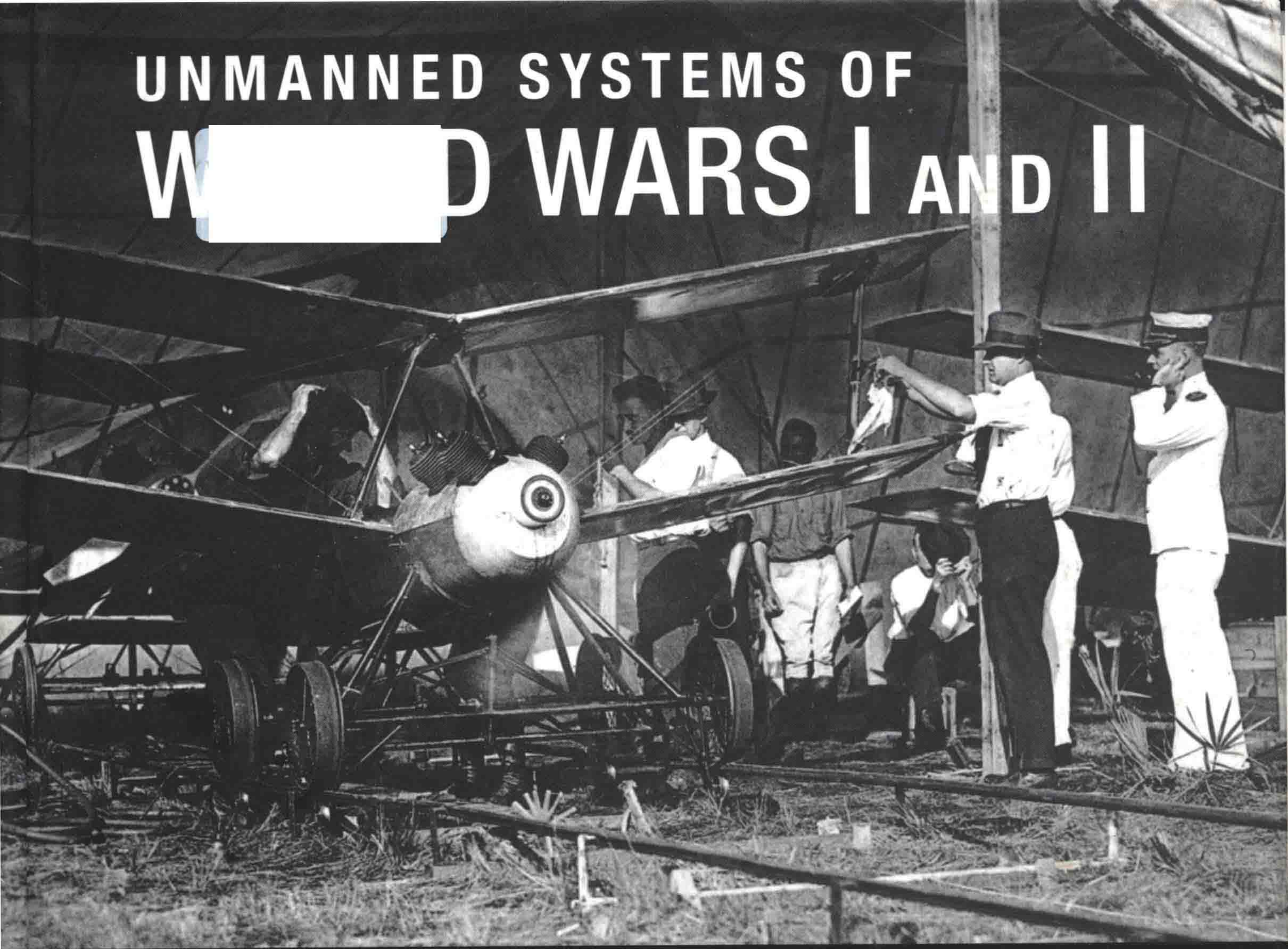
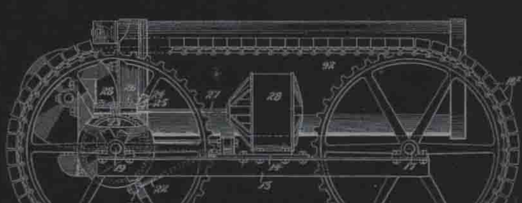
UNMANNED SYSTEMS OF W[redacted]D WARS I AND II





H. R. EVERETT

FOREWORD BY MICHAEL TOSCANO

UNMANNED SYSTEMS OF
WORLD WARS I AND II

H. R. EVERETT

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Foreword

H. R. “Bart” Everett and I have known each other for over 30 years. Before I tell you about the book, let me tell you about the author. Bart is a brilliant robotics engineer, a proven leader, a man of honor, and a good friend. He not only has the technical qualifications and mental fortitude to research and write a book like this, he also has firsthand experience in designing and building many robotic systems over the years, most of them state-of-the-art for their time.

Bart has gathered a long list of achievements in his distinguished Navy career. I have personally interacted with him, and more importantly have spoken with his superiors, peers, and coworkers, whose respect and admiration he has clearly earned. In this day and age there are many well-educated and accomplished individuals. While Bart is both of these, the quality that sets him apart is his character.

Peter W. Singer, distinguished Pentagon analyst, Brookings Institution Senior Fellow, and Director of the 21st Century Defense Initiative, wrote a widely acclaimed and best-selling book, *Wired for War* (Penguin Press, 2009), on the subject of unmanned systems on the battlefield. On page 146, Singer writes:

> When I asked people who they most respected in the field, the name that consistently came up was H. R. (Bart) Everett. Everett is a retired commander in the U.S. Navy, who is now technical director for robotics at the Space and Naval Warfare Systems Center (SPAWAR) in San Diego. As one scientist puts it, “He is one of the true graybeards in the field of robotics.”

When I first met Bart in 1983, he had just received the Captain J. C. Woelful Award for Excellence in Naval Engineering, and was assigned as Director of the Naval Sea Systems Command (NAVSEA) Office of Robotics and Autonomous Systems (SEA-90G). In 1986, he was flag-detailed to the Naval Ocean Systems Center (NOSC) in San Diego to establish an in-house government program in robotic science and technology. That same year, a robot Bart built in 1980 for his thesis project at the Naval Postgraduate School was put on display at Expo ’86, the world’s fair in Vancouver, BC, as the first autonomous security robot.

Meticulously researched, Bart’s current book articulates the perseverance, accomplishments, and technological advances of many passionate people in the early history of robotics. It will help you understand the herculean challenges of that time, and how a generation of visionaries and dedicated professionals created groundbreaking technology that has since been largely forgotten.

Today, the world is just realizing the full spectrum of potential applications for robotics and unmanned systems. As we look forward to the global challenges of the next 10 to 30 years, robotics will be one of the technologies that reshape how we grow crops, explore space, research nature, and protect the men and women who put their lives on the line every day to do their jobs. It is important to recognize the men and women who have paved the way to realizing this tremendous technology. Bart Everett is one of those individuals, and his pioneering achievements will be remembered.

Michael Toscano
President and CEO
Association of Unmanned Vehicle Systems International (AUVSI)
Washington, DC

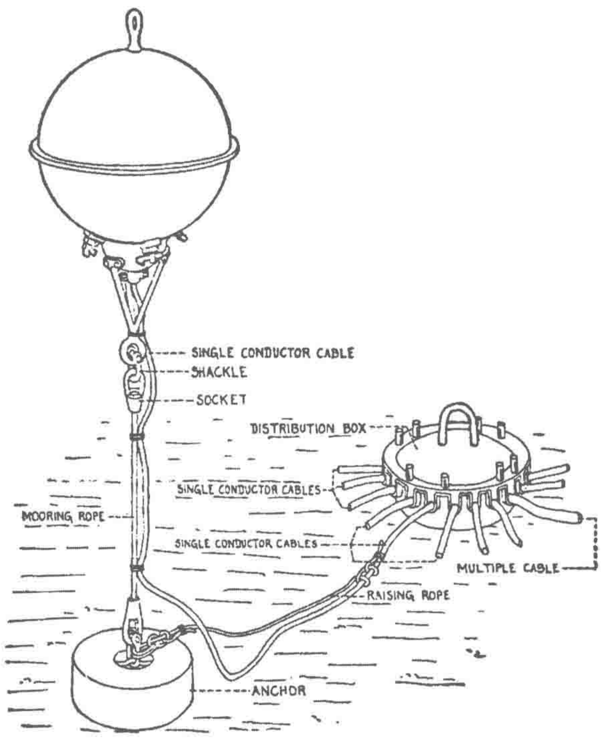
TETHERED TORPEDOES

Always the traditionalists fought hard to preserve anything that had been tried and tested. Always the newcomers struggled to gain adoption of the latest invention. And such is the frailty of human nature that the newcomers of one generation often become the conservative traditionalists of the next.

Edwyn Gray, 1975

Contents

1

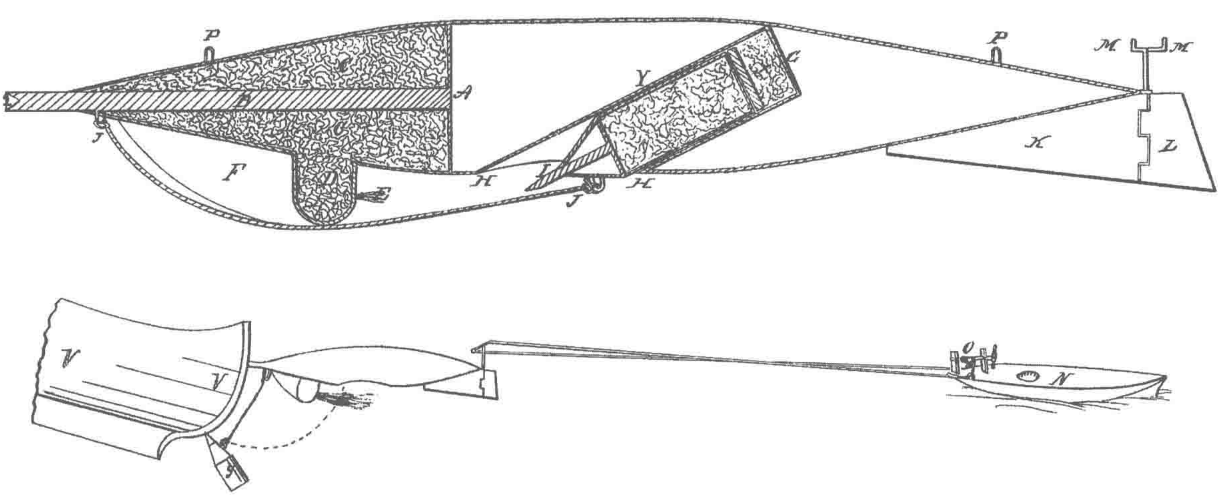


a

b

1.1

(a) Diagram of anchor and distribution box for controlled mines of the type used for US harbor defense during the Spanish-American War and WWI (US Army image; Berhow, 2004). (b) A 2,500-pound mine anchor displayed in the courtyard area between Buildings 622 and 624 at the Space and Naval Warfare Systems Center Pacific in San Diego.



1.2

Callender's proposed torpedo was steered by lines connected to tiller yoke *M* from control boat *N* or from shore (adapted from US Patent No. 39,612; Callender, 1863). Upon impact, the chain-supported magazine *Y* was projected down to explode against the hull of vessel *V*.

THE EARLY DEVELOPMENT OF UNMANNED UNDERSEA VEHICLES (UUVS) WAS MOTIVATED BY THE WIDESPREAD DESIRE FOR IMPROVED ACCURACY OF MARINE TORPEDOES. INITIAL NINETEENTH-CENTURY DESIGNS WERE BY NECESSITY MOSTLY GUIDED BY WIRE. BECAUSE THIS TRAILING TETHER MADE TORPEDOES UNSUITABLE FOR SHIPBOARD USE, THEIR PRIMARY APPLICATION WAS SHORE-BASED COAST DEFENSE. SUCH TORPEDOES WERE A NATURAL EXTENSION OF SUBMERGED HARBOR MINES, WHICH WERE PLACED ON THE BOTTOM OF SHIP CHANNELS, THEN ELECTRICALLY DETONATED FROM A MINE CASEMATE ON SHORE WHEN AN ENEMY VESSEL PASSED OVERHEAD. THIS COMMAND-DETONATION SCHEME WAS LATER APPLIED TO SUBMERGED BUOYANT MINES SUSPENDED FROM A BOTTOM ANCHOR, AS SHOWN IN FIGURE 1.1.

In fact, harbor mines as we know them today were originally called "torpedoes," a term first attributed to Robert Fulton: "The germ of the device is to be found in floating powder vessels, which were first used at the siege of Antwerp in 1585, but the name 'torpedo' was first applied to the machine by Robert Fulton about the year 1800" (Ingram, 1876). Interestingly, Fulton's terminology was not limited to nautical usage but also included what we now call land mines, which were used operationally during the American Civil War:[1]

> Torpedoes for land defense are usually shells of small caliber, 6 and 12 pounders, provided with a percussion or friction device which causes an explosion when the ground over the torpedo is stepped on. Sometimes several are laid in a row, and a piece of board placed over them to increase the chances of explosion.
>
> Larger electrically fired torpedoes were arranged on the land face of the defensive works at Fort Fisher, NC,[2] although the majority of the remote-detonation cables were severed by shell fragments during the Union bombardment. (Knight, 1876)

Similar ground defenses were emplaced at Battery Wagner on Morris Island, SC, which had mounted the most seaward-facing guns guarding Charleston Harbor. Thomas Scharf (1894) points out the downside of such an installation, as experienced in the final hours of the Federal siege of that position in 1863: "Heroic endurance was all that remained for the besieged at Battery Wagner. Even a sortie towards the enemy was denied them, for an ingenious system of torpedo mines, to be exploded by the tread of persons walking over them, had been established by the Confederates in the narrow causeway on that side of the fort."

The marriage of explosives and electricity for remote detonation naturally opened the doors of creativity in search of a self-propelled torpedo that could be electrically steered to its target. In 1863, a nonelectrical remote-steering approach for a dirigible rocket-powered marine torpedo was patented by Mills L. Callender of New York (figure 1.2), antedated to 16 October 1862 (Callender, 1863; Schroeder, 1887). As described by King (1895), "The steering was effected by means of two small lines attached to a rudder yoke and paid out from the operating station, the desired changes of direction being caused by unequal pulling on the tiller ropes."

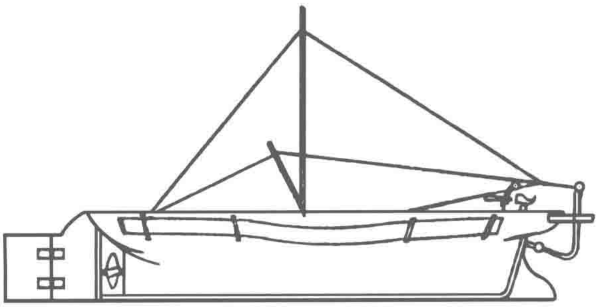
For obvious reasons, this early concept was not viewed as practical for operational use.

WHITEHEAD TORPEDO

A similarly steered concept for coast defense arose in Austria around 1860 (Fyfe, 1907). It was later described by Lieutenant Commander R. B. Bradford, USN, then stationed at the Naval Torpedo Station in Newport, RI:[3] "Some years ago an officer of the Austrian Marine Artillery conceived the idea of employing a small boat floating on the surface, supplied with a boiler for the purpose of generating steam or heated air by means of petroleum lamps, an engine, and a screw propeller; in the bow was to be carried a large amount of gun cotton, or other explosive, which was to be exploded upon contact" (Bradford, 1882).

When this officer died before reducing these ideas to practice, his papers and drawings came into the possession of retired Frigate Captain Giovanni de Luppis of the Austrian Navy (Bradford, 1882). Realizing the concept's potential, de Luppis had a spring-powered model constructed that could be steered remotely from shore by a pair of cables attached to the rudder tiller (Jolie, 1978). In hopes of securing funding for further development, de Luppis presented this 1-meter prototype (figure 1.3) to the Austrian naval authorities in 1864, but it was subsequently rejected on the basis of impractical propulsion and steering (Fyfe, 1907).

De Luppis at this point approached the aspiring politician Giovanni de Ciotta, future mayor of Fiume, Austria (now Rijeka, Croatia), who introduced him to expatriated British engineer Robert Whitehead, manager of Stabilmento Tecnico Fiumano. On 14 August 1864, de Ciotta and de Luppis entered into a contract with Whitehead to collectively refine and commercialize the remotely guided spar-torpedo concept (Lofi, 2009).[4] Whitehead worked diligently with de Luppis on an improved design for several months, but eventually decided the idea of a clockwork-driven cable-steered surface craft was hopelessly impractical (Cahill, 1992; Brown, 2005).



1.3

The spring-powered 1-meter model developed by de Luppis in the early 1860s featured one vertical and two lateral contact booms (one shown) wired to the pistol trigger at far right, which could also be activated by the bladelike projection beneath the bow (adapted from Sleeman, 1889). A photo of this prototype can be seen opposite page 32 of *The Devil's Device* (Gray, 1975)

Whitehead's alternative solution, which he and de Luppis proceeded to develop together, dispensed with the trailing tiller lines in favor of a fully submerged "auto-mobile" torpedo powered by compressed air (Ellicott, 1891). Completed in 1866, the first experimental unit featured a 14-inch-diameter steel hull and weighed only 300 pounds, including a small 18-pound explosive charge of dynamite (Fyfe, 1907). Powered by a 370-psi storage flask made of boilerplate, the custom-designed rotary engine drove a single two-bladed propeller at 100 rpm, producing a top speed of 6 knots over a very short distance of just 200 yards (Gray, 1975).

As described in a contemporary paper, the engine consisted of a small cylinder placed eccentrically within and in contact with the wall of a larger cylinder, made to rotate therein by compressed air admitted through a valve opening in the circumference.[5] British historian Edwyn Gray explains: "A sliding plate next to the valve moved in and out at each revolution, always remaining in contact with the inner cylinder, and compelling the air to act on one side and in the same direction. The propeller was on the central shaft of the outer cylinder to which the inner one was keyed eccentrically" (Gray, 1975).

To minimize the torpedo's tendency to roll about its longitudinal axis, two vertical fins ran the full length of the hull, both top and bottom, while directional accuracy was optimized by adjustable trim tabs installed upon a primitive rudder (Gray, 1975). Depth was controlled by a pressure-activated diaphragm that actuated a pair of horizontal rudders on either side of the hull. As the torpedo descended, increasing water pressure forced the diaphragm inward against an opposing spring; the resulting displacement was mechanically coupled to a crank arm that tilted the horizontal rudders, thereby reducing the rate of descent. Setting the spring tension thus established the desired depth of run.

Or so it appeared in theory. When demonstrated before an Austrian Naval Board in 1866, this early prototype displayed serious depth-keeping problems: "Much to the disappointment of the board and the chagrin of the inventors, it closely imitated the vagaries of a playful porpoise in the water; sometimes diving to a depth of at least forty feet and at others almost springing into the air" (Ellicott, 1891).

Not well understood at the time, a fundamental concept of modern control theory is that effective position control (in this case, depth) for a dynamic system requires both current-position and rate-of-change feedback. Whitehead's initial pressure-activated solution provided only the former and was thus prone to overshoot, resulting in the unstable oscillations described by Ellicott. Despite Whitehead's focused attempts to rectify the problem, a second trial before an eager Austrian Naval Board the following year fared no better.

The board was persistent, however, and requested a third set of trials in 1868 (Fyfe, 1907). After negotiating a three-week delay to further investigate the stability problem, Whitehead was fortuitously struck by an inspirational idea while fretting over his options in bed, unable to sleep (Gray, 1975). The long-sought-after fix was elegantly simple yet brilliant nonetheless: a pendulum-based inclinometer was installed to infer instantaneous rate-of-ascent/descent feedback from the angle of dive. The pendulum deflection with respect to the torpedo's longitudinal axis was then integrated into the mechanical linkages to dampen the effect of hydrostatic pressure upon the horizontal rudders.

The resulting response was slightly underdamped but converged to acceptable stability after a few decaying oscillations, as described by Ellicott (1891): "By careful study and experiment these two influences on the horizontal rudders have been so combined and adjusted that a torpedo makes two or three slight curves above and below its proper depth, and then runs level to the end of its course."[6] This combined diaphragm/pendulum mechanism, which enhanced depth-keeping accuracy to plus or minus 6 inches (Gray, 1975), became Whitehead's legendary "secret" that he closely guarded for decades to come.[7]

The Austrian Naval Board subsequently resumed their 1868 trials with two models thus improved: a 346-pound version 14 inches in diameter and 11 feet 7 inches long; and a 650-pound 16-inch weapon that was 14 feet 1 inch long (Fyfe, 1907). As Fyfe reports, "The trials were carried out at Fiume; the Austrian gunboat *Genese* was handed over to Mr. Whitehead to fit with a bow ejecting tube,[8] and the target consisted of the yacht *Fantasie*." Jolie (1978) indicates that one of these models achieved a top speed of 6.5 knots with a range of 200 yards.

Needless to say, the spectacular performance of these refitted Whitehead-Luppis torpedoes was more than well received by the board. As reported by Bradford (1882), "In 1869, Austria purchased the secret of Mr. Whitehead, price unknown, but conceded to him the right to manufacture at the following rates: $600 each for the small size; and $1,000 each for the large size." Fortunately for Whitehead, the financial impact of the Seven Weeks War left the Austrian Empire in no position to purchase an exclusive license (Gray, 1975). Whitehead subsequently negotiated a new contract with de Luppis for full control of all future sales, which the latter came to very much regret in hindsight by the time of his death in 1875 (Hollings, 1991). By that year, the 14-inch Whitehead torpedo could achieve a speed of 18 knots with a maximum range of 550 yards (Cahill, 1992), and the international torpedo race was about to hit its stride.

Immediately following his success in Austria, Whitehead was invited by the British Admiralty to participate in comprehensive trials at Sheerness, which culminated with the sinking of a target hulk on 8 October 1870. The official report of the supervising Naval Commission concluded that "any maritime nation failing to provide itself with the submarine locomotive torpedo would be neglecting a great source of power, both for offence and defence" (Brown, 2005).

In April 1871, the British government purchased several Whitehead torpedoes under a contract that included a nonexclusive license to manufacture their own. It was further stipulated that the Admiralty was to be immediately informed of and free to use all subsequent improvements made by Whitehead (Sleeman, 1880). Engineers at the Royal Laboratory of Woolwich Arsenal immediately set to work upon the first British-built design, introducing a twin-screw propulsion scheme that Whitehead himself soon adopted (Gray, 1975). The key advantages of this improved approach included greater efficiency and markedly reduced tendency for roll.

Although a number of recent sources report Whitehead received £15,000 upon signing this contract, plus £2,500 for trial expenses, Bradford indicates otherwise: “The total amount paid to Mr. Whitehead at the time was £17,500, not including £2,500 for expenses attending the Medway experiments. The English have purchased a large number of these torpedoes since, and ordered 200 during the excitement attending the threatened war with Russia in 1878” (Bradford, 1882). Indeed, the international level of military interest in the torpedo was rising, as illustrated by Lieutenant W. S. Hughes, USN, summarizing expenditures as of 1887: “It is no exaggeration to say that during the last ten years a hundred millions of dollars have been expended by European nations in efforts to secure a *reliable*, self-moving torpedo. In the United States immense sums of money have been likewise devoted to the same end, not by National Government, but by private individuals, firms, and corporations” (Hughes, 1887).

As assessed by Ensign John Ellicott, USN, in the 1890 annual report of the Office of Naval Intelligence, the maximum speed of the Whitehead continued to grow with each passing year: “The older models should maintain the prescribed depth and straight course for a distance of from 400 to 500 yards at a speed of 20 to 24 knots. The latest models, more fish-like in shape, fuller forward and with a finer run, have attained a speed of 30 knots for 425 yards and 24 knots for 875 yards” (Ellicott, 1890). By 1891, the 18-inch-diameter Whitehead could achieve 33 knots with a maximum run of 1,100 yards (Murphy, 1891).

To achieve a corresponding improvement in accuracy, Whitehead began experimenting with a primitive Russian gyro as early as 1890, but switched to a precision-built unit invented by Ludwig Obry in 1895 (Cummings, 2003). Though simple enough by today’s standards, adapting the concept of gyro-stabilized heading control in the late nineteenth century is further testimony to Whitehead’s insightful genius. Whenever the torpedo drifted in azimuth, the spinning gyro wheel retained its original bearing, the relative difference physically influencing a pneumatic servovalve that controlled the steering actuator to turn the torpedo and eliminate the error (Fletcher, 1912).

As the main armament of fleet warships became more effective at increasingly greater standoff distances, however, the comparatively short range of contemporary torpedoes seriously detracted from their perceived tactical merit. Any increase in run time only exacerbated the accuracy problems, and so tethered systems continued to be seen as a potential solution to the need for both increased propulsion power and better heading control. Nonetheless, Whitehead’s ever-evolving torpedo design remained the recognized benchmark against which all subsequent contenders were measured for quite some time.

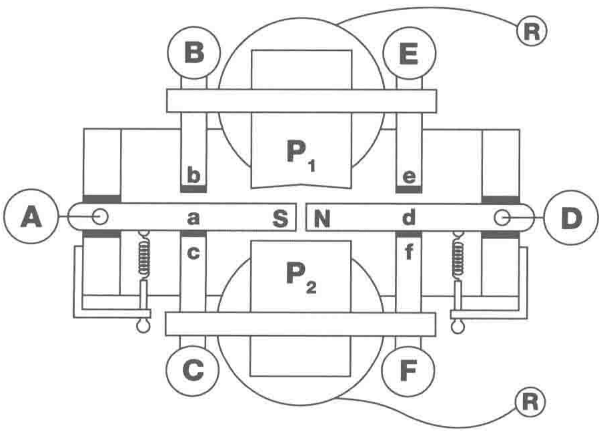
REMOTE STEERING

While their inherent inaccuracy made the early automobile torpedoes prime candidates for remote control, systems based on radio frequency would not become technically feasible until Edouard Branly’s introduction of the coherer in 1890.[9] Even then, reliable underwater reception was another challenge that would require several decades to resolve. A hard-wired umbilical link, on the other hand, had a number of advantages over the wireless approach that initially made it better suited for multifunction control, in addition to being more robust. The obvious way to direct more than one remote action, for example, was to provide individual control circuits using a multiconductor cable (the drawbacks being increased cable diameter and a consequent reduction in length).

It was soon found that a single-wire cable (with a seawater return path), which was smaller and much cheaper, could be made to achieve equivalent results by varying the direction and magnitude of its current. A polarized relay with a permanent-magnet armature was used to decode current direction,[10] while a number of these devices with varying coil sensitivities (hence pull-in thresholds) could easily discriminate its magnitude. An alternative approach employed a single polarized relay in conjunction with a step-by-step relay to first select a desired action, as for example with a positive current flow, and then activate the chosen actuator using a reverse current.[11]

As illustrated in figure 1.4, a polarized relay typically consisted of two single-pole, double-throw contact configurations *a-b-c* and *d-e-f*, which differed only in the polarity of their permanent-magnet armatures *a* and *d*. When the direction of current flowing through the relay coils (via binding posts *R*) was such that the electromagnetic pole P_1 was north and P_2 was south, the spring-loaded armature *a* was attracted away from contact *c* to close with contact *b*. Meanwhile, the position of relay armature *d* on the right side of the drawing was unaffected. When the relay-coil current was caused to flow in the opposite direction, the situation was reversed so that P_1 became south and P_2 north, causing armature *d* to be attracted to contact *e* and armature *a* to be repelled.

By way of example, solenoid actuators for remotely steering a torpedo to the left or right could be controlled by the normally open contacts *a-c* or *d-e* of the polarized relay depicted in figure 1.4. With no current applied to the single-conductor tether, the electromagnetic field of the relay coil is not energized, both armatures are in their normally closed positions, and the torpedo goes straight. Applying a suitable current closes one set of contacts and energizes its associated steering actuator, while reversing this current closes the other set and reverses the direction of turn.[12]



1.4

A typical polarized-relay configuration employed a pair of permanent-magnet armatures *a* and *d* to actuate either of two sets of electrical contacts *a-b-c* or *d-e-f*, depending on the direction of the coil current flowing between binding posts *R* (US Patent No. 319,633; Sims, 1885, redrawn by Todd Everett).

The concept of electrically steering a "fire ship" from shore was proposed in 1862 by Captain W. H. Noble, but never pursued (Stotherd, 1873). Without mentioning the date, W. H. G. Kingston (1876) attributes the first actual design of electrical steering to "a Mr. Morshand," who remains for now otherwise unidentified: "Several crewless torpedo-boats have been designed, the first by a Mr. Morshand, who proposed to propel it by a compressed air engine, and to steer it from shore by electricity."

Kingston (1876) also mentions similar plans by Colonel John Archibald Ballard of the Royal Engineers: "More recently, Colonel Ballard of the Royal Engineers and others have proposed plans for steering crewless torpedo-boats by the same agent." Further details regarding Ballard's proposal are provided by Lieutenant Colonel R. H. Stotherd:

> Some time ago, Colonel Ballard, R.E., suggested the idea of steering a torpedo by electricity. He proposed to employ a relay battery in the torpedo itself, by which a rudder could be worked, the relay being set into action by means of a primary current passing through two insulated wires, to be reeled out from the torpedo itself as it advanced through the water. The motive power proposed for the torpedo, might be compressed air, or any other agent by which the desired result of progression could be attained. (Stotherd, 1873)

Additional information is found in a late nineteenth-century encyclopedia entry written by Henry L. Abbot (1895): "The fish-torpedo steered and controlled by electricity was first patented by Lieut.-Col. Ballard, Royal Engineers, in Aug., 1870, and again by Lieut.-Col. Foster, U.S. Engineers in 1872. It has been independently elaborated by Mr. Lay and H. J. Smith in the U.S., and by Col. von Scheliha in Russia."

Ballard reportedly fitted his remote-steering apparatus to a steam launch for testing by HMS *Excellent* (Stotherd, 1873). A recognized authority on underwater engineering, Lieutenant Colonel John Gray Foster, US Army Corps of Engineers, received a US patent in 1872 for an electrically powered and steered torpedo, which apparently was never built (King, 1895; Roden, 1899).

The above introductory discussion is indicative of the plethora of very early attempts to create a marine torpedo that could be successfully guided to its target under remote control. Many versions of each type were built in most of these cases, and performance often varied with each change. As a result, there is considerable disagreement in the historical references, particularly newspaper accounts, which are generally reliable with regard to dates but often misleading in terms of their technical descriptions. The uneducated and opportunistic press wrote about early marine torpedoes with a mixture of naive hype and sensationalism, which created even more confusion and erroneous accounts. As Commander Peter Bethell beautifully expressed the problem in the introduction to his series of articles on "The Development of the Torpedo": "In the country of the blind the one-eyed man is king, and it has been possible in the past for pseudo-technical writers and frauds to feed the public with articles and even books relating to underwater weapons, displaying in the process a floridity of imagination so reckless as to amount almost to invention" (Bethell, 1945–1946).

Some of the more significant nineteenth-century torpedo development efforts are reviewed in the following sections, though they by no means provide a full account. To facilitate this discussion, I will define in advance some of the contemporary terminology:

- *Dirigible*: steerable, as in a dirigible airship that can be maneuvered at will, unlike a balloon that drifts with the wind. A dirigible torpedo was remotely guided by an operator.
- *Controllable*: a dirigible torpedo that could also be remotely started, stopped, and in some cases exploded.
- *Automobile*: a torpedo that carried its source of propulsion energy onboard.
- *Locomotive*: a torpedo for which the propulsion energy, typically compressed air or electricity, was provided from an external source.