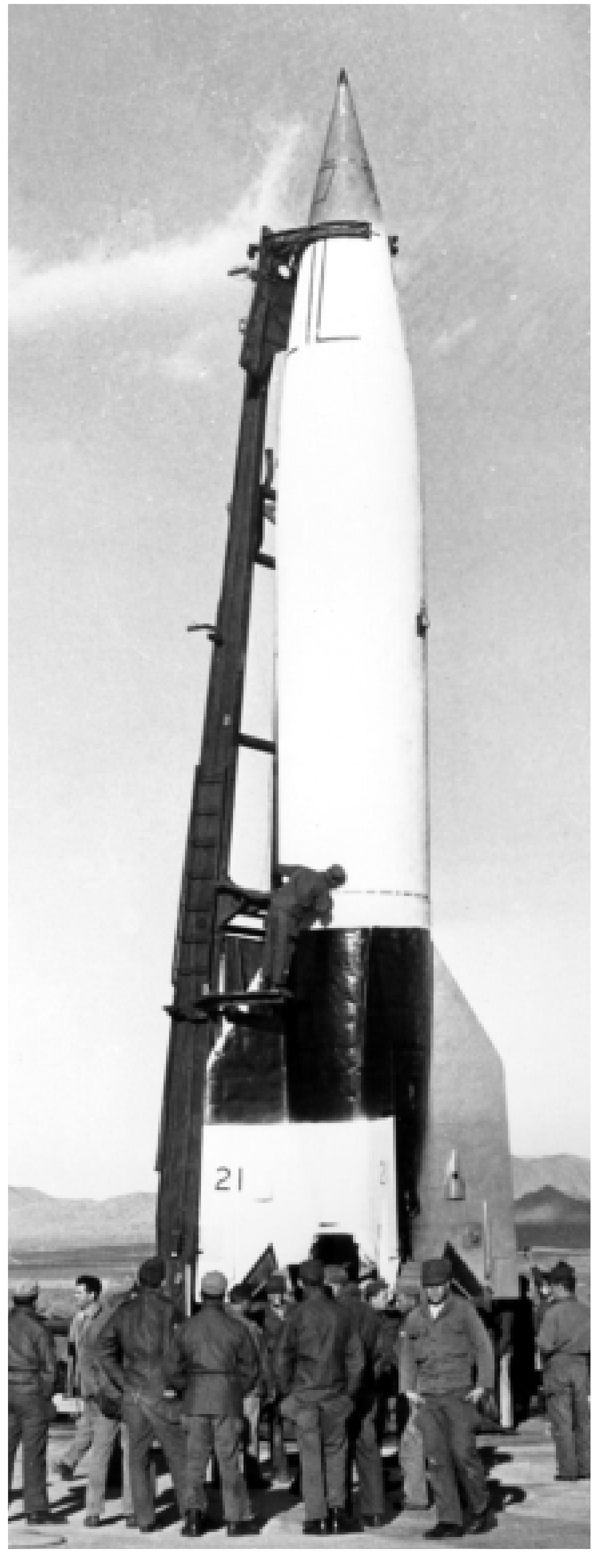
The foundation that Bush envisioned was eventually realized in the National Science Foundation, but various wrangles held up the NSF's establishment until 1950. In the meantime the nation's scientists continued to receive fairly extensive federal support from an agency assembled in 1946 out of various Navy Department offices - the Office of Research and Invention, soon renamed the Office of Naval

Research, with Vice Admiral Harold G. Bowen as its first commanding officer. President Harry S. Truman signed the bill that established ONR on August 1, 1946:

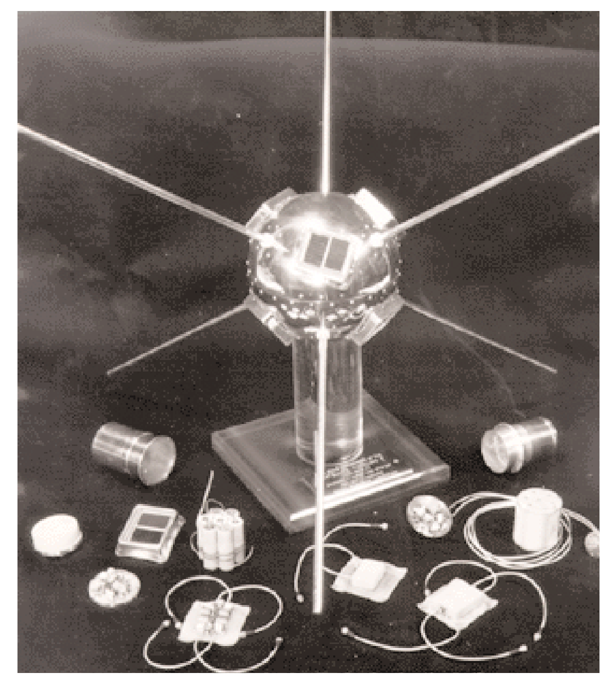
> Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, that there is hereby created and established in the Office of the Secretary of the Navy an Office of Naval Research, which shall be charged with such duties relating to (1) the encouragement, promotion, planning, initiation and coordination of naval research; (2) the conduct of naval research in augmentation of and in conjunction with the research and development conducted by the respective bureaus and other agencies and offices of the Navy Department; and (3) the supervision, administration, and control of activities within or on behalf of the Department of the Navy relating to patents, inventions, trade-marks, copyrights, royalty payments and matters connected therewith; as may be prescribed by the Secretary of the Navy.
>
> **The Senate report on the bill offered this perspective on Congressional intent:**
>
> The purposes of this bill are to establish an Office of Naval Research in the Department of the Navy; to plan, foster and encourage scientific research in recognition of its paramount importance as related to the maintenance of future naval power and the preservation of national security; to provide within the Department of the Navy a single office, which, by contract and otherwise, shall be able to obtain, coordinate, and make available to all bureaus and activities of the Department of the Navy world-wide scientific information and the necessary services for conducting specialized and imaginative research; to establish a Naval Research Advisory Committee consisting of persons preeminent in the fields of science and research, to consult with and advise the chief of such office in matters pertaining to research.[18]
>
> The House report offered these thoughts:
>
> Research, test, and development are vital to the Navy in effectively and properly carrying out its responsibilities. Activity along these lines is of long standing. It is directed primarily toward the development of new weapons and to the improved strategic use of older weapons. The emphasis is on the functional use of things or combinations of things in a military sense. Functional military use however is not limited to destructive applications. Developments in the design of ships and aircraft and improvements in their power plants; advances in the fields of medicine and surgery; and creative and applied research in electronics are but a few of the Navy's research and development activities that in their constructive application promote the Nation's welfare and health. Other results of Navy research might be enumerated. Among them would be the development of the Norden bombsight; the first government sponsored study in the practical application of atomic energy; fundamental research, and development of radar and the development of the proximity fuze.[19]

ONR's support for basic research would prove

Navy V-2 tests. NRL's V-2 rocket mission being prepared for launch from White Sands, New Mexico in 1947. The mission obtained photographs related to rocket performance and geographic features on Earth.
(US Navy photo - Naval Research Laboratory)



Dr. Robert Goddard. Dr. Goddard, the "father of modern rocketry" who enjoyed a long association with the Navy, examines rocket components after 1937 test flight. (US Navy photo - Naval Research Laboratory)



Vanguard. NRL's Vanguard I, the second satellite in space, weighed only 3.2 pounds with a diameter of 6.4 inches. Its miniaturized electronics payload included six solar cell assemblies, a battery pack, radiation sensors, two transmitters, and six antennas. It is the oldest man-made object still in space. (US Navy photo - Naval Research Laboratory)

remarkable. In February of 1949 Scientific American ran a feature article on ONR whose full title was as positive as any government flack could desire: 'The Office of Naval Research: It has pioneered so fruitfully in the support of basic science that it stands as a model for the planned National Science Foundation'.[20] Model and pattern it was, departing from Bush's five fundamentals only in that it had responsibility for the Navy's corporate laboratory, the Naval Research Laboratory (NRL).

It exerted its influence in other ways, too. Alan Waterman, the Yale physicist who had served as ONR's first chief scientist, became the first head of NSF. (ONR has since its inception retained the wartime practice of having a senior uniformed officer as director (Rear Admiral Bowen was the first Chief of Naval Research) and a senior scientist as the director's immediate deputy. The pattern has become common, designed to ensure that a research organization enjoys both military clout and scientific credibility.)

In those immediate postwar years several historical accidents came together to produce a climate of opinion in which support for pure science was relatively uncontroversial. Americans credited big science, pure science, with having done much to win the war. Indeed, even given the traditional American fascination with invention, progress and technology, the Second World War forced technical and scientific advance into popular thinking about defense to an unprecedented extent. People remembered the shock of the Japanese attack in the Pacific, and how closely run the convoy battles of the North Atlantic had been, and wanted never to be caught short again. Technology would be a principal guarantor of security. They also had vivid memories of the Depression and sought ways of escaping the periodic downturns of the business cycle.

Science and technology seemed to meet these national needs. A fresh influx of demobilized students returned to American universities, there to enjoy the fiscal legacy of wartime research. Academic scientists had grown accustomed to doing government work, and continued to receive a sympathetic hearing from ONR's project officers.

The original permanent basic research establishment, ONR, has evolved over the last 50 years into something more diversified and in some respects more accountable than its founders envisioned. A major change occurred in 1992, when the old Office of Naval Technology (ONT) and Office of Advanced Technology (OAT), separate agencies that reported to the Chief of Naval Research, were folded into ONR. With the absorption of ONT and OAT, ONR was reinvented in a way that returned it to its roots, resuming responsibility for applied research and technology demonstrations. Since then ONR has worked to integrate the research it supports and to produce an investment portfolio that does justice to its several constituencies: Congress, the Fleet, industry, and universities.

The move to integration.

As their names imply, the Office of Naval Technology and the Office of Advanced Technology had been responsible for research that had a clear and relatively short-term payoff in terms of devices and techniques that the Navy and the Marine Corps could actually use. ONT brochures that ▸

survive in ONR's archives are filled with pictures and descriptions of hull coatings, radar masts, missile control surfaces and the like. Development of such items falls into the Department of Defense budget activities known as 6.2 and 6.3 funding: applied research and advanced technology demonstration. The Office of Naval Research, by contrast, had been largely involved with 6.1 funding: basic research. Roughly speaking, basic research seeks to advance understanding of processes and properties. Applied research then seeks ways of altering, manipulating, or using those processes and properties. Advanced technology demonstrations, finally, involve taking the results of applied research and actually fabricating things that perform some useful function, that provide some desirable capability. Higher numbered budget activities-6.4 and up - no longer belong to the administrative world of science and technology proper, but rather to acquisition, operations and maintenance and so on. They lie outside the scope of this discussion, but it should be borne in mind that results from 6.1, 6.2, and 6.3 ultimately feed projects in those other categories as well.

The picture the budget activities suggest when one lays them out like this, is an eminently rational one. Each level hands on the product to the next for refinement in a smooth, linear, efficient progression - a kind of assembly line that mills concepts into hardware. In fact, however, the research enterprise is so notoriously difficult to integrate in such a straightforward manner that counsel against naïve optimism is common. Nobel laureate Joshua Lederberg is often quoted among research managers as advising that 'the best way to achieve scientific progress is to resist the temptation to control it'. Paul Nitze as Secretary of the Navy encountered the perennial challenge of showing that research pays by demonstrating that basic work actually generated some particular weapon, tool or system. He talked about this when he addressed ONR's vicennial celebration in 1966:

I would note that the exercise of actually attempting to trace such parentage is often more academic than fruitful, for the trace quickly becomes dim and no rational sequence seems to prevail. This is inevitably the nature of creative ideas, basic answers and basic data for which - once we have them - applications are seen. Yet data by themselves are sterile; it is the ephemeral idea that makes them useful.[21]

Nitze's words were by no means a counsel of despair, and were not taken as such. ONR's assumption of responsibility for basic, applied, and demonstration research suggested anew that efficiencies might be realized from vertical integration. If work supported from all three budget activities - 6.1, 6.2, and 6.3 - could become mutually supporting, all of the customers would win. Congress would get a properly frugal disbursement of public funds, the operating forces would get capability options they could exercise at their discretion, industry would get the benefit of high-risk research and development and university scientists would get relatively unrestricted support for projects of their own selection and design. ONR believes it has found the appropriate agents of such integration in the staff scientists who serve as its project managers. They have the appropriate technical expertise and scientific credibility to administer awards and recognize quality - in the marketplace of science and technology, they are the Navy's ultimate smart buyers.

The Cold War

The science the nation got in return for its support won us the great twilight struggle of the Cold War. It in no way diminishes the contributions so many others - nonscientists, political leaders, scholars, journalists, industrialists, workers, soldiers, airmen, sailors and Marines - made to Cold War victory to single out scientific achievement. Science proved the sine qua non of our surviving the most dangerous period in human history and of our prevailing over the only adversary we have ever faced that was capable of extinguishing us as a nation. The famous symbol of Cold War scientific competition is of course Sputnik and the rival space programs it instigated, but a more serious, and more dangerous, competition was carried on in the oceans. And in that competition Naval science and engineering gave us the decisive edge.

To take one of the most important cases, our superiority in strategic ballistic missile submarines provided us with our ultimate, effectively invulnerable, deterrent. That superiority, like all others, was a relative one - we were able to secure our own force while holding the Soviets' at risk. Our ability to do these things rested directly on post-war ocean science. We would have been nowhere, to take one example, without our understanding of the deep sound channel. The capabilities of our passive acoustic anti-submarine warfare systems - about which the Soviets certainly suspected the worst - kept the Soviets from wanting to begin a strategic exchange. They knew they could not win it. Our understanding of the ocean enabled us to hide our submarines; they were never able to exploit the ocean environment well enough to find us.


Project Starshine. Project Starshine, a public outreach program by the Navy and NASA involved more that 25,000 students in seventeen countries. Here, the Project Director, Dr. Gill Moore, assists students to polish the mirrors that were attached to the sphere. The mirrored sphere, ejected from the Space Shuttle, reflects sunlight allowing students to learn how to track an orbiting satellite.
(US Navy photo - Naval Research Laboratory)

In the early 1950s the Navy began the installation of the Sound Surveillance System (SOSUS). The wartime discovery of the mixed layer by Allyn Vine and Brackett Hersey, and the coordinate discovery of the deep sound channel by Maurice Ewing and Lamar Worzel suggested new possibilities for undersea surveillance. Their work prompted the Navy to install a series of long, fixed hydrophone arrays positioned at key locations on the sea bottom. The acoustic data were processed ashore. SOSUS was always upgraded to keep pace with advancing submarine technology. In the Cold War's poker game, it gave us the ability to read the other guy's hand. Today SOSUS and other long-range acoustic measuring systems based on its technology are tools for other uses.

The Navy had recognized in the 1950s that nuclear-powered submarines and ballistic missiles had become the decisive strategic implements of national power. It understood that our ability to operate these weapons successfully, and to counter the Soviet submarine threat, would be crucial to deterring general war. This understanding began to coalesce during a famous series of meetings at Woods Hole, Massachusetts. There Naval and scientific leaders blocked out the research and development strategy that would serve us so well throughout the Cold War. Admiral Arleigh Burke, then Chief of Naval Operations, asked the National Academy of Sciences' Committee on Undersea Warfare to study the implications of nuclear propulsion for anti-submarine warfare. In response to the extraordinary effectiveness of the first-generation nuclear submarines in fleet battle exercises, Admiral Burke commissioned in 1957 a study of anti-submarine warfare responses to the new nuclear boats. He asked the Committee on Undersea Warfare to suggest possible responses to the new technology, a matter of some urgency since the Soviets were developing their own nuclear vessels and the United States anti-submarine warfare community as yet had not found a way of countering this emerging threat.

The Committee undertook Project Nobska (named after the Nobska lighthouse near Woods Hole) in response to Admiral Burke's request. The Project's co-chairs were Ivan

Getting of Raytheon and Columbus Iselin of Woods Hole. They met the requirements of their charter, but they also saw another opportunity for the Navy. A constellation of new technologies in submarine design, missile propulsion, warhead design and missile guidance was forming in the mid-1950s. The Committee saw that these could collectively realize a new, secure, reliable form of strategic deterrence, and proposed to the Navy an entirely new class of warship - the ballistic missile submarine. Project Nobska thus became one of the direct ancestors of the Polaris, Poseidon, and Trident programs, which secured the American deterrent through the most dangerous years of the Cold War.

Another outcome of Arleigh Burke's enlightened stewardship of the Navy was Project TENOC (from 'The Next Ten Years in Oceanography'), a study whose recommendations Burke formally endorsed on January 1, 1959. Under TENOC the Navy underwrote the establishment or expansion of the oceanographic programs at universities around the country. As Burke put it, 'The number of oceanographers presently available in the United States are insufficient to meet the increasing military and civilian demands for their services. The several institutions sponsoring oceanographic curricula have indicated their willingness to increase their enrollments in this discipline. Involved in this expansion are requirements for additional sea-going and shore-based laboratory facilities'. The fleet of Navy-owned, university-operated research vessels whose use we enjoy today are one of the legacies of Project TENOC.

TENOC's strategy, a refinement of the sort of partnership that has long marked the history of oceanography, was a success. The scientists got support for their research; the Navy and the nation got the benefits of their results. This diverse, decentralized approach to science let us take advantage of the creative energies of the great founders of modern ocean science and engineering. We owe these men and women more than we could possibly repay.

Partnership with academic researchers

ONR sought from the time of its founding to secure the principle of federal support of basic research. In the early years this was relatively easy, as it involved to a great extent the distribution of remaining wartime largesse. The nation was also dazzled by recent scientific triumphs, convinced that scientists had done much to win the war, and determined never to undergo another shock like Pearl Harbor. This easy situation, however, would not long endure. Congress wanted to see that the taxpayers were getting some payoff for their contribution, that money wasn't simply being shoved down the rat hole of 'a lot of professor theories and all that stuff' as Senator McClellan put it.[22] For all that the United States has enjoyed, for the past 50 years, a healthy, extraordinarily creative community of research universities.[23]

Naval basic science - 46 Nobel laureates and counting.

Most readers will know that the United States has dominated the Nobel Prizes since the Second World War. Some will understand that the fruitful partnership between the government, universities and industry is largely responsible for the remarkable record of American science over the last half century. But fewer are aware of the Department of the Navy's role in achieving that record.

It is indeed notoriously difficult for non-scientists to see the payoff in support for basic science. ONR has funded 46 Nobel laureates, and a discussion of their work is as good a way as any to show how basic research affects us. The effects are by no means always immediate, nor are they even readily predictable. But if we follow the history of the Nobels since 1950, we can see some fascinating trends that give us some hints about the future. The first ONR-supported investigators won their prizes in physics, chemistry, and medicine. These fields will reappear over the next four decades, as will the families of important applications - material science, chemistry, biochemistry.

The first Naval Nobel was won by Felix Bloch, who was honored in 1952 with the prize in physics 'for developing techniques of magnetic measurement in atomic nuclei'. ONR-sponsored scientists who win Nobels are only the most visible members of the Naval scientific and technological community. But they nicely evoke the importance of the close working relationship ONR has formed with America's great university-based researchers.

ONR has funded 46 Nobel laureates, and a discussion of their work is as good a way as any to show how basic research affects us.

And laureates like Jerome Karle remind us of the importance of Naval research facilities like NRL. A Naval Research Laboratory scientist won the Nobel in chemistry in 1985, and his colaureate's work was also sponsored by ONR. NRL's Jerome Karle and his colleague Herbert Hauptmann developed a way of directly inspecting the structure of atoms by evaluating the electron densities revealed by X-ray crystallography. Their technique enabled chemists to advance their work in at least two crucial areas: biochemistry (where a precise knowledge of the structure of protein and other molecules is essential to understanding their action) and the molecular mechanisms of chemical reactions. Their citation notes their 'outstanding achievements in the development of direct methods for the determination of crystal structures'. Dr. Karle continues his work today at the Naval Research Laboratory. Note how many of these prizes are awarded for the invention of a technique or an apparatus. That is very much in the spirit of Alfred Nobel, who wanted especially to honor science that yielded practical applications. ▸

The pictures in this file were taken aboard the Canadian Coast Guard research vessel *Frederick Creed* while she was engaged in Office of Naval Research sponsored studies off the North Carolina capes in December 1999. The boom shown in the pictures holds finely calibrated devices for making extremely precise observations of the ocean-atmosphere interface, the surface of the water where wind and waves interact in extraordinarily complex ways. The mast depicted in one photograph contains sensitive anemometers for measuring wind speed. The project *Frederick Creed* participated in - the Shoaling Waves Experiment, or SHOWEX - is a good example of interservice and international scientific cooperation. Sponsored by the Office of Naval Research with lead scientists from the University of Miami and support from the U.S. Army Corps of Engineers, SHOWEX made important contributions to our understanding of the complex physics of shallow waters. The *Frederick Creed* carried Canadian oceanographers and hydrographers as well as Americans. (*US Navy photos—Office of Naval Research*)

Walter Kohn's work in quantum chemistry has shown us how to use advanced mathematics to understand enormously complex systems. Kohn made a fundamental advance in quantum chemistry by showing that it is unnecessary to consider and calculate the motion of each individual electron in a molecule in order to describe reactions that molecule undergoes. One can study molecules instead by knowing the average number of electrons located at any one point in space. It is possible, for example, with Kohn's computationally simpler method to explain how enzymatic reactions occur. Density-functional theory is now one of the most widely used tools of quantum chemistry. ONR has enjoyed a long and close relationship with Dr. Kohn over the past several decades. The citation in his 1998 chemistry Nobel recognizes him 'for development of the density-functional theory'.

The next generation of scientists and engineers will come from young researchers now just undertaking their careers as graduate students or junior faculty. The importance of involving these talented Americans - as citizens - in research that helps provide for the common defense can scarcely be exaggerated. ONR provides the Navy and Marine Corps with a presence on the campuses of our research universities that offers much to both the military and civilian sectors.

ONR continues to look for the best talent it can find among young investigators, and continues to foster mathematics, science and engineering education at all levels. One of its initiatives for inspiring path-breaking work is its promulgation of the Naval Science and Technology Grand Challenges. These are visionary challenges that will answer a compelling Naval need some 30 to 50 years in the future, designed to make scientists and engineers aware of the long-term interests of the Navy and Marine Corps. They are intended to be very difficult, but probably achievable, and to offer multiple opportunities for investigators from many disciplines. Currently the Department of the Navy has four Naval Science and Technology Grand Challenges: Naval Battlespace Awareness, Electric Power Sources for the Navy and Marine Corps, Naval Materials by Design, and Multifunctional Electronics for Intelligent Naval Sensors. These are the sorts of topics that should inspire fruitful basic research.

ONR provides the Navy and Marine Corps with a presence on the campuses of our research universities that offers much to both the military and civilian sectors.

National Naval Responsibilities and Future Naval Capabilities

ONR originally was chartered to support basic science. In 1960 the Office of Naval Technology (ONT) supported applied research. As the decade progressed it was folded into a responsibility of the Office of the Chief of Naval Research, which was intended to become responsible for the integration of science and technology from basic research through applied research to advanced technology development. In 1992 ONR assumed full responsibility for all three levels of research, and so assumed its present form.

Public funds are not unlimited, and must be used prudently. When funding declines, if the number of scientific and technical programs remain the same, then funding fails to achieve 'critical mass'. Nothing reaches the level at which it might be productive. We must also remember that a number of areas that are uniquely important to the Department of the Navy are not supported by investments from industry, the other Services, the National Science Foundation (NSF), the National Institutes of Health (NIH), or other Federal sponsors of research. As a result, the health, strength, and growth of these fields depend on the investments made by the DoN S&T program. ONR must ensure U.S. world leadership in these few unique areas through research, recruitment and education, in order to maintain an adequate base of talent and sustain critical infrastructure for research and experimentation.

The purpose of establishing National Naval Responsibilities is to allow ONR to meet its responsibilities to maintain the health of identified Navy-unique S&T areas in order that:

- A robust U.S. research capability to work on long-term S&T problems of interest to the DoN is sustained;
- An adequate pipeline of new scientists and engineers in disciplines of unique Navy importance is maintained; and
- ONR can continue to provide the S&T products necessary to ensure future superiority in integrated naval warfare.

Additionally there are several areas where ONR has a national obligation for science and technology. Ocean acoustics is one of them. Supporting our undersea superiority through modern sonar to provide anti-submarine warfare, mine countermeasures and unchallenged maritime operations. Other areas are under continuous evaluation, including research into naval architecture, hydrodynamics and underwater weapons.

The goal of the Department of the Navy's science and technology investment strategy is to provide the Navy and Marine Corps with future capability options. The process is designed to achieve this goal. The current process is fragile. It depends upon us being smart buyers - or better yet, smart investors - and we can only be smart buyers as long as we hang onto vital scientific and engineering expertise in places like ONR and NRL.

The Department of Defense is charged by the President with helping him discharge his Constitutional responsibility for the common defense. Part of that responsibility is knowing what you need in order to defend the Nation, and that knowledge has to drive our investments in science and technology. And controlling the process that determines what those investments will be remains an inherent part of that responsibility.

What the Nation gets from Naval science and technology

What would happen if Naval science and technology budgets were eliminated? Would they be transferred to other agencies? History gives us little cause for optimism on this point. And even if the funds were to go elsewhere for application to research, it is unlikely that other agencies - no matter how competent, well-intentioned, and hard-working - would soon be able to replace the networks of support, communication, and cooperation that have evolved within the Naval research community over the past fifty years. Naval science and technology investment represents an irreplaceable national asset.

If you want to see Naval science and technology's monument, go to any factory, laboratory, hospital, or school, and look about you.

In the late 19th Century American security and prosperity rested on agriculture, steel, railroads, and oil. In the 21st Century they will rest on information technology, material science, and biotechnology. None of these fields would have achieved their present state or future promise without research supported by the Department of the Navy. William Jennings Bryan just over a hundred years ago castigated the nation's short-sighted neglect of its farmers in favor of its financial speculators by saying the grass would grow in the streets of every city without the Midwest's thousands of small farms. Today, without the thousands of researchers in government, industry and universities, we would be looking at a nation as barren, cheerless and without hope as the one Bryan warned against.

ONR continues to pursue basic and applied research in areas like acoustics, chemistry and biochemistry, electronics and electromagnetics, plasma physics, optics and photonics, information science, materials science, ocean and atmospheric science, computer science, behavioral and cognitive science, and space science. The quiet, daily work of science, conducted by government, industrial and academic researchers throughout the country, remains one of the fundamental supports not only of our nation's security - the common defense - but of our nation's well-being - the general welfare. It used to be said of the great architect Christopher Wren that if you sought his monument in London, look about you. At the beginning of the third millennium of this era, as we enjoy a standard of living enriched by technology undreamed of in the history of the world, if you want to see Naval science and technology's monument, go to any factory, laboratory, hospital, or school, and look about you. ●

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10 Naval Historical Center, Naval Aviation Chronology.

11 Christman, Albert B., Sailors, Scientists, and Rockets, volume 1, Washington: Naval History Division, 1971, pages 16-18. Millikan was an influential member of the National Research Council, which contributed much to the organization of science for national defense during the First World War.

12 Like many inventions and discoveries, radar emerged in several different places at about the same time from work being carried out independently by various researchers. The earliest patent for a device we can recognize as a kind of radar was issued to a German researcher. Britain's Watson-Watt developed a radar at about the same time NRL did. Marconi himself observed shortly before NRL actually did it that location of ships by reflected radio frequency energy ought to be a practical possibility. For an account of NRL's early work on radar, see Ivan Amato's Pushing the Horizon: Seventy-Five Years of High Stakes Science and Technology at the Naval Research Laboratory, Washington: U.S. Government Printing Office, 1998, chapter 3.

13 Naval Historical Center, Naval Aviation Chronology.

14 Naval Historical Center.

15 Pfeiffer, John E., 'The Office of Naval Research,' Scientific American, Volume 180, Number 2, February 1949, pages 11-15.

16 Sapolsky, Harry, Science and the Navy: the History of the Office of Naval Research. Princeton: Princeton Universiry Press, 1990, page 8.

17 Bush, Vannevar, Science, the Endless Frontier. Washington: Office of Scientific Research and Development, 1945.

18 Senate Report 1628 of 28 June 1946.

19 House Report 1833 of 29 March 1946.

20 Pfeiffer, op. cit., page 11.

21 Nitze, Paul H., 'Perspectives on Naval research,' in F. Joachim Weyl, editor, Research in the Service of National Purpose: Proceedings of the Office of Naval Research Vicennial Convocation, Washington: U.S. Government Printing Office, 1966, page130.

22 Sapolsky, op. cit.., page 69. McClellan, as it happened, was criticizing an Air Force sponsored study of Soviet political economy, but his skepticism and suspicions of the professariate are typical of attitudes found not only in Congress, but among uniformed officers as well.

23 For an account of the unique role research universities play in the United States, see RADM Paul G. Gaffney II's 'Challenge and Response,' The Journal of Research Administration, volume 1, number 1, January-February 2000, pages 5-8.