# REINVENTING THE DRONE, REINVENTING THE NAVY

## 1919–1939

*Angelina Long Callahan*

Invention is often perceived as an isolated event, attributable to a momentous "first" or to a single, patent-holding inventor. However, rather than questioning what qualified as the first drone aircraft or to whom the title as its "inventor" belongs, this article maps out the winding uncertainties of technical evolution—exploring how seemingly failed projects laid groundwork for the U.S. Navy's first successful radio-controlled drone aircraft.

Situated as they are among a cluster of interwar emerging technologies, drones provide an instructive case study through which to consider how the U.S. Navy's research-and-development (R&D) communities function as a strategic asset. When the availability of one subcomponent can jeopardize an entire research project, such factors as institutional stability, the circulation of ideas, and willingness to reevaluate naval doctrine become critical to national security. So too does the ability of experts to recognize a (perhaps temporary) dead end when they face one. This article will flesh out, for this case, the actors and activities of innovation, emphasizing how the collaborative nature of this work can mitigate the uncertainties and risks of R&D.

This article is divided into five sections. The first is a case study of invention, recounting the acts of collaboration that were necessary for the development of the first American radio-controlled aircraft. To build this prototype, the electrical engineer Carlos Mirick consulted a variety of research partners, integrating cutting-edge

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instruments and subassemblies from colleagues performing R&D in Navy and industrial laboratories and manufacturing firms.

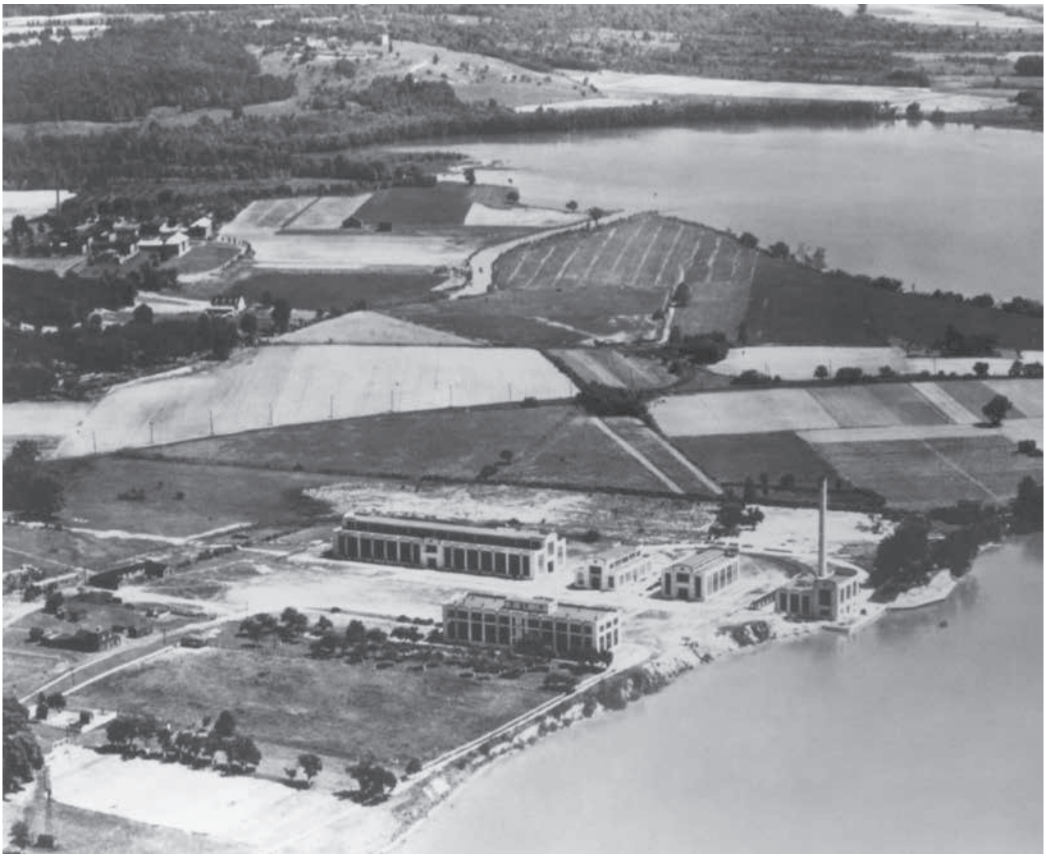
Second, this article describes how Rear Admiral Stanford C. Hooper, often remembered as the "father of naval radio," administered resources and directed research to render the high-frequency (HF) band of the electromagnetic spectrum a much more reliable operating range for radio. Facing interwar budget cuts and losing a substantial number of naval researchers to the private sector, Hooper labored to retain a cadre of resourceful and engaged scientists and engineers in the early 1920s, centering them at the Naval Research Laboratory.

Building on this background, the article's third part shows how the Naval Research Laboratory's broad range of R&D programs and organizational stability provided these projects with institutional continuities and connectivity to a wide range of fleet research problems enabled the resurrection of (useful) elements years after the cancellation of R&D projects. The fourth section describes how elements of "failed" guided-missile projects were transferred to new lines of R&D, yielding previously unanticipated results—bombsights, target-drone battleships, and target-drone aircraft—all of which fostered the meticulous reevaluation of operational and tactical doctrine by the U.S. Navy in the years leading up to the Second World War.[1]

The article closes with reflections on the calls that have been prompted recently by the proliferation of drone technology among potential adversaries and the increasing complexity of battle networks for a more centralized forum to coordinate autonomous-systems research, development, and use.

## CASE STUDY IN INVENTION: THE *WILD GOOSE* "FLYING BOMB"

Between the 1890s and World War I, the proponents of radio managed to secure a toehold in the U.S. Navy, owing not only to the utility of the hardware but to the fact that Great Britain and Germany were developing technical and duopolistic leadership in the field of communications.[2] In the United States during this time, the Naval Consulting Board had identified a need for a general research center, but the proposal had for years been mired in debate over how best to characterize the laboratory's work.[3] Would it be an "invention factory," turning out new prototypes for submarines and ships on a monthly basis?[4] Would it engage only in adapting commercial inventions to Navy needs, not producing, therefore, matériel in competition with private industry? The nature of the laboratory's work would influence the logic of its location, another point of contention. After nearly a decade of debate the Naval Research Laboratory (NRL) was founded in the Bellevue neighborhood of Washington, on the Potomac River near the southernmost corner of the District of Columbia. NRL's location near downtown Washington was something of a compromise among proponents of Annapolis, Maryland, and



NRL, preceded by disparate and highly specialized facilities, was the first facility established to serve the research and technical needs of the entire Navy.

All photos courtesy NRL

Sandy Hook, New Jersey.[5] It appealed to naval officers like Hooper, who headed the Bureau of Engineering (BUENG) Radio Division and who also oversaw the founding of NRL's Radio Division, because it was conveniently accessible from the Naval District Washington headquarters.[6] It contained for the moment only two divisions, Radio and Sound.

In a sense, the current U.S. unmanned aerial vehicle (UAV) effort can be traced to NRL's Radio Division, which opened with just nineteen engineers and four physicists in the spring of 1923.[7] They had been brought there from BUENG's Radio Test Shop, the Radio Research Laboratory, the Aircraft Radio Laboratory, and the Anacostia Naval Air Station, adjacent to the new site of NRL. Experts and skilled shop workers at the Washington Navy Yard were also transferred to the laboratory, as all navy yards were now to cease pursuing their own dispersed and uncoordinated research problems.[8] Stated Rear Admiral Stanford Hooper, "Our idea is that all research should be concentrated here where we have employed Physicists and Radio Engineers of the highest quality." Significantly, he predicted that through these measures "research along various lines can be thoroughly co-ordinated."[9] This coordination appealed to the Navy Bureau of Engineering in part because bringing researchers to one centralized facility streamlined an "unwieldy and expensive" collection of post–World War I Navy facilities.[10]

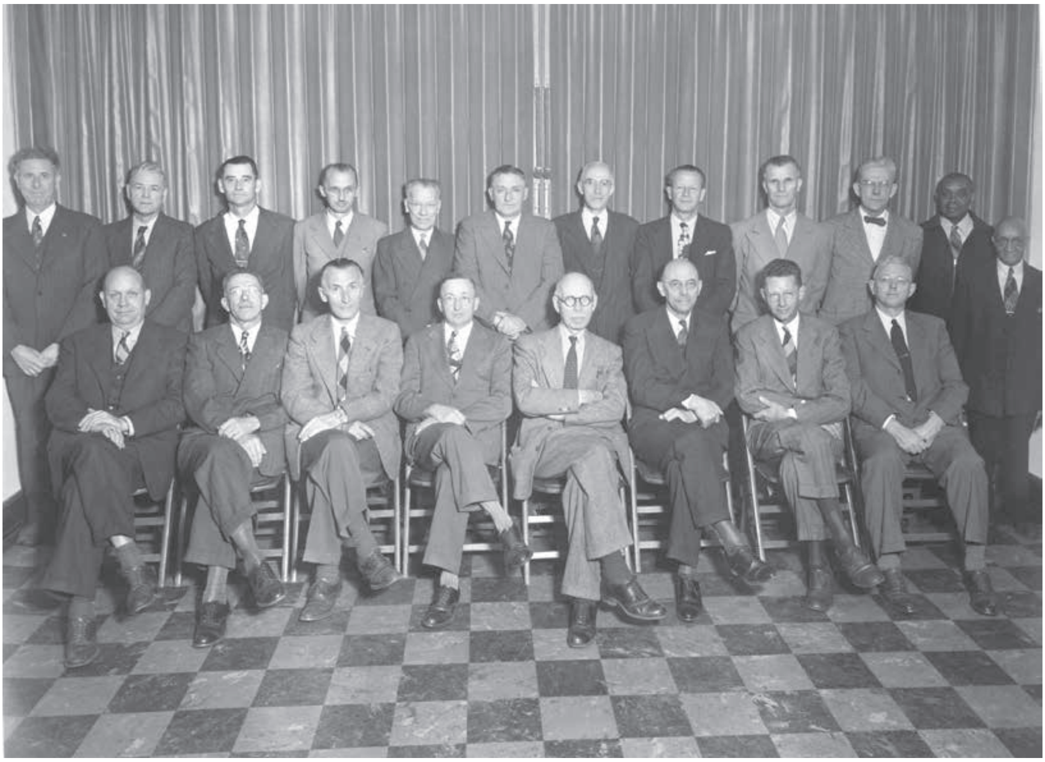
Radio Division researchers reported for duty on 16 April 1923, a full three months before NRL's dedication and formal opening.[11] Over the course of ten days, naval air station experimenters relocated downstream from the Anacostia River to NRL's dock on the Potomac—loading and unloading the barge full of equipment themselves.[12] Setting up shop with "temporary wires strung here and there" and using portable generators for power, experimenters set to work reassembling their tools and lab equipment.[13] One of many experienced and resourceful engineers who had been circulating among communities of mechanicians and was now setting up shop at NRL was Carlos B. Mirick. With a Cornell University degree in electrical engineering, Mirick had served as an engineer in Washington, D.C.'s National Electrical Supply Company until World War I. Following service as a Naval Reserve officer, he returned to the Electrical Supply Company as a vice president of engineering. Soon after, he returned to the Navy and in 1919, the Navy's naval air station loaned Mirick to the Air Mail Service, where he helped develop direction-finder loops for navigation and helped develop the radio direction finder for the famed *NC-4* transatlantic flight.[14] In February 1922, BUENG invited him to begin work on linking radio transmitting stations and remotely piloted aircraft.

That winter Mirick began construction of what was to be the first American remotely piloted aircraft, intended to be a guided bomb. He set to work in a sheet-iron garage, referred to as the "longwave shack." Lumbering about the unheated shop in a fur-lined flying suit, he experimented with a variety of setups, working toward a transmitter, receiver, and relay capable of controlling an aircraft from as much as twelve miles away. Reflecting back later on his work on BUENG's "flying bomb" project, Mirick would credit several other inventive thinkers for their contributions. In the spring of 1922, he began a tour of military and commercial facilities, surveying various equipment and methods he might incorporate. Among his visits was one to the Hammond Research Laboratory in Cambridge, Massachusetts. John Hays Hammond, Jr., and his colleagues were laboring to develop radio control for torpedoes, having recently demonstrated the efficacy of radio control of ships.

In addition to Hammond, a renowned radio-control expert, Mirick's project materialized in a fascinating confluence of aviation figures and artifacts. The N-9 seaplane Mirick was using dated back to a 1915 flying-torpedo project led by Lawrence Burst Sperry, inventor of the Sperry gyrostabilizer. Sperry's "unpiloted" plane differed from Mirick's primarily in that Sperry's had been supposed to navigate by preset automation rather than radio control. When Sperry's N-9 had consistently—though narrowly—missed targets, he had requested permission to use radio control to adjust for wind-induced creep. The Naval Consulting Board denied his request, although one historian asserts that postwar aerial torpedo achievements indicate that radio signals would have effectively corrected the flight path.[15] Nevertheless, Sperry's project was canceled. Inspiration for Mirick's ground-control selector switches came through "confidential channels" late in World War I, in the form of indications that German researchers were experimenting with a radio-controlled torpedo boat operated by a modified remote control adapted from wireless telegraph systems. Mirick contracted with an Illinois teletype manufacturer, the Morkrum-Kleinschmidt Company, for the production of two eight-circuit selector switches designed to his specifications. The Kleinschmidt switches were retrofitted into the N-9 by a then-obscure Carl Norden at the U.S. Naval Proving Ground in Dahlgren, Virginia. Through this cooperation the Navy capitalized on Norden's experience as a former partner of Elmer and Lawrence Sperry, with whom he had helped develop the first generation of gyrostabilizers for automated control of aircraft systems. Once Sperry's now-surplus gyrostabilized N-9 and the teletype switches were secured, as Mirick later recalled, modestly describing his own contribution, "the next requirement was to develop a radio link to consist of a receiver and a relay capable of actuating this selector switch while in flight."[16]

The Navy's consolidation of researchers and resources at NRL put Mirick in contact with a number of other experts with overlapping interests in radio. There he completed his bench work on the project, integrating input of scientific researchers, radio engineers, shop workers, contractors, and military specialists. The Radio Division fostered a broad portfolio of investigations, delving into the fields of aircraft direction finding, radio control, communications and radio standards, instrumentation, and the fundamentals of radio-wave propagation.[17]

The photo on the next page shows a few of Mirick's colleagues who frequently consulted with him. These included A. Hoyt Taylor, Louis Gebhard, and Leo C. Young, all of whom had worked together at the Great Lakes Naval Radio Station during the war, where Taylor had taken on the role of supervisor and mentor to Gebhard and Young. Years later, Gebhard would recall that Taylor (as superintendent of the NRL Radio Division) tended to think in broader, more theoretical terms than did his colleagues, who were advancing the field at more technical levels: "We had the ideas of how to do the things that he may not have had. I don't think that he had any great capability of winding a coil or anything like that. . . . But now, he didn't have to do it; he could let other people go ahead and do it."[18] Taylor engaged in radio-propagation experiments on a number of naval ships and in collaboration with amateur radio operators the world over. Through these



Seated (left to right): G. E. Jacobson, W. B. Burgess, R. B. Meyer, L. C. Young, A. H. Taylor, L. A. Gebhard, O. C. Dresser, T. M. Davis.
Standing: E. E. Brock, W. H. Dyer, R. J. Colson, F. W. Struthers, E. L. Powell, D. H. Ness, R. B. Owens, A. E. Meininger, J. J. MacGregor, C. B. Mirick, A. L. Harris, J. W. Johnson.

experiments he labored meticulously to map the ionosphere's effect on HF radio-wave propagation; his early atmospheric and ionospheric studies made important connections with HF radio tinkerers and experts who would contribute to Navy R&D.[19] Over time, Taylor increasingly devoted his energies to administration, helping BUENG translate Navy needs into functional hardware and researchers communicate promising new ideas to their sponsors in the Navy bureaus.[20] In these early days of HF research, Taylor and Young pitched their first proposal for radio detection and ranging—later known by the acronym "radar." (The proposal was unsuccessful. Many years later, Hooper would recall that the bureau turned it down because of problems with vacuum-tube reliability.)[21]

Indeed, NRL radio researchers—pioneers in the use of the more cantankerous radio frequencies of 1,300 kilocycles and higher—made do without a number of instruments that would be ubiquitous by the 1940s. There were no signal generators, and there was no field-strength measuring equipment or means of measuring radio-frequency gain ("except by methods of comparison based on the use of a shunted telephone connected at the receiver output").[22] A colleague working on radio transmitters would recall that though a number of items were ordered from private industry—meters came from the meter company, relays from relay companies—coils and capacitors were generally made in-house, since they demanded "special design," project by project.[23] In many cases, industrial partners willingly adapted to NRL's demanding specifications. Louis Gebhard, a radio research engineer who had transferred from Marconi Wireless to the Navy in 1917 and was to become associate superintendent of the NRL Radio Division, later recalled the responsiveness of such firms:

> We cooperated with these people and similarly when we got into quartz crystal work, we had to have accurate temperature control. So we worked with a precision instrument company who would provide us with thermostats and thermometers that were high precision. We would work with them: they would bring samples down and put them in and determine how they would work; we would make suggestions as to improvement, to fit into things that we wanted to do for the Navy and quantity production.[24]

The lack of standardized instruments and subcomponents reflects the fact that the laboratory workers were operating on the frontiers of their field, before mass-produced (or for that matter, entirely reliable) parts could be purchased to fill essential needs. Working with industrial partners, NRL researchers labored to improve the reliability of prototypes. This quality-control work, in turn, facilitated the transition to mass production of reliable parts.

NRL's offices and workshops embodied the cutting edge of radio, in microcosm. The Aircraft Radio Group that Mirick headed was complemented by five other Radio Division research groups covering a broad spectrum of activities, from the most basic scientific inquiry to mission-oriented R&D and instrument development. Any of the twenty-three Radio Division personnel could be transferred among the groups—Aircraft Radio under Carlos Mirick, the Transmitter Group under Louis Gebhard, General Research under Leo Young, Direction Finders under Warren B. Burgess, Receivers under Thomas M. Davis, and the Precision Measurement Group under the physicist John M. Miller. In Mirick's opinion, "the best feature" of the radio-control equipment of his N-9, which he dubbed *Wild Goose,* was a much-needed six-stage, choke-coupled radio-frequency amplifier, designed and built under the direction of Dr. Miller.[25] (Miller, also credited with contributing to Mirick's receiver, would spend much of his career developing the piezoelectric crystal hardware and theory necessary to standardize and measure HF radio.)[26]

Mirick later reported, with no hint of embarrassment, that all materials but the vacuum tubes, Miller's amplifier, and the Morkrum telegraph selectors had been salvaged from "old and condemned radio sets."[27] For this purpose he undoubtedly made use of NRL's surplus machinery dump—an agglomeration of some three dozen railroad cars full of surplus radio equipment, tools, cables, wire, and scrap metal. Years later Taylor recalled how "during the lean and hungry days of the middle and late ’twenties the dump turned out to be a godsend to the Laboratory.” In fact, “it was no uncommon sight to see two or three engineers poking around through this pile looking for some usable item.” Of course, the dump was not without its problems—in summertime the piles of rusting machinery among sprouting weeds and wildflowers proved hospitable for rattlesnakes.[28]

Establishing an effective radio link between the ground station and the aircraft controls was not just a matter of digging spare parts out of the NRL dump and cobbling them together with Miller’s amplifier and contractor-supplied switches. There was the work of actually retrofitting the radio-control system to the seaplane.[29] Beyond that, integrating radio control required careful monitoring of instrument weights, equipment dimensions, and electrical demands. Planes at that time had no power supplies for auxiliary electrical instruments, so Mirick’s radio equipment had to include its own.

But how to test a radio-controlled seaplane? Chief Radioman Elmer Luke was assigned to pilot the craft remotely, from its ground station, and Lieutenant John Jennings Ballentine, officer in charge of the proving ground’s naval air detail, handled in-flight backup. Between 25 July and 15 September 1924, the collaborators flew the *Wild Goose* a number of times, experimenting with varying degrees of remote control.[30] During these test flights Ballentine, a pilot, rode on board, monitoring specially designed lights to assure himself that radio commands were coming through, prepared to intercede manually if radio communication failed.

In the course of these test flights the team determined that Mirick’s radio setup was transmitting and accepting commands adequately but that the system had disconcerting limitations. The Morkrum selector switch functioned to specifications, but, “like a one-armed paper hanger,” Mirick worried, “it could do but one thing at a time.”[31] It could turn right, turn left, raise the elevator, lower the elevator, throttle on, or throttle off—but only sequentially. The aircraft could not be made, for instance, to turn and bank, or descend and reduce throttle, at the same time. That summer, Mirick decided to make a selector of his own design, one that would permit concurrent commands and operation that more closely resembled piloted flight.

Carlos Mirick knew of a gentleman in Springfield, Ohio, who was working on a relay capable of controlling multiple branch circuits at once. But it proved too large to be adapted to the N-9, and Mirick and Chief Luke set about miniaturizing the system. “Working on similar lines” to the Ohio relay, they mounted tuned steel reeds (not unlike tuning-fork tines) in an old watch-case telephone receiver.[32] The unit’s four circuits permitted fewer operations (forward and reverse, right turn and left turn) than the Morkrum switch, but they did make simultaneous commands possible on a wheeled joystick-controlled prototype.

In redesigning the relay, Mirick adapted the interface from switches to an aircraft's control stick the size of a pencil. Before they could test the preliminary system on an aircraft, Mirick and Luke fabricated a battery-powered, three-wheeled cart. Turning again to cannibalized parts, they even pilfered a front wheel from the "velocipede" of Luke's young child Robert.[33] In his September 1923 patent application for an "Electrical Distant-Control System," Mirick explained that since its operation was "identical with the 'joy stick' provided in aircraft for controlling the machine," this new device was "particularly applicable in maneuvering aircraft without a pilot. . . . [A]n operator at the radio transmitter at a shore station who is an experienced aviator may therefore move the lever . . . in the same manner in which he is accustomed to operating the 'joy stick' in aircraft."[34] The joystick controls could not be developed and adapted to the *Wild Goose* in time for its test program; it would have greatly increased the safety of operation for the backup pilot, whose life depended on the craft's (and radio controller's) performance.[35] Several times during the test flights the N-9's control gear malfunctioned, sending the plane into dangerous spins. Given this touchy performance of the *Wild Goose,* each time Ballentine rode as backup operator of the experimental craft he risked becoming one of many Navy pilots and experimenters killed in interwar aviation R&D.

On 15 September 1924, the N-9 flew its first and last truly remotely piloted mission, with only a sandbag (for weight) belted into the pilot's seat. Because Dahlgren personnel had expressed concern that a radio-controlled craft might "get out of control or crack up over land," threatening buildings and personnel, Lieutenant Ballentine devised a safety measure: his assistant aviation officer, Lieutenant J. E. Ostrander, "took off gallantly in a galloping D.H. [de Havilland] land plane," armed with bricks and ready to throw them at the *Wild Goose*'s propellers, thus downing it without using live ammunition.

Overall, the radio equipment performed quite well, except for a couple of moments when the control "seemed to stick." At one point, when the seaplane failed to respond to repeated right-turn commands and lost considerable altitude, the operators cut the throttle and decided to land it on the Potomac. Seeing that it was too late for a safe landing, they opened the throttle again, hoping to make a second attempt. However, the command took effect too late, and the plane's pontoons struck the water with great force. In his report Ballentine stated that the plane rose again approximately fifty feet, then made a satisfactory landing. However, unbeknownst to its operators, one of the aging pontoons had cracked, and it now took on water, causing the plane to sink after an otherwise successful flight. Ballentine speculated that a newer pontoon would have absorbed the shock of the first touchdown, given the fact that the radio-control equipment remained intact. More important, Ballentine and Mirick agreed, what was required was development of a more refined form of control, such as the joystick.[36] *Wild Goose* having sunk in the Potomac, damaging its electronics beyond repair, it was not until 11 December 1925 that the collaborators could make a second attempt, with new plane and electrical equipment. Unfortunately, the second plane too was lost, when it porpoised excessively on takeoff.[37] Funding for the "flying bomb" stopped that year.

Had it all come to naught?

## "HIPPED ON HF": BUENG CULTIVATES COMMUNITIES OF INNOVATION

As illustrated above, Mirick and his colleagues operated on the cusp between the known and unknown. In spite of its yet unpredictable nature, HF radio required the least electrical power, its systems were the lightest, and its antennae the shortest (as was evidenced in those days by the two radio towers, one 430 feet high and one six hundred feet, looming over Arlington Cemetery's low-frequency station for transatlantic communication).[38] Thus, aviation remained one of the critical applications driving researchers to pioneer the high frequencies for communication, navigation, and, for some, radio guidance.

Before and after he secured resources to support the Radio Division at NRL, Stanford Hooper kept abreast of and even publicized Navy experimentation and achievements in HF radio. Information for HF radio inventors, tinkerers, and users circulated in the BUENG Monthly Radio and Sound Report, the *Proceedings of the International Radio Engineers* (IRE), magazines such as *Radio News* (in which the Navy briefly secured a page each month for the service's radio news and pictures), the American Radio League's *QST* (the traditional brevity code for "calling all stations"), and *Popular Radio* (in which Hooper also published).[39]

Indeed, "amateur" implied not so much "not professional" as the use of frequencies deemed too high to be reliable for service use. Today, "high frequency" radio is defined as beginning at three megahertz—or three thousand kilocycles per second (kcs), in the parlance of the 1920s. Mirick's superintendent, Taylor, and his contemporaries, however, considered "high frequencies" as beginning where medium-frequency waves began exhibiting the unpredictability of the ionospheric skip-distance effect—starting between 1,300 and 1,500 kcs. Thus, when Hooper relied on "amateur" radio operators to aid in his experiments, he engaged a broad spectrum of people, ranging from leisure-time ham radio operators to university professors.

The career of Hoyt Taylor, indeed, illustrates the permeability of seemingly distinct fields of radio: academic, hobbyist, and naval. In 1916 Taylor, then a physics professor at the University of North Dakota, submitted a paper to the IRE *Proceedings* concerning radio receiving systems. It described the potential of concealing a radio antenna underground—an idea that, unbeknownst to him, was being pursued by the Navy in a classified project, under contract. The Navy, learning of the manuscript, asked Taylor to retract it; he responded graciously with "a very fine patriotic letter stating that he was very glad not to publish the article, that he was very happy to be able to cooperate with the Navy," and offering his assistance if needed in the future.[40]

In time, BUENG's Radio Division, under Stanford Hooper, discovered that its contractor working on a radio direction finder "could make it work but he couldn't explain how it worked. . . . [O]f course, I [Hooper] couldn't understand how it worked and neither could Mr. Clark of the [Engineering] Bureau."[41] Hooper wrote Taylor asking him to undertake the task of discovering the scientific principles by which the radio direction finder operated. Taylor accepted. Three years and a world war passed before Taylor's paper on the subject was published in IRE's June 1919 *Proceedings.* In the meantime, the professor found himself drawn into the war effort, first as a civilian and then, in the Naval Reserve, as district communication officer of the Great Lakes Training Station, then commanding officer of the Navy receiving and control center at Belmar, New Jersey, supervising the transatlantic network. After the war he went on to lead the Hampton Roads Air Station Experimental Division and finally to head the Naval Aircraft Radio Laboratory at Anacostia Naval Air Station (whence he was transferred to NRL).

The multiform careers of Taylor, Mirick, Luke, and Miller show that though it is tempting to classify radio experts of that era as products of either industry, the Navy, or academia, these individuals commonly passed among two of these communities or more. Mirick's career demonstrates the permeability of these fields, by which winding chains of innovations were fostered, with devisers of cutting-edge ideas producing novel systems based on experiences of colleagues in other fields. As people moved, so too did their ideas.[42]

Just as the pool of Navy-supported radio experts was reduced to meet shrinking postwar budgets, the world of amateur radio was taking off, with a growing number of users spending an increasing amount of money on ham radio sets and parts. In 1922 alone, the American radio industry was worth about sixty million dollars (in 1922 dollars—about $813 million today).[43] Stanford Hooper's archived papers are interspersed with more than a dozen letters from colleagues and naval subordinates bidding farewell as they accepted positions in RCA, Marconi, and many smaller radio firms.[44] On one hand, private industry functioned as an alternate career path where the Navy's innovative thinkers could build constituencies in private industry or weather interwar reductions in force. But on the other hand, Hooper and Taylor were left struggling to retain their choice research corps. By the time NRL began coming together in 1922, Hooper, its

BUENG proponent, had seen to it that the facility would possess a staff that was well qualified, if—as was characteristic of the interwar Navy—undermanned and underfunded.

NRL administrators grappled with what seemed to them limitless research problems and at the same time inexorable cuts to salaries, travel funding, and matériel. In June 1923, as the laboratory was still tooling up, Edgar G. Oberlin, its director, and Taylor wrote the head of the Bureau of Engineering outlining the nineteen research problems that would guide NRL's radio work. Of these, one alone was "almost sufficient in scope to tie up every man in the laboratory who knows anything about tube transmitters." They reported that no one was available to be assigned to six of the research problems.[45]

In the face of resource limitations, many questioned the prudence of devoting researchers to the uncertain field of HF at all. Throughout the early and mid-1920s the Navy researchers' advance into the HF spectrum was met with resistance from naval officers worried that people who were in one officer's words "hipped on HF" might be leaping too quickly into an unproven field. From their perspective, these frequencies demanded too much money and occupied too much of NRL's time. "I have to keep my eyes [figuratively] on the ground," explained one critic, convinced that work in HF would come at the expense of improvements to more reliable communications technologies already in the fleet.[46]

Hooper, who had faced similar resistance with the adoption of lower-frequency radio at the turn of the century, believed that making Navy users more knowledgeable would facilitate modernization. Thus, from the first a radio school was colocated at NRL. In February 1925, as BUENG was building up to routine operation in the high-frequency spectrum, Hooper wrote Taylor of his hope that a constituency of radio operators could be built who were not only open to the improvement of their hardware but willing to collaborate in its systematic "reinvention." Hooper and Oberlin agreed that the school's physical and intellectual proximity to the cutting edge of radio research would enrich the students' training. With an understanding of the adaptability of HF radio to needs of the Navy, fleet radio officers would be able to "make intelligent recommendations" that would "fit with those in Washington." Hooper intimated, "It has always been my experience that the Fleet lagged way behind the Research Staff in recommendations, because of lack of knowledge as to what *could* be done." This disconnect, he knew, could delay the approval of new equipment for years.[47]

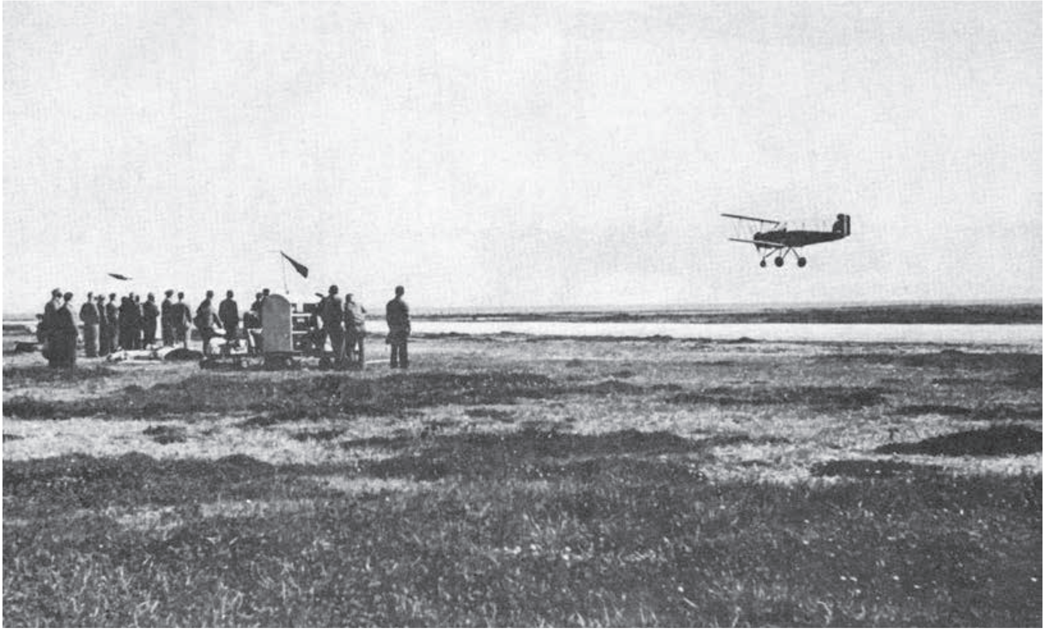
By 1927, one of Taylor's amateur collaborators temporarily employed by the Navy and soon to return to the private sector reported to readers of the U.S. Naval Institute *Proceedings* that "high frequency radio is in the Navy to stay. It is surpassing any other form of radio by leaps and bounds. . . . With apparatus occupying only a tiny amount of space, as compared to the ancient arc[,] . . . the ships of the fleet are maintaining direct contact with Washington over distances practically impossible on low frequency and with infinitely less power."[48] Such advancements in hardware and human resources would buttress the reliability and performance of NRL's next generations of radio control.

## RADIO AND 1930S MODERNIZATION: THE PROMISE AND THREAT OF AIRPOWER

For ten years, plans for a remotely controlled "flying bomb" lay dormant in BUENG and the Bureau of Ordnance (BUORD). However, Mirick and his group at NRL remained anything but inactive. In spite of the *Wild Goose*'s apparent dead end, NRL retained the plans for radio-control equipment and adapted it to ostensibly unrelated undertakings by other groups. The most immediate beneficiary, Carl Norden, used Mirick's system to synchronize the release of bombs, testing and calibrating experimental bombsights in the late 1920s.[49] Working alongside Dahlgren engineers, Norden developed a mechanical system to render bomb trajectories more predictable and effective. This preliminary research led eventually to the famous Norden bombsight.

While the efficacy of the Norden bombsight remains disputed, perhaps the most rewarding return on Mirick's radio-control system was in gradually "unmanning" targets, making it possible for ships, aircraft, and submarines to attack realistically maneuvering targets with minimal risk to Navy personnel. In 1930 Mirick personally oversaw the installation of his sequential radio controls on board the destroyer *Stoddert* (DD 302) and in 1932 on the converted battleship *Utah* (AG 16, originally BB 31). These ships served as test beds for three and nine years, respectively, proving worthy quarries for surface ships, submarines, and aircraft. Personnel who would otherwise have been exposed to great danger on the bridge operated the craft from a safe distance (though skeleton crews often remained below deck on ships). Thus, the ships could imitate the speed and evasive maneuvers of a well-commanded ship under attack, with minimal risk.[50]

Radio controls intended for Mirick's "flying bomb" were thus transferred to new communities, where they were used to refine operating procedures for the Navy's oldest and newest equipment. Battleships, cruisers, and destroyers practiced long-range firing on drone-towed target rafts. Submariners stalked and fired on surface targets. Naval aviators used drone target ships to develop tactics for dive-, torpedo, and high-level bombing. This was to prove a critical time in the Navy's development of carrier techniques and doctrine, in terms of both interservice rivalry and heightening international tensions.[51] Thus, it may be that the twilight years of *Stoddert, Utah,* and other ships used in similar ways were their most historically significant. *Stoddert,* operating in the Mobile Target Division 1 out of San Diego, helped train aviators assigned to *Saratoga* (CV 3),



NRL's second generation of aviation radio control was first tested on 19 November 1937. Less than a year later, NRL's system provided guidance for the nation's first maneuverable aerial target.

the second American ship originally commissioned as an aircraft carrier.[52] In the increasingly tense years of the late 1930s, *Utah* towed targets for battle practice, provided mobile target services to submarines, and served as a mobile target for Patrol Wing 1, as well as for attack aircraft based on the carriers *Lexington* (CV 2), *Saratoga,* and *Enterprise* (CV 6).

Throughout the 1930s and even into the 1940s, Navy commanders employed NRL radio controls in intensive field trials—both on the sea and on the wing. Yet all the while the laboratory's research in remote control remained a work in progress. As something of a prototype, *Stoddert* eased the transition to the next generations of radio-controlled target ships, including *Boggs* (DE 136), *Lamberton* (DD 119), and *Utah*. When not under radio control as a target, *Utah* served as a fleet machine gunners' school; in 1938, *Utah* gun crews practiced firing on remotely piloted N2C-2 aircraft simulating dive-bombing attacks. Radio control for these aircraft—descendants of Mirick's *Wild Goose*—had been designed by NRL's Radio Division.

## REINVENTING THE NAVY: N2C-2 DRONES

It was not until the failure of the Naval Disarmament Conference of 1935–36 that the paths of the Naval Aircraft Factory, NRL, the Bureau of Aeronautics (BUAER), BUORD, and BUENG converged in pursuit of a field-ready and mass-producible target drone. When the Japanese delegates walked out of the London conference, fifteen years of voluntary arms limitations among the U.S., British, Japanese, Italian, and French navies ended; a naval race seemed unavoidable and war probable. The U.S. Chief of Naval Operations, Admiral W. H. Standley, who had attended the conference, returned home determined to revive radio-control research, this time for target aircraft. War production was imminent, and drones would not only aid in the training of sailors and pilots but help Navy leadership evaluate current antiaircraft practice.

The systems that resulted could be identified as the first drones, not because they were the first remotely piloted aircraft (they were not), but because these were the first remotely piloted aircraft given that name. The name was likely suggested by NRL's Hoyt Taylor, who was confident that "to those who know anything about honey bees, the significance of the term will be clear. The drone has one happy flight and then dies."[53] While in the United Kingdom, Standley had observed demonstrations of target planes operating under the QUEEN BEE program; he returned declaring that an urgent need for targets demanded that researchers push development and experimentation to the very limit.[54] Many viewed the exercises that would then be conducted not simply as tests of the skills of gunners but as a way to settle a dispute between BUAER and BUORD regarding the overall efficacy of antiaircraft weapons. For its part, BUENG, as home of the Navy radio research, expressed its "keen desire to handle the development of the radio equipment."[55]

BUAER, meanwhile, searched for an aviator qualified in aerodynamics and capable of supervising the radio equipment R&D. In July 1936 it selected Lieutenant Commander Delmar S. Fahrney. Just as Mirick had surveyed the state of the art in 1922, Fahrney was instructed to engage in a comprehensive study of previous projects in radio control.[56] Assigning the project maximum priority, BUENG placed NRL in charge of radio control, working with the engineering group at the Naval Aircraft Factory. In a continuity that undoubtedly saved time and money, former chief radioman Elmer Luke returned to work full-time on radio control, this time as a civilian researcher improving an oscillating-reed circuit recognized by all parties as based on a principle that had been engineered into a workable system under the guidance of Hoyt Taylor, Carlos Mirick, Leo Young, and Matthew Schrenk in the 1920s. More than fifteen years after Mirick had begun the first round of work, NRL's radio engineers improved on his electromechanical airfoil controls, making them reliable enough for the simultaneous operation of multiple functions.

Demonstrations held on 17 February 1937 succeeded, with the "mother plane" twenty-five miles from the drone. The filter managed to segregate signals for aileron, elevator, throttle, and autopilot using a magnetically driven reed to vary magnetic flux through a coupled coil, thus averting complications experienced with Mirick's earlier filter, which had used a vibrating contactor. Whereas Mirick exercised resourcefulness in securing custom-made switches, relays, amplifiers, and the like for his N-9 HF equipment, an NRL report observes that the N2C-2 project had been bequeathed over the previous decade "comparatively sturdy and dependable high-frequency units *used as standard equipment*. . . . With more reliable sending and receiving equipment the prospects for success were greatly enhanced."[57] High-frequency radio was coming into its own, with standardized and mass-producible assemblies and parts.

Lieutenant Commander Fahrney, who had been the chief inspector of the Naval Aircraft Factory before becoming the officer in charge of the drone program, proved a valuable partner to NRL. In hindsight, Taylor felt, "One reason that progress for this problem in earlier days [i.e., Mirick's "flying bomb"] had not been more rapid was because no strong high level of coordination had been applied to it. Captain Fahrney supplied this in an admirable fashion."[58] Once made rugged, reliable, and affordable, HF radio control could be "black-boxed" and applied to fleet exercises. Thus the radio-controlled drone, once the subject of Mirick's R&D, became a diagnostic tool in and of itself.

The results of this drone development, known as Special Project D, proved heartening to the radio researchers but generated data that appalled naval commanders preparing for a probable war. In 1938, the chief of BUAER sent congratulations to the chief of BUENG on the performance of NRL equipment in drone tests. He reported with pleasure that in 187 flying hours under radio control, few failures had occurred. This reliability he attributed to the vision, technical judgment, and directive ability of NRL scientists and engineers. The ability to "unman" aircraft in field test demonstrations revealed that neither antiaircraft (AA) gunners nor their equipment was performing to satisfaction. In the spring of 1939, multiple drone-target runs on the destroyers USS *Patterson* (DD 392) and *Reid* (DD 369) and the battleship *Idaho* (BB 42) produced but a dozen or so bullet holes and no drone kills. Taylor later recalled that "it was quite a while before one of these targets was brought down by a Naval gunner"; in the meantime much troubleshooting ensued, reshaping antiaircraft doctrine for years to come.[59]

In August 1938, N2C-2 drones made scheduled runs over the carrier *Ranger* (CV 4). Its gun crews, well trained by the standards of those days, failed to score a single hit. In September 1939, *Utah* expended 1,500 rounds from its 1.1-inch batteries against nine dive-bombing "attacks" without downing a drone. NRL's Louis Gebhard would recall, "The rapid increase in the use of drones quickly revealed the inadequacy of our antiaircraft defense against maneuvered targets and led to more rapid improvement of our fire-control systems."[60] But ultimately, as Admiral Claude C. Bloch, then Commander in Chief, U.S. Fleet, stated, "The firings against radio-controlled target airplanes have proved of inestimable value in testing the efficiency of the antiaircraft defense of the Fleet and in determining the procedures which should be used to make antiaircraft fire most effective."[61]

Between 1939, when a drone services group was formed, and the fall of 1940, gunners began scoring more hits, learning how resilient aircraft were against AA weaponry and, again, showing what Navy leadership could anticipate in battle. In spring 1940, the Secretary of the Navy designated Rear Admiral Ernest Joseph King to make a special study for the improvement of antiaircraft batteries. That August, the Chief of Naval Operations created the Navy Department Antiaircraft Defense ("King") Board to study options for improving antiaircraft batteries. Ultimately, the target drone trials led to a number of fleet adaptations.[62] By December the King Board had declared that the Navy's lack of close-range AA gun defense constituted the "most serious weakness in the readiness of the Navy for war."[63] In this way drone tests led to demands for improved optical fire-control systems, encouraged the installation of radar fire control on ships, aided in development of proximity fuses for AA guns, and finally, made it clear that gunners needed more training and longer assignments to that specialty. Through the early years of World War II, demand for drones rose steadily. The Navy soon exceeded its supply of surplus military aircraft and began procuring small commercial planes to use as targets—twenty a month in 1942, then sixty, and finally eighty a month in 1943, by which time the U.S. Army and the Royal Navy had begun placing orders too.[64] Through the end of the Second World War, drones continued to be employed in gunnery training; radio control was installed in F6F aircraft to simulate kamikaze attacks. In 1946, radio-controlled F6Fs were transported to Bikini Atoll to monitor and evaluate a whole new weapon—the atomic bomb.[65]

## YESTERDAY AND TODAY: LESSONS FOR MAINTAINING THE STRATEGIC EDGE

This interwar case study offers six lessons for thinking about research and development today. The point is not to claim that U.S. drones were invented by NRL researchers, in isolation. They were not. NRL was but one institution through which the Navy advanced its stake in the fast-developing radio age. There, researchers adapted innovative ideas from across the United States and abroad to Navy needs; they worked to forecast plausible capabilities of the U.S. Navy and potential adversaries; and they kept on hand experts to aid in matters ranging from patent disputes with private industry to emergency R&D, such as Project D. What matters here are the difficult decisions faced by researchers, their administrators, Navy sponsors, and collaborators operating at the cutting edge of radio R&D.

For the world's navies, the interwar period was a time of intense scrutiny, from naval leadership, citizens, budget makers, and potential adversaries. Because of its response to this interwar scrutiny—testing, evaluating, and rethinking the role of old and new battle platforms—when the "sleeping giant" was awakened in December 1941, the U.S. Navy bore little resemblance to the Navy of 1919. Historians have observed that the interwar Navy, constrained as it was by postwar drawdowns, Depression-era budgets, and disarmament agreements, "fostered an innovative spirit among American admirals that made them better able to fight the Pacific war."[66] Yet it is critical to note that it was by no means the treaty limitations, fiscal conservatism, or interservice rivalries that facilitated innovation. Instead, these conditions shaped the political economy in which naval administrators, researchers, and engineers operated, a setting that occasionally made them more amenable to technological change.

The first lesson arises from the fact that during this time engineers invented neither submarines, nor aircraft, nor HF radio. Instead, military and civilian experts spent the interwar decades methodically testing the efficacy of those technologies in laboratory and field trials and weighing plausible adjustments to preexisting systems. It took a tremendous amount of work in a number of institutions to bring research to the point of producing prototypes, and then effective operational systems. But ultimately, these years of exploratory HF-radio R&D laid a foundation on which Navy researchers and their industrial partners were to build for decades.

Second, the field of radio is big and still growing. Like aviation and space, it is defined as much by the fundamental properties of a medium as by the technologies and countermeasures necessary for operation therein. From 1924 to 2014, drones have represented only one platform in a rich field of promising technologies at the cutting edge of research. As illustrated by the case of Carlos Mirick, at this epistemic edge critical breakthroughs commonly result from tracking down and integrating tools and insights from complementary fields, be the source a division down the hall or a manufacturer in another country. Such interactions remain necessary conditions for revolutionary innovations as well as incremental adaptations.

Third, for many, natural and man-made vagaries of the electromagnetic spectrum do not matter until they impede operations; such impediments are often stumbled on, though sometimes they are anticipated. Similarly, good ideas may circulate by chance, or they may be preemptively cultivated. A recent study analyzed the origins of the aircraft carrier angled flight deck.[67] One of its findings was a disconnect between the U.S. Navy's aviators, who recognized the utility of deck-edge aircraft carriers as used by the Royal Navy (RN), and the Navy's technical specialists: "There was plenty of talent available to both navies, but having the right individuals in the right place at the right time is often a matter of chance, and chance favored the RN."

In fact, administrators like Hooper and Taylor did accept that some variables must inevitably be left to chance. It was not simply the invention of radio control that aided the Navy in those interwar years of testing, evaluation, and painful retrenchment but innovation coordinated with both serendipitous and structured circulation of ideas. This interaction fostered the adaptation of both successful ideas and seemingly failed ones to new activities, leading to this essay's fourth observation: in many regards, material and intellectual connections mitigated the uncertainty and risks of exploratory R&D—scientists moving among laboratories, engineers sharing building plans with industrial partners, researchers critiquing one another's methods and consulting with operators. Among these communities, good ideas persisted and breakthroughs in fundamental knowledge were disseminated. These circumstances could cast the concept of "R&D dead end" in a new light. Indeed, neither Lawrence Sperry's defunded guided bomb, Hammond's torpedo development, Mirick's *Wild Goose,* nor even Fahrney's aspirations for a follow-on guided-missile program reached their intended ends.[68] Fourth, in the larger fields of radio, aviation, and naval tactics, these seeming dead ends contributed to the successes of other platforms, programs, and careers that were conducive to the U.S. victory in World War II. In an institutional setting of stability and intellectual latitude, as well as sustained receptivity to testing, evaluation, and (re)training, ideas and hardware weathered periods of uncertainty and were applied to entirely new projects, where they flourished.

Whereas in 1923 NRL conducted R&D with two in-house research divisions, by the end of World War II the laboratory's pool of expertise had expanded considerably in scale and scope, but still featured many overlapping research problems. Recalled Hoyt Taylor:

> I can not [*sic*] close this account of the functions of the Radio Division without calling attention to the fact that many of our problems are linked with other Divisions upon whom we may call freely for aid and assistance in solving our problems. In particular, the Division of Physical Optics has been of enormous assistance in the Wave Propagation studies and naturally a very close connection exists between the Sound Division and the Radio Division, many of whose problems almost overlap. The Divisions of Physical Chemistry and Metallurgy have also come frequently to the aid of the Radio Division. The presence of these other Divisions is therefore of material aid and assistance to the solution of radio problems peculiar to the Naval service.[69]

By 2014, this, the Navy's corporate research laboratory, employed more than 1,500 technical personnel in eighteen division-level organizations. It functions today as a microcosm of the sciences, with a multeity seldom found within one institution.

Whereas Ballentine and Mirick circulated among engineers, Navy radiomen, radio physicists, and the service's most capable pilots, these days drone R&D is more likely to bring together a plasma physicist and an expert in artificial intelligence. This change is, in part, a reflection of a broad and consistently expanding sampling of the sciences available to the Navy in NRL, including the Nanotech Institute, Tactical Electronic Warfare Division, Center for Biomolecular Science and Engineering, and the Laboratory for Autonomous Systems Research, all formed since 1923. But also, today's work demands far more complicated inputs for payloads and systems integration.

Vehicles of the twenty-first century operate in networks of ever-extending reach. The notion of "remote control" takes on new meaning when drone operators and their aircraft are thousands of miles apart. In what has been described as "remote split operation," drone pilots often function in different cities, time zones, or continents from their environments of interest. Autonomous systems, robotics, distributed systems, UAVs, or remote split operation, call them what you will—these capabilities bring with them many new complexities, in design, management, and institutional jurisdiction. As researchers have sought a more centralized forum to facilitate R&D, policy experts and a few military commanders have begun to question the curious lack of an arena for formal exchanges concerning the development and operation of UAVs, and of robotics writ large.[70]

Proponents of such forums resist relying on chance. They are calling for more sustainable and more widely reaching institutions to facilitate interorganizational research, development, and testing to improve field operations. In 2007, thirty-three researchers representing five NRL divisions coauthored a report proposing a joint task force to oversee the development and evaluation of weapons systems.[71] Therein they argued that distributed autonomous systems of sensors—on wing, land, and water—would prove themselves as interservice joint-task-force assets for forward operational sensing, search and rescue, fleet and land mine countermeasures, and antimissile defense.[72] Significantly, the report suggested that a tiered systems-development process would combine the skills of military operators, academia, industry, and management and operational contract laboratories. These collaborators might contribute to a "red team" that would participate in developing and evaluating improved joint systems capabilities by taking the perspective of potential adversaries and deliberately devising challenges.

No such red team was instituted. A few years later, in 2011, the chief of the operations branch at the Joint and Army Experimentation Division observed that there was still "no unified strategy or governance structure that moves away from the stove-piped approach and integrates concept development, requirements, and capabilities assessment."[73] Echoing to a degree Hooper's HF concerns of a hundred years earlier, that commentator wished not only to "prove with analytical rigor that robots are a preferred solution to address capability gaps" but to create a centralized forum for discussing the best possible operation of these new systems, as well as their consequences.[74]

As our case studies lead us to expect, critical breakthroughs in complementary fields are indeed advancing the fields of drone R&D. To what degree will today's researchers, administrators, sponsors, and industrial partners leave such variables to chance? Scientific and manufacturing innovations like improved autopilot, smaller microprocessors, and lighter and more durable materials have ushered in a renaissance for remotely piloted aerial vehicles, taking them well beyond the form and function of the early twentieth century and arguably to the point of "autonomy." Miniaturization and mass production have helped reduce costs to the point at which remotely piloted craft can be considered "expendable," even disposable. Many suggest this—a hundred years into drone testing and development—is just the beginning of what the drone platform can offer when integrated with other emerging systems: improved navigation, fuel cells, laser communication, improved remote sensing, remote memory storage, and various forms of countermeasures, and counter-countermeasures.

Fifth, the United States has never in fact been alone in the field of drone R&D. Since at least the 1920s, radio researchers have benefited from inputs from abroad (such as intelligence concerning German torpedoes or feedback from the British QUEEN BEE proof-of-concept aircraft). More often, however, radio R&D has been driven by military *threats* from abroad.[75] Thus one of the "consequences," mentioned above—that is, mass production and economies of scale are driving down prices but in doing so are also dissolving barriers to entry by potential adversaries. Nine decades after the first "unpiloted" flight of *Wild Goose,* a host of new battlefield threats face drone operators, commanders, and developers of Navy equipment. The current Chief of Naval Operations, Admiral Jonathan Greenert, has predicted that by 2025, radar, electro-optical sensors, and "precision-guided weapons will be the norm among our adversaries and competitors—from terrorist groups to criminal organizations to our maritime peers."[76] This gradual convergence of technical capabilities aids nonstate actors, terrorists, and insurgents, who pose sustained threats to foreign and domestic security.

Thus—sixth, and finally—as isolated technologies become available to adversaries, well-governed and effective networks among the armed services, intelligence community, and their diverse research-and-development communities may prove the critical edge for the United States.

## NOTES

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1. For an overview of that reevaluation see Albert A. Nofi, *To Train the Fleet for War: The U.S. Navy Fleet Problems, 1923–1940* (Newport, R.I.: Naval War College Press, 2010).
2. Capt. L. S. Howeth, *History of Communications-Electronics in the United States Navy* (Washington, D.C.: U.S. Government Printing Office, 1963), chaps. 3–10.
3. In 1915, the Naval Consulting Board began petitioning for the formation of (in the words of Josephus Daniels, Secretary of the Navy, in September 1915) "an adequate central establishment where the ideas of its own officers as well as those suggested by civilians could be taken up and patiently developed in the same way that such ideas are handled in great manufacturing establishments." Quoted in David Allison, *New Eye for the Navy: The Origin of Radar at the Naval Research Laboratory,* NRL Report 8466 (Washington, D.C.: Naval Research Laboratory [hereafter NRL], 1981), p. 25.
4. David van Keuren, "Science, Progressivism, and Military Preparedness: The Case of the Naval Research Laboratory, 1915–1923," *Technology and Culture* 4 (October 1992); Allison, *New Eye for the Navy,* chap. 2.
5. Though the Naval Consulting Board was appropriated $1.5 million for NRL on 4 March 1917, the laboratory's location was not resolved until February 1918. Details of this conflict and compromise are available in Allison, *New Eye for the Navy,* pp. 28–32.
6. Stated Hooper, "I felt very strongly that it ought to be located near enough to Washington to help people like myself in charge of research and development work who could easily avail themselves of the facilities and make frequent visits to the laboratory. . . . [O]therwise, we had to take the train and spend a day or two every time they [*sic*] made a visit to the laboratory." Rear Adm. Stanford C. Hooper, USN, Ret., "Navy History of Radio-RADAR-SONAR," p. 746, Stanford C. Hooper Papers, box 24, Library of Congress Manuscript Division, Washington, D.C. [hereafter Hooper History of Radio].
7. "Personnel under Present Title and Pay," folder NRL Historical Records 1916–1939, NRL History Office, NRL, Washington, D.C.
8. Stanford Hooper to H. H. Bouson, USN, 1 March 1926, folder January–April Correspondence 1926, Stanford C. Hooper Papers, box 7, Library of Congress Manuscript Division, Washington, D.C.
9. Ibid.
10. Hooper described Navy radio research as being scattered across the United States from New London, Connecticut, to Pensacola, Florida. Material assembled by Rear Admiral Hooper for Hooper History of Radio, pp. 745–46.
11. Louis A. Gebhard, oral history interview by David K. Allison, 12 September, 19 September, and 3 October 1977, p. 26, NRL History Office, NRL, Washington, D.C.; Hoyt Taylor, *The First 25 Years at the Naval Research Laboratory* ([Washington, D.C.]: NAVEXOS [Executive Office of the Secretary of the Navy], 1948), p. 13.
12. Louis A. Gebhard, *Evolution of Radio Electronics and Contributions of the Naval Research Laboratory,* NRL Report 8300 (Washington, D.C.: 1979) [hereafter *Evolution of Radio Electronics*], p. 26.
13. Hoyt Taylor, *Radio Reminiscences: A Half Century* (Washington, D.C.: NRL, 1960), p. 104.
14. Ibid., p. 77. See also Richard K. Smith, *First Across: The US Navy's Transatlantic Flight of 1919* (Annapolis, Md.: Naval Institute Press, 1973).
15. Thomas Parke Hughes, *Elmer Sperry: Inventor and Engineer* (Baltimore: Johns Hopkins Press, 1971), p. 269; Carlos Mirick, "A Wild-Goose Chase: Early Navy Work on Pilotless Aircraft and Ships," U.S. Naval Institute *Proceedings* (July 1946), p. 947.
16. Mirick, "Wild-Goose Chase," p. 947.
17. Allison, *New Eye for the Navy,* p. 37.
18. Gebhard, oral history interview.
19. Henry Stroke, ed., *The* Physical Review: *The First Hundred Years—A Selection of Seminal Papers and Commentaries* (New York: American Institute of Physics, 1995). Taylor and

E. O. Hulbert's "The Propagation of Radio Waves over the Earth," dating from the 1926 *Physical Review,* is listed on pp. 1126–27.

20. Allison, *New Eye for the Navy,* p. 45.
21. Details of their rejected proposal and repeated efforts can be found in ibid., pp. 40–41. Years later Hooper would explain that the reason BUENG chose to hold off on investing in radar was that radio researchers lacked "a proper generator or [vacuum] tube, which could generate short waves" (ibid., p. 40).
22. Mirick, "Wild-Goose Chase," p. 947.
23. Gebhard, oral history interview, p. 28.
24. Ibid., p. 29.
25. Mirick, "Wild-Goose Chase," p. 948.
26. Miller acquired his PhD from Yale in physics in 1915. A radio physicist and patent expert, he left NRL for a position in Atwater Kent Manufacturing Company, then went to the RCA Radiotron Company. He returned to NRL's Radio Division in 1940, ultimately serving as NRL's scientific research administrator in 1952. In 1953, the Institute of Radio Engineers awarded Miller the IRE Medal of Honor for "his pioneering contributions to our basic knowledge of electron tube theory, of radio instruments and measurements, and of crystal controlled oscillators." "John M. Miller Biography," *IEEE Global History Network,* www.ieeeghn.org/.
27. Mirick, "Wild-Goose Chase," p. 949. In fact, only recently had vacuum tubes become commercially available, with mass production slowly lowering cost.
28. Taylor, *First 25 Years at the Naval Research Laboratory,* p. 7.
29. By 8 October 1922, the press was reporting that the teletype could function several hours at a time, with the transmitter and seaplane receiver (described as a printer) fifty miles apart. These experiments were early proof-of-concept exercises, demonstrating that radio communications could be established between the assemblies at such distances. Stanford C. Hooper, "Typewriter Operated from Seaplane in Flight," *Washington, D.C., Sunday Star,* 8 October 1922.
30. Officer in Charge [Ballentine] to Inspector of Ordnance in Charge, 17 October 1924, folder Naval Aviation Radio Controlled Flight Experiment 1924, Papers of John J. Ballentine, box 18, Library of Congress Manuscript Division, Washington, D.C. [hereafter Ballentine Papers].
31. Mirick, "Wild-Goose Chase," p. 950.
32. Ibid.
33. Watching the machine wander by itself over the streets of NRL, stopping, starting, and turning corners, Mirick observed that the revolving, riderless pedals lent the contraption "a somewhat jaunty air"; it was soon christened the Electric Dog. Parenthetically, Mirick suggests that young Robert Luke harbored no ill will over the Navy conscription of his velocipede; Luke became an NRL radio engineer during the 1940s.
34. Carlos Mirick, inventor, Electrical Distant-Control System, U.S. Patent 1,597,416, filed 1 September 1923. The patent was issued in August 1926, listing Mirick as inventor, naming no assignee. Currently, where an invention is made by a government employee, the government of the United States, as represented by the Secretary of the Navy, is listed as the assignee of the patent if any of the following conditions apply to the making of the invention: if the invention was made during working hours; if the invention was made with a government contribution of facilities, equipment, materials, funds, or information, or the time or services of other government employees on official duty; or if the invention bears a direct relation to or was made in consequence of the official duties of the inventor. The author thanks the NRL Head Office of Associate Counsel for Intellectual Property for assistance on this point.
35. Taylor, *Radio Reminiscences,* p. 126.
36. In Ballentine's report: "The disadvantage of only being able to work one control at a time was especially apparent during the landing, when it was desired to use the elevators and the throttle at the same time." Ballentine, "Radio Controlled Flight Experiment, Report Of," 17 October 1924, folder Naval Aviation Radio Controlled Flight Experiment 1924, Ballentine Papers, box 18.
37. Mirick insisted that this was not owing to a failure in the radio controls. Mirick, "Wild-Goose Chase," p. 951.
38. High-frequency radio could broadcast to distances on a par with the transatlantic low-frequency radio; however, the reach of HF

communication remained quite unpredictable and unreliable at the time. Regarding the more compact nature of antennae and power supplies, Hooper recalled that the powerful spark-gap transmitter made enough noise to be heard half a mile away. Hooper History of Radio, p. 763.

39. The BUENG Monthly Radio and Sound Report was limited to Navy readers.
40. Hooper History of Radio, pp. 843–45.
41. Ibid.
42. For an excellent sampling of the circulation of radio experts among communities of radio innovation, see Raymond Yates and Louis Pacent, *The Complete Radio Book* (New York: Collier & Son, 1922), chap. 17, "Who's Who of Radio," pp. 286–315.
43. Hugh Aitken, *Syntony and Spark: The Origins of Radio* (Princeton, N.J.: Princeton Univ. Press), pp. 499–501.
44. Evidence of this exodus from the Navy to the private sector includes letters addressed to Mr. Young of RCA, 14 April 1920, folder January–April 1920, box 3; and to Commander Hooper, 12 June 1920 ("present salary is inadequate and . . . I have no assurance that there is a future for me in Government service"), folder May–August 1920, box 3. William Ellis to Commander Hooper, 5 April 1922, folder April 1922, box 4, credits the Navy for Ellis's rich on-the-job training: "I have been able to perfect myself in the fundamentals and theories of radio communication." On 7 April 1922 Hooper wrote Ens. W. A. Eaton that "although I am very sorry to see you leave the services, I will do nothing to prevent your taking advantage of the very advantageous conditions in radio on the outside"; folder April 1922, box 4. H. H. Buttner wrote Hooper on 5 May 1922, "Due to the intense activity in the radio field, I have been offered several rather attractive situations by outside concerns. . . . My decision is partly due to the probability of curtailment of Navy activity in general and radio work in particular"; folder May 1922, box 4. In a letter of 20 October 1922 addressed to "My dear Captain," Hooper suggests that to keep an Ens. C. D. Palmer ("probably the best radioman in practice") from taking advantage of one of many "good offers" made for him to leave the Navy, Palmer be transferred to work with Hoyt Taylor at NRL, where he might carry on his experimental work in radio; folder October–Nov 1922, box 4. Quotations from Stanford C. Hooper Papers, Library of Congress Manuscript Division, Washington, D.C.
45. Taylor and Oberlin to Director of BUENG, "Radio Telegraph Research Problems," 2 June 1923, folder NRL Historical Records 1916–1939, NRL History Office, NRL, Washington, D.C.
46. Letter to S. C. Hooper, unsigned, 12 February 1925, folder January–June 1925, Stanford C. Hooper Papers, box 5, Library of Congress Manuscript Division, Washington, D.C.
47. Stanford Hooper to Hoyt Taylor, 6 February 1925, folder January–June 1925 [emphasis added], Stanford C. Hooper Papers, box 6, Library of Congress Manuscript Division, Washington, D.C.
48. Lt. Cdr. F. H. Schnell, "The First Long Range High Frequency Radio Tests," U.S. Naval Institute *Proceedings* 53 (September 1927), p. 968.
49. Carl Norden is characterized as "an observer and occasional participant in the pilotless aircraft trials. Later, when the sight was being tested and calibrated at Dahlgren, a means was needed for releasing the bombs—from the ground—by remote control. Quite naturally, the Dahlgren engineers turned to Mirick's radio system." "The First Radio Controlled Airplane," unpublished manuscript, folder Radio Guidance, NRL History Office, NRL, Washington, D.C.
50. *Dictionary of American Naval Fighting Ships,* s.v. "Stoddert," www.history.navy.mil/; "USS *Stoddert* (DD-302; Later IX-35, AG-18 & DD-302), 1920–1935. Briefly Renamed *Light Target Number 1* in 1930–31," *Naval Historical Center* [*sic*—Naval History and Heritage Command website], www.history.navy.mil/. Reminiscent of the N-9 *Wild Goose, Utah* was also guided by a Sperry "metal mike," or gyro pilot, to help keep the ship on course. "USS *Arizona* Memorial: Submerged Cultural Resource Study—USS *Arizona* and Pearl Harbor National Historic Landmark," *National Park Service,* www.nps.gov/.
51. This was as much a matter of proving the potency of ships against attacking aircraft as the efficacy of carrier-based aircraft against land-based planes. See Russell Weigley, *The*

*American Way of War: A History of United States Military Strategy and Policy* (Bloomington: Indiana Univ. Press, 1977), pp. 223–65.

52. *Dictionary of American Naval Fighting Ships,* s.v. "Stoddert." USS *Langley* (CV 1) was originally commissioned as a collier.

53. "I believe I am responsible for this name for pilotless target planes." Taylor, *Radio Reminiscences,* p. 96.

54. William Trimble, *Wings for the Navy: A History of the Naval Aircraft Factory, 1917–1956* (Annapolis, Md.: Naval Institute Press, 1990), pp. 188–90.

55. Howeth, *History of Communications-Electronics in the United States Navy,* p. 480.

56. Ibid.

57. "Radio Control of Target Drones (N2C-2 Training Plane Used as First Radio-Controlled Experimental Target Drone)," folder Radio Guidance, NRL History Office, NRL, Washington, D.C. [emphasis added]. The report is undated but bears a handwritten note indicating that the original was transferred in 1962.

58. Taylor, *Radio Reminiscences,* p. 217. Granted, in 1923 the geopolitical incentive to innovate was not what it would be in the 1930s.

59. Ibid., p. 218.

60. Gebhard, *Evolution of Radio Electronics,* pp. 228–29; Howeth, *History of Communications-Electronics in the United States Navy,* pp. 483–84; Delmar S. Fahrney, "The Birth of Guided Missiles," U.S. Naval Institute *Proceedings* (December 1980), pp. 55–56.

61. Gebhard, *Evolution of Radio Electronics,* p. 228.

62. Howeth, *History of Communications-Electronics in the United States Navy,* p. 220.

63. Ibid.

64. Ibid.

65. Gebhard, *Evolution of Radio Electronics,* p. 229; Office of the Historian, Joint Task Force One, *Operation Crossroads: The Official Pictorial Record* (New York: William Wise, 1946), pp. 51, 60, 82.

66. Roger Dingman, "Navies at Bay," *Naval History* (December 2010), pp. 28–35.

67. Thomas C. Hone, Norman Friedman, and Mark D. Mandeles, "The Development of the Angled-Deck Aircraft Carrier: Innovation and Adaptation," *Naval War College Review* 64, no. 2 (Spring 2011), p. 75.

68. In 1939, Fahrney began work on combat assault drones in Project DOG and Project FOX. Five years later, the Navy conducted combat tests of the drones; most reached their targets, but they had little if any effect on the Pacific campaign. Delmar Fahrney later tried without success to establish that the 1930s drone projects had been precursors to later U.S. guided-missile projects and that he himself was the "father of guided missiles." After the Second World War, Fahrney sought a decoration for his drone work, for which the chief of the Bureau of Aeronautics, Adm. Alfred M. Pride, would not recommend him. Apparently Fahrney wished the recognition for combat-drone applications, not target-drone testing and use. See "The Reminiscences of Admiral Alfred M. Pride, USN (Retd)," oral history (Annapolis, Md.: U.S. Naval Institute, 1984), pp. 174–77, and Fahrney, "Birth of Guided Missiles," pp. 59–60.

69. A. Hoyt Taylor, "Functions of the Radio Division of the Naval Research Laboratory," folder NRL Historical Files 1916–1939, NRL History Office, NRL, Washington, D.C.

70. P. W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York: Penguin, 2009), p. 362.

71. Jill Dahlburg et al., "Developing a Viable Approach for Effective Tiered Systems," NRL Report NRL/MR/1001-07-9024 (Washington, D.C.: NRL, 2007).

72. Ibid., p. 7.

73. Lt. Col. Anthony S. Cruz, "The Robot General," *Armed Forces Journal,* June 2011. At the time, Cruz worked in the Army Capabilities Integration Center, Training and Doctrine Command at Fort Monroe, Virginia.

74. Cruz suggests that such a forum would demand not brick-and-mortar expansion of facilities or a proliferation of research institutions but more modest exchanges, such as seminars and panel discussions.

75. By a matter of days, British researchers beat Mirick's *Wild Goose* to remotely piloted flight.

76. Adm. Jonathan Greenert, "Navy 2025: Forward Warfighters," U.S. Naval Institute *Proceedings* 137 (December 2011), p. 21.