The Origin of the APL Strategic Systems Department

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In 1957, the Navy's Special Projects Office approached APL for assistance in developing the Polaris Fleet Ballistic Missile (FBM) Strategic Weapon System. The primary task was to define and execute a comprehensive FBM test and evaluation program to validate the integrated weapon system design. The launch of Sputnik created a widespread view that a "missile gap" existed with the Soviet Union. In response, the United States accelerated all ballistic missile programs and assigned the highest national priority to Polaris. On 1 August 1958, the APL Polaris Division, the forerunner of our Strategic Systems Department, was created to focus dedicated support on this national priority program. This article discusses the origin of the FBM Program, the roots of our involvement in it, details of significant contributions made by APL, and the evolution of programs that define our Department today.
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INTRODUCTION

On 1 August 1998, the APL Strategic Systems Department (SSD) celebrated 40 years of continuous support to the Fleet Ballistic Missile (FBM) Program. During that interval, the Navy's Strategic Systems Programs (SSP) has developed and deployed three generations of increasingly capable strategic weapon systems (Polaris, Poseidon, and Trident) and six submarine-launched ballistic missile (SLBM) variants: Polaris A1, A2, A3; Poseidon C3; and Trident I (C4) and Trident II (D5). The FBM Program is unquestionably one of the largest, most successful weapon system development efforts ever attempted.[1–4] It is remarkable that a program of this stature began on such tenuous footing.

The Special Projects Office (SPO), the predecessor of SSP, was created in November 1955 under Rear Admiral William F. Raborn in response to an "urgent" Department of Defense need to develop an Intermediate Range Ballistic Missile (IRBM). The initial SPO program involved a joint effort with the Army to adapt their liquid-fueled Jupiter missile for sea-basing. Few thought this concept could become a practical naval weapon. Raborn envisioned a solid-propellant ballistic missile on a submarine, always ready and invulnerable to detection and attack, as the ideal deterrent. Unfortunately, solid-rocket technology had not progressed sufficiently to enable production of large-diameter high specific impulse (I_{sp}) solid-propellant rocket motors.

Significant advances in navigation, inertial guidance, and materials technologies plus entirely new technology bases for underwater launch and reentry systems were also needed to make this vision a reality. Although the challenges were daunting, Raborn initiated an alternative development program to pursue a solid-propellant SLBM and recruited Captain (later Vice Admiral) Levering Smith (Fig. 1), one of the Navy's top solid-propellant experts, to lead this effort.

Not surprisingly, Levering Smith knew of APL's accomplishments, capabilities, and programs by the time he reported to SPO in 1956. He was a wartime colleague and friend of Drs. Ralph E. Gibson and Alexander Kossiakoff, the APL Director and Assistant Director for Technical Operations, respectively. In Levering's previous assignments—as the Associate Technical Director of the Naval Ordnance Test Station, Inyokern, California (later named China Lake), and Commander, Naval Ordnance Missile Test Facility, White Sands Proving Ground, New Mexico—he presided over many of APL's guided missile tests. In early 1957, Smith approached Dr. Gibson for assistance in developing Polaris. He requested that APL provide a full-time technical advisor to the program and consider helping SPO in the planning and execution of the Bureau of Ordnance (BuOrd) test and evaluation program to validate the FBM subsystems and integrated weapon system designs. The principal reasons for SPO asking us to undertake this effort were our status as an independent university laboratory with an established reputation for technical excellence and integrity, and our extensive experience in guided missile technology (Bumblebee Program) and associated shipboard launching and fire-control systems. In particular, the APL-led shipboard integration and testing of the Terrier missile was uniquely valuable.

Figure 1. RADM Levering Smith. As the SPO Technical Director (SP-20, 1957–1965) he led the team that conceived, built, and deployed the first-generation Polaris Fleet Ballistic Missile Strategic Weapon System. Under his leadership as Director of SPO (1965–1977), a fleet of 41 SSBN submarines became the backbone of the nation's nuclear strategic deterrent. (Photo courtesy the U.S. Navy.)

Gibson recognized the national importance of Polaris and the potential for APL to make significant contributions. He agreed to "loan" Dr. Richard B. Kershner, head of the APL Terrier Program, to Levering Smith on a half-time basis. In mid-1957, Dick Kershner became SP-2001. He served as both an independent technical advisor to Smith and a "special representative of the Laboratory" with the aim of identifying Polaris needs where APL expertise might assist. A formal APL contract was established with SPO on 1 October 1957.

The scope of APL's support increased dramatically by mid-1958 as the first missile developmental flight tests approached and because of the accelerated Polaris schedule caused by the launching of Sputnik. On 1 August 1958, the APL Polaris Division was created to handle the expanding effort. The Polaris Division is the origin of our Strategic Systems Department.

Throughout 40 years of support, APL has made many significant contributions to the FBM Program. Two early "breakthroughs" were particularly important: (1) satellite navigation, leading to the Navy's Transit system, and (2) the canted, rotatable-nozzle thrust vector control system, which enabled Polaris to use a new high-energy solid propellant to achieve its 1500 nmi IRBM range objective.

The planning and execution of the operational test and evaluation programs for Polaris and its successors established a continuing requirement for our support. SSD has developed new and innovative test concepts, analytical methodologies, and special instrumentation to address the challenging and unique evaluation requirements of each new generation of FBM Strategic Weapon System (some of these are discussed in other articles within this issue). This "cradle-to-grave" life-cycle evaluation process provides a crucial mechanism to identify deficiencies and trends and to initiate material, procedural, and training improvements to maintain the exceptional reliability and readiness that are a hallmark of the FBM Program.

THE NATIONAL BALLISTIC MISSILE PROGRAM

Long-range ballistic missile concepts were studied in the United States beginning in 1946 but were not developed because of technology limitations and the lack of clear military requirements. The atomic weapons used to end World War II were large and heavy. Ballistic missiles to carry these weapons required new and powerful propulsion systems, reliable guidance concepts, and high-temperature reentry materials.

Until such technology became available, the aircraft was the preferred long-range nuclear weapon delivery system. The military services believed that practical long-range ballistic missile weapons were at least a decade away. Thus, ballistic missile research proceeded at a leisurely pace until the Soviet Union exploded its first atomic weapon in 1949. The Korean War followed soon thereafter, as did intelligence reports of Soviet ballistic missile tests. The emerging Soviet threat revitalized the dormant U.S. ballistic missile initiatives. In 1948, the "Key West Agreement" had assigned our armed services separate roles in nuclear warfare. The Intercontinental-range Ballistic Missile (ICBM) went to the Air Force, the Army was authorized to develop an IRBM, but a Navy ballistic missile role was not acknowledged.

The highest-priority post–World War II Navy missile development was directed toward an anti-air fleet defense capability, the BuOrd-sponsored "T-missile" programs (Terrier, Tartar, and Talos) developed by APL. Simultaneously, the Navy Bureau of Aeronautics commenced developing the first submarine-based strategic weapon, the turbojet-powered Regulus I missile, and had ambitions for a fleet of submarines armed with advanced air-breathing cruise missiles.

In early 1954, President Eisenhower appointed a special committee chaired by James Killian of the Massachusetts Institute of Technology to review the status of long-range missile developments in an effort to define a national ballistic missile program. Officially known as the Technologies Capability Panel, the Killian Committee's report, *Meeting the Threat of Surprise Attack,*[3] became the foundation for initial U.S. strategic planning. The report emphasized the need for the "urgent" development of IRBMs, noting that developing a 1500-nmi IRBM would be "much easier and have greater assurance of success" than the 5500-nmi ICBM. Specifically, the committee recommended that "There be developed a ballistic missile (with about 1500 nautical miles range and megaton warhead) for strategic bombardment; both land-basing and ship-basing should be considered."[3]

The President acknowledged that ballistic missiles should receive the highest priority, but decided that the development programs would be limited to a primary and a backup design for both an ICBM and an IRBM. Because the Navy had not developed a consensus on the value of ballistic missiles to their mission, DoD assigned responsibility for the early missile development programs to the Air Force (ICBM 1, Atlas; ICBM 2, Titan; IRBM 1, Thor) and the Army (IRBM 2, Jupiter). To participate, the Navy would have to convince one of the other services to enter into a joint program.

On 17 August 1955, Admiral Arleigh Burke became Chief of Naval Operations, and within 24 hours of taking office, he arranged for a briefing on the status of the Navy IRBM concept, which was being called the Fleet Ballistic Missile. The Admiral was convinced that a mobile offensive ballistic missile had tremendous military advantages and that the Navy could best offer that mobility. He immediately built support for the FBM and cobbled together a joint effort with the Army to develop a sea-based version of its liquid-fueled Jupiter. On 8 November 1955, Secretary of Defense Wilson issued a memorandum to the military services authorizing the development of an IRBM at "the maximum speed permitted by technology."

The IRBM component of the National Ballistic Missile Program (Fig. 2) became the "land-based development by the Air Force (IRBM 1) and a Joint Army–Navy program (IRBM 2) having the dual objective of achieving an early shipboard capability and providing a land-based alternative to the Air Force program."[3] Within a week, the Navy SPO was created (17 November 1955) to evolve the Navy's strategic ballistic missile role, with Rear Admiral Raborn as its first Director. A Joint Army–Navy Ballistic Missile Committee was formed to coordinate the development of the Jupiter missile for Navy use. The division of responsibilities left the primary missile development tasks with the Army, while the SPO would concentrate on the shipboard systems necessary to integrate the missile into large Mariner-class merchant ships, and later onto a submarine.

The Jupiter missile was large and heavy and had not been designed for shipboard handling, maintenance, or ship dynamics. The most critical issue, however, was its liquid oxygen fuel. This required complex shipboard plumbing and pumps, causing excessive fueling delays. Boil-off of liquid oxygen posed a particularly intractable problem in a submerged submarine. There was great concern regarding the safety of handling liquid propellants aboard all ships. Raborn was convinced that the Navy should develop a solid-propellant missile as an alternative to Jupiter and base it on a submarine. He wanted a simple, rugged, reliable, and instantly ready missile "like a cartridge in a gun."

Unfortunately, propulsion technology had not advanced sufficiently to make this approach practical. Production of large-diameter high I_{sp} rockets was limited by the mechanical properties and manufacturing techniques for existing propellant formulations. Other solid-propulsion challenges were unstable combustion, inability to assure thrust termination at the precise velocity-to-be-gained (for accurate warhead delivery),

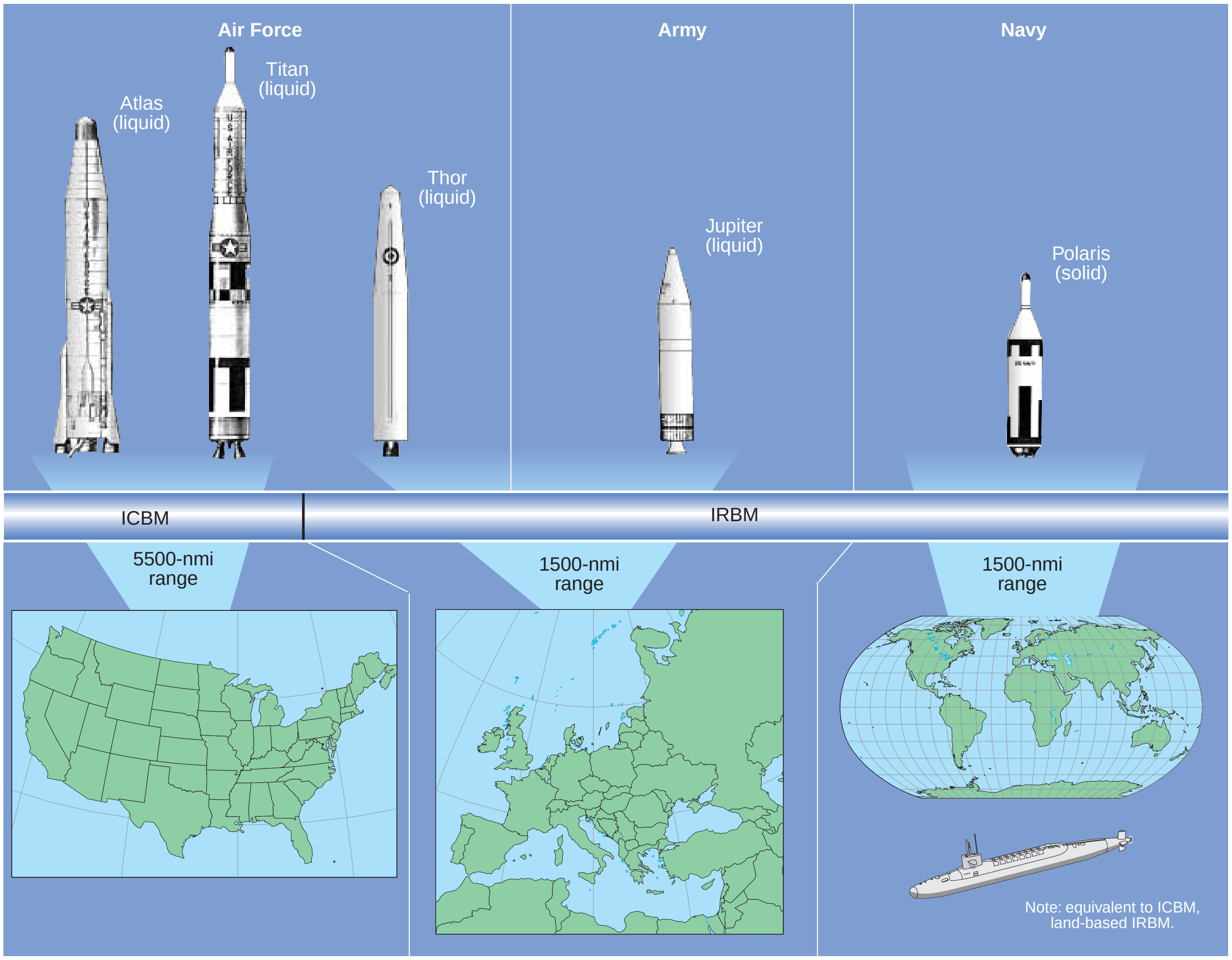

Figure 2. Strategic ballistic missile development in the United States began with four programs, a primary and a backup for an ICBM (Atlas, Titan) and an IRBM (Thor, Jupiter), which were land-based in the United States and overseas with NATO allies, respectively. The Navy proposed a novel solid-propellant missile (Polaris) based on a submarine as an alternative IRBM. It was mobile, always ready to launch, invulnerable to detection and attack, and did not require negotiations for a foreign deployment locale. This appealing concept led to the Fleet Ballistic Missile Strategic Weapon System.

thrust vector control schemes, nozzle reliability, and construction techniques for large combustion chambers. Nevertheless, the promise of solid propellants was so compelling that Raborn and the SPO team set out to gain support for a solid-fueled approach as an alternative FBM.

In January 1956, SPO asked the Lockheed Missiles and Space Division (LMSD) and the Aerojet-General Corporation for assistance in developing solid-fueled SLBM concepts. The two companies quickly responded with a conceptual design for a missile with clustered 40-in.-dia. rockets carrying the large Jupiter warhead, called "Jupiter-S" (Fig. 3). This initial concept was impractical but served to convince DoD that the Navy's research into solid fuels would be of long-term benefit to all missile programs.

In March 1956, SPO secured approval for "systems studies" of a solid-fueled IRBM 2. With the outline of a formal program in hand, Raborn recruited Captain Levering Smith to head the pursuit of a practical solid-fueled FBM design. Smith officially reported to SPO in May 1956 as the first Head of the new Propulsion Branch (SP-27, later renamed the Missile Branch).

During the summer of 1956, SPO participated in a crucial study on antisubmarine warfare held at Nobska Point, Woods Hole, Massachusetts. The study group learned of the stunning news that drastic reductions in the size and weight of significant-yield nuclear warheads were imminent, enabling a much smaller solid-propellant missile than the Jupiter-S. The Nobska panel concluded that a fleet of nuclear submarines armed with the smaller missile would be a far better strategic deterrent than the ongoing FBM Program and recommended that the Navy adopt the new missile concept.

Strengthened by this information, Arleigh Burke and Raborn convinced the Navy of the merits of this new approach (named Polaris by Raborn). *On*

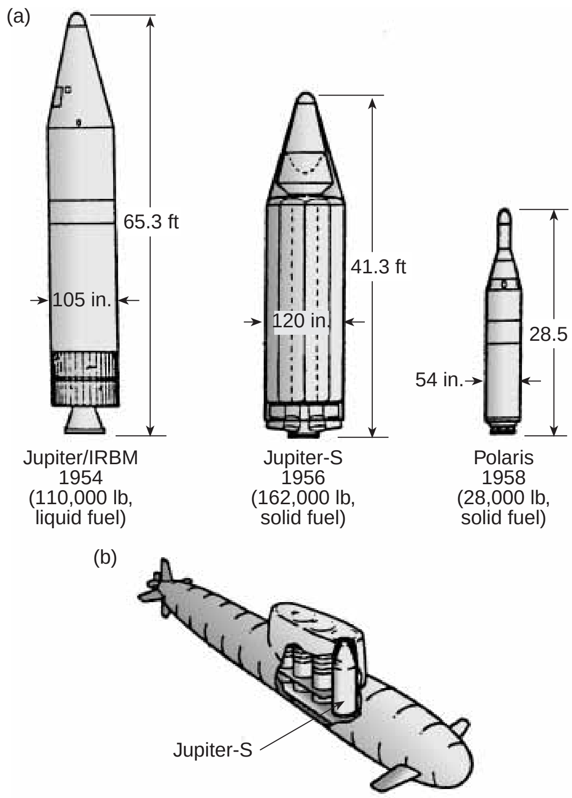

Figure 3. The Navy Special Projects Office was originally chartered to adapt the Army Jupiter/IRBM missile for sea-basing. An alternative solid-propellant missile approach led to the Jupiter-S, and finally to Polaris. Polaris was small enough to be based on an existing submarine in sufficient quantity (16) to make it a practical strategic deterrent.

8 December 1956, the Secretary of Defense approved the recommendation to terminate Navy participation in the Jupiter Program and concentrate on Polaris, signifying the official beginning of the FBM Program. SPO continued to recruit the cream of the BuOrd engineering staff to form a strong systems engineering and technical direction team to manage FBM development. A study group, which later became the permanent Steering Task Group, was organized to identify trade-offs and select envelope parameters for the Polaris weapon system by March 1957. In December 1956, Levering Smith was appointed Deputy Technical Director, and by July 1957, he became the SPO Technical Director (SP-20), spearheading the development of Polaris.

THE ALLEGANY BALLISTICS LABORATORY

The seeds for APL involvement in the FBM Program were sown at the end of World War II. At that time Commander Levering Smith was Head of the BuOrd Rocket Propellant Research and Development Division. While there, he became a colleague of Ralph Gibson, who had led the wartime research on solid-rocket weapons under Dr. Clarence Hickman's Section H, one of the family of university affiliated entities organized by the National Defense Research Committee (NDRC) to focus the scientific community on important World War II military needs. One mission of Section H was to improve the characteristics of existing solid propellants with a research and experimental test program aimed at understanding and controlling the internal ballistics of rockets. Section H began the first Navy development of solid-propellant weapons at the Naval Powder Factor, Indian Head, Maryland, under contractual arrangements with George Washington University (GWU) in October 1941. With the need for additional laboratory space, Section H moved to an alternate site near Cumberland, Maryland, which they named the Allegany Ballistics Laboratory (ABL). ABL operated under an NDRC contract with GWU from February 1944 until the end of the war.

As World War II was winding down, ABL was faced with demobilization and an uncertain future. APL, on the other hand, was successfully transitioning (Fig. 4) from its wartime mission—the development of the proximity (VT) fuze under NDRC/Section T—to its post–war era mission to develop guided missile technology (Bumblebee Program) that would defend the Fleet from an advanced air threat.

In the summer of 1945, Gibson and Kossiakoff, then Director and Assistant Director for Research at ABL, respectively, visited our Laboratory to explore the application of Section H rocket expertise to the Bumblebee Program. They found the challenges irresistible and instead of returning to their prewar academic careers, they decided to join the APL staff along with several other ABL colleagues, including Drs. Frank T. McClure, Kershner, and a year later, William H. Avery. These five eminent scientists collectively brought to APL not only an extraordinary background in propulsion, but also a unique group of visionaries who would have a profound impact on the destiny of our Laboratory.

Also during this time, Levering Smith recognized the enormous future potential of solid rockets and took decisive action to protect the momentum that had accumulated during the war. In late 1945, he brokered an arrangement to preserve ABL by persuading the Hercules Powder Company to operate it for BuOrd as a government-owned/contractor-operated facility. With help from Gibson, he arranged for continuity of ABL activities in support of Bumblebee development needs under APL technical direction. Hercules moved several hundred employees from other sites to support this effort.

These actions had an immediate payoff, as ABL produced the first large, operational solid-propellant motor for APL's Terrier missile. The wartime experiments of Drs. John Kinkaid and Henry Shuey (Explosives Research Laboratory, Bruceton, Pennsylvania)

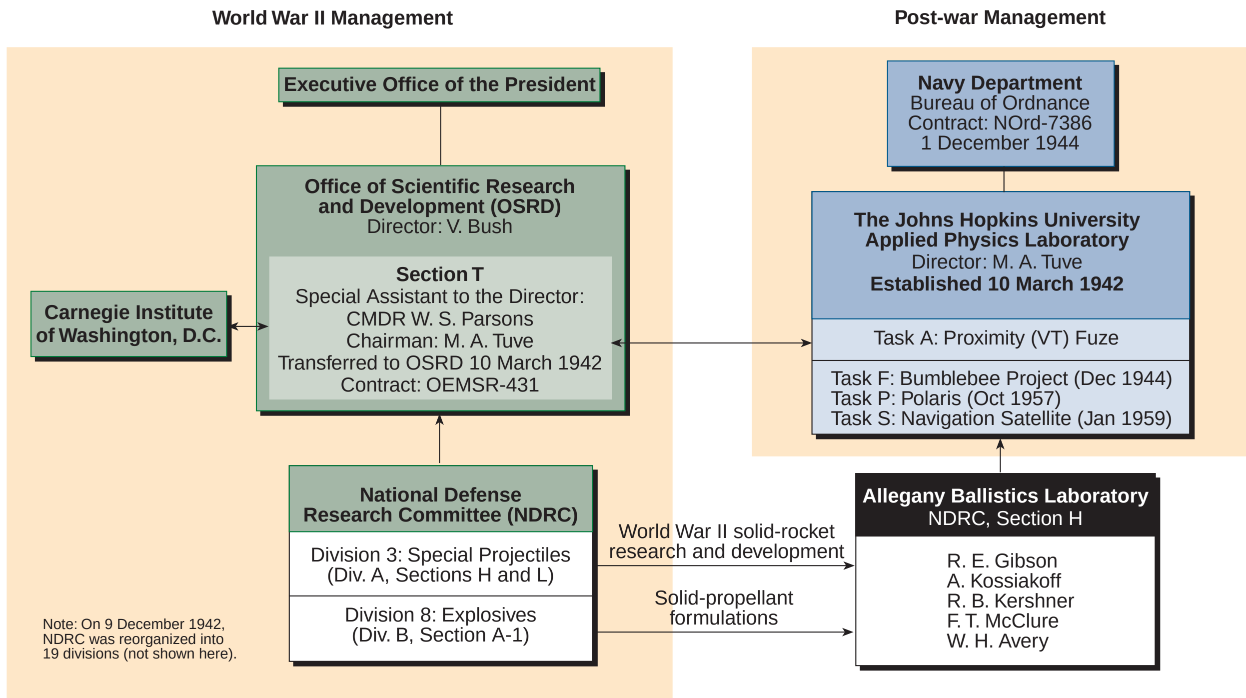

Figure 4. Transition of APL to the post-war era. OSRD was created to facilitate technology transfer of NDRC-developed prototype weapons to industry. NDRC/Section T became APL under The Johns Hopkins University (10 March 1942) to oversee the wartime production of the proximity (VT) fuze. APL began transitioning to its post–World War II era mission under contract to the Navy (1 December 1944; the Bumblebee Program). The Allegany Ballistics Laboratory staff shown here transferred to APL at the end of the war. Each rose to a leadership position and played a prominent role in charting the future course of APL.

had resulted in a manufacturing process for double-base solid propellants that allowed them to be cast into molds. This process was used by Drs. Lyman Bonner and Richard Winer at Hercules/ABL to produce the Terrier motors.[5] The process was unique in that it was "scalable" to larger-diameter motors, thus establishing the foundation for an order-of-magnitude increase in the size of solid-fuel motors for ballistic missiles and space exploration. Little did Levering Smith know in 1945 that his swift action to preserve ABL would be of extraordinary benefit to the Polaris Program that he would lead many years later. The collaboration between APL and Hercules/ABL continued and produced an important propulsion breakthrough for Polaris.

THE POLARIS AD HOC GROUP

In the fall of 1956, as SPO was marshaling its forces to push for approval of Polaris, Admiral Raborn decided that a technical peer review of the program would be helpful. Acting upon Raborn's request, Dr. C. C. Furnas, Assistant Secretary of Defense for Research and Development, assembled an independent team of experts, called the Polaris Ad Hoc Group, whose objective was to review the critical technical problems involved in the FBM Program. Furnas formally invited APL to lead this review. Kossiakoff was asked to chair the group, and Avery participated as a panel member along with five experts from other organizations.

The group traveled to various FBM contractor sites and examined technical phases of the program, particularly those concerned with the solid-propellant rockets. Although the program was still in its formative stage, two missile configurations had been defined, Polaris A, an "interim" developmental variant intended only to flight-test candidate missile technologies, and Polaris B, which was planned to be the first operationally deployed tactical missile. At that time, the objectives for the interim Polaris A capability were to achieve submarine basing by 1 January 1963, have a surface launch capability only, have provisions to adapt to a surface combatant ship, and achieve a 1200-nmi range. Polaris B objectives were to establish a fully operational submarine basing by 1 January 1965, both surface and submerged launch capabilities, and a 1500-nmi IRBM range.

The Ad Hoc Group made important recommendations to SPO in July 1957. Their findings indicated that the interim Polaris A was on track but that the technology and design to achieve the tactical Polaris B capability were less certain. A significant Polaris B range penalty resulted from using steel motor cases with heavy nozzles and inert components on both stages; the ability to meet the 1500-nmi range would also require development of an entirely new high-energy propellant, better than any that existed. The Ad Hoc Group anticipated the problems that this new propellant's higher-temperature exhaust gases would impose on the survivability of inert parts, particularly nozzle throats and jetevators. (The jetevator is a solid ring of molybdenum on each of the static motor nozzles that is rotated into the exhaust stream for thrust vector control.) They cautioned that the new Polaris B propellant could pose a risk from an increased detonation hazard or unstable resonant burning phenomenon. If such problems arose, they would go undetected until late in developmental testing, which would pose a major risk to meeting the deployment schedule. As a result, the group concluded that a major improvement in the state of rocket art would have to be made before Polaris objectives could be met, and that the importance of the Polaris objectives warranted a backup program on a competitive family of propellants. APL assisted SPO and Hercules/ABL in creating this backup propulsion program.

THE IMPACT OF SPUTNIK

On 4 October 1957, the Soviet Union stunned the world by placing Sputnik I, the first artificial Earth satellite, in orbit. The successful orbiting of the much larger and heavier Sputnik II followed only a month later. In response, the highly publicized attempt to rush an American satellite (Vanguard) into orbit was spectacularly unsuccessful. These events created a widespread view that we were lagging the Soviets in missile technology (the so-called "missile gap"). American technical prowess had suffered a huge setback that threatened to undermine public trust in the capabilities of the military and the policies of the Eisenhower administration. A dramatic and sweeping response was organized in the military and civilian sectors of the government, emphasizing the importance of science and technology (a legacy we live with today). The response to Sputnik included

- Resurrection of the Explorer Project, which successfully launched the first U.S. satellite on a military (Jupiter) missile
- Creation of the National Aeronautics and Space Administration (NASA)
- Creation of the Advanced Research Projects Agency (ARPA) and the DoD Research and Engineering organization
- Authorization for development of both Thor and Jupiter IRBMs as well as the mobile Army Pershing 1
- Acceleration of the Atlas ICBM and Polaris IRBM strategic programs

The accelerated Navy program advanced the interim Polaris capability by 2 years (June 1961) and the operational system by 18 months (April 1962). Polaris A, originally intended only as a test bed, was modified to allow both submerged and surface-launch capability, and it become the first deployed tactical missile (designated Polaris A1). Its shorter range (1200 nmi) provided the interim weapon system capability. Polaris B, the original tactical missile design (redesignated Polaris A2), retained its 1500-nmi IRBM range specification with an earlier deployment milestone. A new requirement for an advanced missile with a range of 2500 nmi (Polaris A3) was added with a planned mid-1964 deployment milestone. What was a hectic pace at SPO became an urgent "wartime-like" development of extensive visibility.

THE APL POLARIS DIVISION

A contract for APL to support SPO and Polaris (Task P) was established in Amendment No. 88 to NOrd-7386, covering a 1-year term beginning 1 October 1957. A Special Projects Group (CLS, established 15 November 1957) was formed under Kershner with 10 part-time Bumblebee staff. The initial Polaris tasks assigned to APL were shipboard safety and damage control, weapon system test and evaluation, and research into unstable burning of solid-rocket propellants. On 1 December 1957, Kershner left the Terrier Program to become the Supervisor of the Polaris Program and Assistant, Bumblebee Supervisor for Polaris. The latter position reflected APL's intent to perform appropriate engineering development work for Polaris in addition to studies, experimental work, and the principal task of defining the FBM operational test and evaluation program. Once the active test phase for the Polaris AX missile developmental flight tests neared, the scope of the APL effort increased dramatically. The Laboratory's Polaris Division (PO) was created on 1 August 1958 to dedicate efforts to these needs. Figure 5 shows the structure and evolution of the APL organization supporting the FBM Program.

The APL Polaris Division is the forerunner of our Strategic Systems Department. Three new groups were formed: Polaris Analysis and Performance Requirements (POA) under Robert C. Morton, Polaris Evaluation and Test (POE) under Dr. Robert K. ("Kirk") Dahlstrom, and Satellite Navigation Development (POS) under Kershner. POA was assigned to coordinate analysis of the Polaris subsystems with operational concepts to define performance requirements and to produce a test concept for the integrated weapon system. Morton, Supervisor of the Terrier Systems Group (TES), had led the shipboard integration and testing for Terrier, including definition of performance requirements and planning for its BuOrd evaluation test program. Dahlstrom, "Doctor D" to his colleagues, was known as the wizard of experimental test evaluations. He participated in the proximity (VT) fuze program, assisted in the development of the Navy's torpedo influence exploder, supervised the APL flight test project that developed the supersonic ramjet engine,

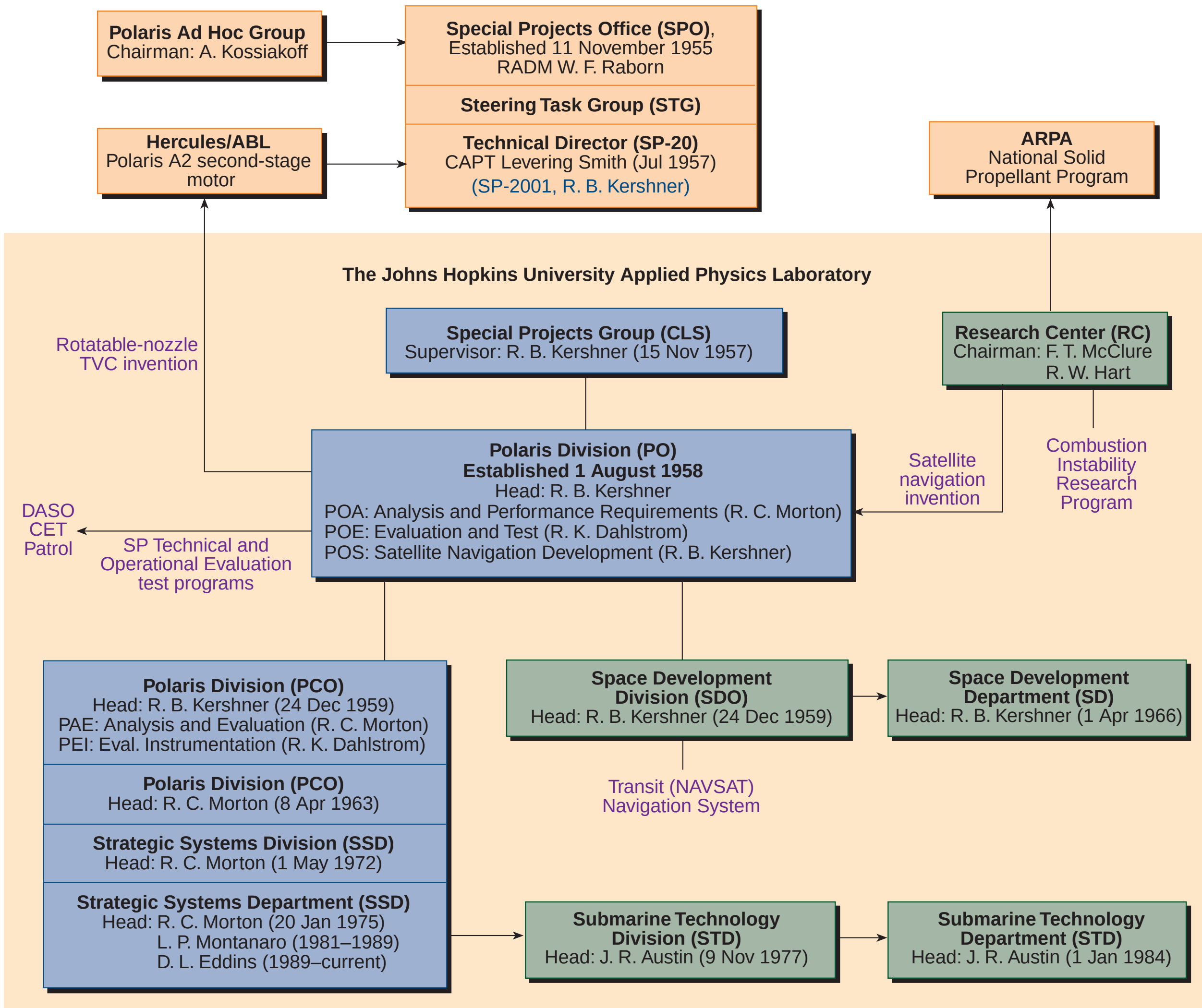

Figure 5. Evolution of the APL organization supporting the Fleet Ballistic Missile Program.

and served as Assistant Supervisor of the APL Talos Division. Doctor D's reputation in reading obscure telemetry and divining the underlying explanation for problems was legendary throughout the Navy. Levering Smith specifically requested that Dahlstrom lead the APL effort to conduct the independent analysis of the Polaris missile developmental flight test program. The tasks for which POE were responsible included the review of flight test instrumentation and operations plans, establishment of data requirements, telemetry processing, and independent flight evaluations.

POS was initially tasked to perform studies of a worldwide navigation concept based on satellites, an idea conceived by APL scientists listening to Sputnik. On 15 January 1959, this activity evolved into a new program: Task S, Satellite Doppler Navigation Systems, focused on the development of techniques, equipment, satellites, and ground stations to prove the feasibility of the new navigation concept called Transit. This led to the creation of a new Space Development Division (SDO) under Kershner, the origin of the APL Space Department. The Polaris weapon system evaluation tasks in POA and POE were merged to form the core activity that has evolved over 40 years into our Strategic Systems Department.

APL'S CONTRIBUTIONS TO THE POLARIS FBM PROGRAM

The Laboratory conducted many small studies and engineering investigations for SPO at the outset of the Polaris Program. These involved reviews of the Polaris guidance electronics packaging approach, limitations on jetevator steering control, staging and warhead separation concepts, issues related to a land-based version of Polaris, submarine vulnerability and system firing rates, missile shipboard safety, and conceptual design of a launch tube quenching system. APL designed and fabricated the prototype Polaris A1 reentry system nose fairing eject mechanism that was later adopted by LMSD. The Laboratory's major activities in support of Polaris are summarized in the following paragraphs.

Satellite Navigation (Transit)

A prime example of the unexpected benefits of scientific curiosity is the invention of satellite navigation by APL scientists in March 1958. Drs. William H. Guier and George C. Weiffenbach were intrigued with the Doppler shift of radio transmissions from Sputnik, and they used this effect to precisely determine its orbital parameters. Frank McClure had the brilliant insight that, by inverting the calculation of orbital parameters, one could accurately locate (navigate) position on the surface of the Earth. In his historic 18 March 1958 memorandum, McClure disclosed the invention of Doppler satellite navigation, noting the "possible importance of this system to the Polaris weapon system." His satellite-based navigation concept would let submarines at sea precisely update their inertial navigation systems from a covert posture, in all weather conditions, anywhere in the world, thereby enabling the Polaris weapon system to maintain its system accuracy. Gibson and Kershner immediately briefed Raborn and Smith, who enthusiastically endorsed the idea and asked APL to prepare a proposal for a program implementation. This proposal led to Task S,[6] the Transit Satellite Navigation System.

Thrust Vector Control of Solid-Fueled Rockets

Attainment of the 1500-nmi IRBM range required a new high-energy solid propellant and novel thrust vector control (TVC) and termination schemes. Aerojet General, the initial Polaris rocket motor contractor, approached the problem by adding massive amounts of powdered aluminum to a polyurethane-based propellant formulation to increase I_{sp} (a breakthrough discovered by Atlantic Research Corp. in January 1956) as well as to control unstable burning phenomena.

TVC for a solid-propellant IRBM had never been demonstrated. LMSD was planning to use a jetevator for Polaris TVC on both stages. However, the jetevator TVC concept exhibited serious problems when used with the new aluminized propellants. First, the elevated motor exhaust temperature induced cracking and failure from thermal shock; second, the aluminum-oxide exhaust particulate had a tendency to deposit on the jetevator, causing it to jam.[7] The approach was adequately modified for use with the Polaris A1 motor propellant but was determined to present a high risk for use with the new propellant needed for Polaris A2. An alternative TVC concept would be required.

Maximizing the performance of the second stage produced the most effective approach to gaining additional range capability. APL performed a systematic review of TVC schemes for SPO. This review led Kershner and Frank H. Swaim to invent a new TVC concept using a canted, rotatable nozzle (Fig. 6).[8,9] Unlike the jetevator, the rotating nozzle minimized the loss of axial thrust in steering, thereby maximizing range capability. This invention provided a simpler, lighter-weight, and more reliable approach to TVC for advanced solid-fueled rockets and represented a propulsion breakthrough for the Polaris and Minuteman ballistic missile programs.[10] With SPO support, APL assembled a prototype demonstration team; Cleveland Pneumatic Industries, Inc., built the new nozzles, and Hercules/ABL integrated them into a prototype motor. Tests of the new motor in February 1959 were successfully conducted at the Naval Propellant Plant, Indian Head, Maryland.

The range of the interim Polaris A1 missile had to be increased by another 300 nmi to meet the specified minimum 1500-nmi IRBM range expected from Polaris. The combination of the APL rotatable-nozzle TVC invention with the Hercules/ABL-pioneered lightweight filament-wound fiberglass epoxy-resin motor case and their high I_{sp} castable double-base propellant offered a significant integrated performance enhancement, which approached the needed range increment. SP-20 supported this "alternate" Polaris second-stage design commencing in June 1958 and adopted this approach for the A2 missile in early 1959.

The Polaris A2 missile IRBM range was ultimately achieved by lengthening the A1 first-stage design by 30 in., keeping the same proven A1 propellant and jetevator TVC in the larger first stage (to avoid too many radical changes at one time) and adding the Hercules/ABL–APL enhanced-performance second stage. On 10 November 1960, the first successful flight test of the Polaris A2 achieved a range exceeding 1400 nmi. APL's leadership, and the TVC invention of Kershner and Swaim, were vital to achieving the first successful solid-fueled IRBM (Polaris A2).

Research on Unstable Burning of Solid-Rocket Propellants

APL began a theoretical and experimental research program to explain the mechanism of unstable burning and to find a means to control solid rocket propellant instability. The accelerated national ballistic missile programs, along with the emerging importance of large-scale solid-rocket motors, prompted the Director of Defense Research and Engineering, Dr. Herbert York, to create a nationwide triservice solid-propellant research program at ARPA. Since significant work had already begun at APL under Robert W. Hart, McClure, and Avery in support of Polaris, York asked McClure, Chairman of the APL Research Center, to lead the

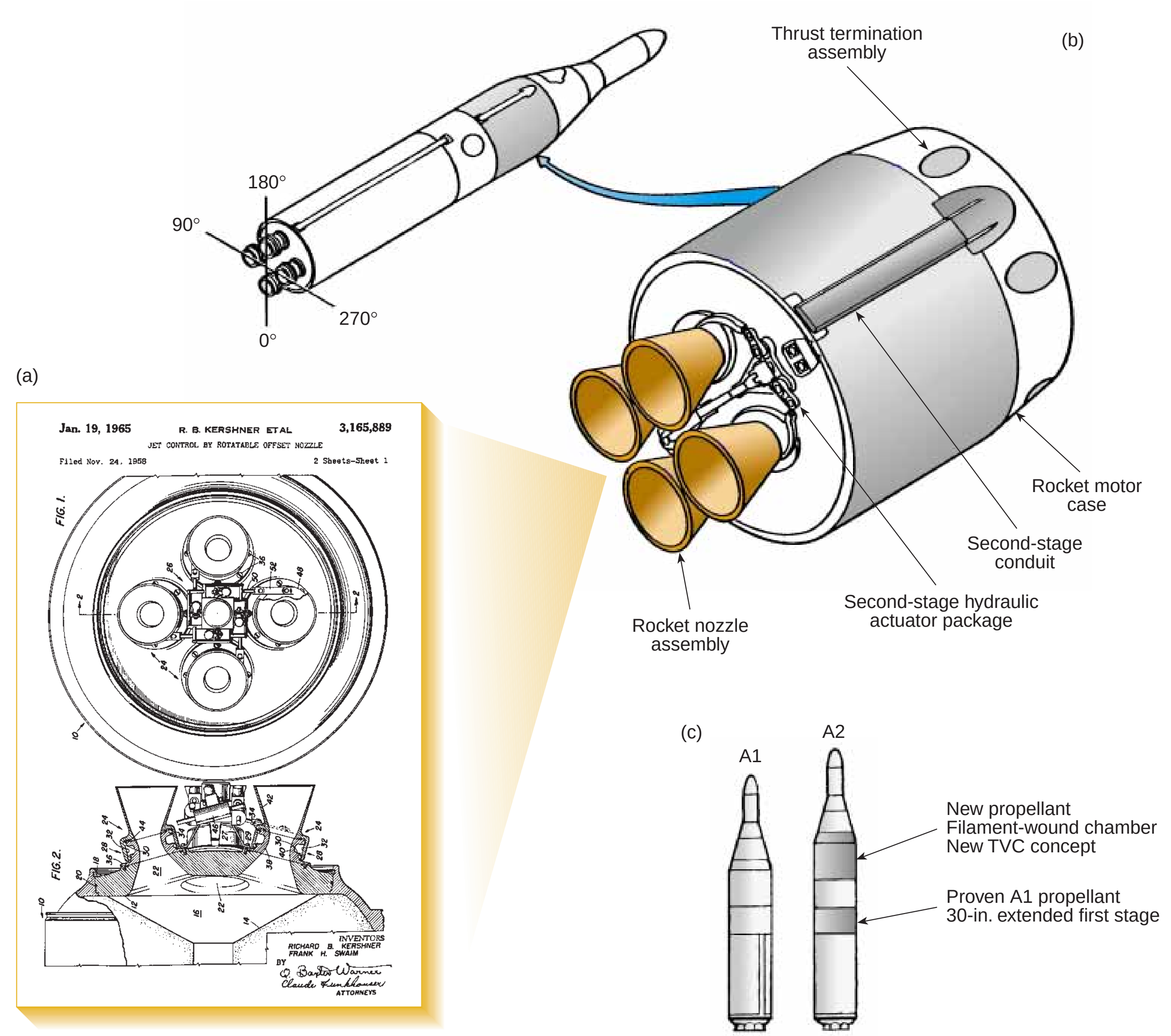

Figure 6. This APL-invented canted, rotatable-nozzle thrust vector control system (a) enabled Polaris to use new high-energy solid propellant to achieve its 1500-nmi IRBM range performance objective. APL collaborated with Hercules/ABL to develop an "alternate" Polaris second-stage rocket motor design (b) that was adopted for the tactical A2 missile. A 300-nmi range improvement over A1 was achieved in the A2 by lengthening the first stage and adding this Hercules/ABL–APL high-performance second stage (c).

nationwide combustion instability research effort. The contributions made by McClure and Hart led to the fundamental understanding and empirical characterization of unstable burning phenomena (acoustic resonance). Levering Smith would later comment on the significance of this work in remarks presented at the APL dedication ceremonies in memory of McClure on 3 December 1973:

> By 1957, the importance of the submarine-carried solid-propellant missile as a deterrent of nuclear war was becoming clear. But it was also clear that, if the development ran into problems of combustion instability, we would be at a loss to deal with them because the underlying physical principles were not well enough understood. Mac [McClure] was persuaded to become leader of a panel on the combustion instability of solid propellants to direct and coordinate a program supported by the Special Projects Office. The stimulating leadership and remarkable technical insight that Dr. McClure gave to the work of the panel from 1957 to 1964 accounted to a major extent for the success of the program. During this period about 100 papers were published, 33 from APL, of which 26 were authored or co-authored by Frank McClure. The work of McClure and Hart led to a definition of a practical test of the susceptibility of potential rocket propellants to burning in an unstable way, so that after 1964 only formulations that were free from this hazard were chosen for full-scale development. Thus, a major contribution was made to creating the engineering tools needed to confidently design large, as well as small, solid propellant rocket motors. As a result, incalculable savings have been realized in the Polaris, Poseidon, and Minuteman programs.

FBM Test and Evaluation Program

The FBM development effort included three basic test programs, a research and development (R&D)

program, a preliminary acceptance program called the Shipyard Installation and Test Program, and the Special Projects Technical and Operational Test Program. The last program was developed by APL and consists of two phases, now called DASO and CETs (Demonstration and Shakedown Operation/Commander-in-Chief [CINC] Evaluation Tests). The DASO is conducted at Cape Canaveral, Florida, and includes the firing of a test missile to certify the integrated performance of the weapon system hardware, procedures, and crew. This operation validates that each new or overhauled SSBN is ready to transition to the operational Commander and also provides important performance data. The second phase involves a periodic random selection of a deployed SSBN from the Fleet, conversion of several tactical missiles to a test configuration, and a launch operation simulating the tactical scenario as closely as possible, including the use of tactical communications assets.

The CET Program allows the current capability of the deployed force to be derived from demonstrated results throughout the life of the weapon system. Planning for the weapon subsystem test and evaluation program was led by Bob Morton and the POA staff; Kirk Dahlstrom and POE concentrated on the Polaris missile and reentry body developmental flight test evaluations (Fig. 7). The Polaris development effort culminated with the successful launch of two Polaris A1 missiles from USS *George Washington* (SSBN-598) on 20 July 1960. APL Polaris Division staff onboard and ashore participated in the technical review of subsystem performance, which resulted in approval to conduct these historic launches.

The APL analysis support for Polaris was originally intended to be temporary, lasting only through the first five SSBNs. However, as the Polaris Fleet began conducting tactical deterrent patrols, new problems were encountered and questions were raised within DoD concerning the submarine's ability to know its position accurately enough to ensure that the desired system accuracy was being achieved. Levering Smith prevailed upon APL to expand its support to develop an appropriate Patrol Evaluation Program. This led to the development of formal patrol data requirements and the first-generation Patrol Operational Readiness Instrumentation. The first APL SSBN tactical patrol evaluation was conducted for USS *Theodore Roosevelt* (SSBN-600) in November 1962. A new office was created within SPO (SP-205) to handle the test and evaluation programs and interface with the operational forces.

The Laboratory recommended that SPO initiate a new test concept called the Weapon System Readiness Test (WSRT) as part of the Patrol Evaluation Program. The WSRT sends a test message to the Fleet, which causes each tasked SSBN to conduct a simulated launch exercise. The WSRTs provided a means to

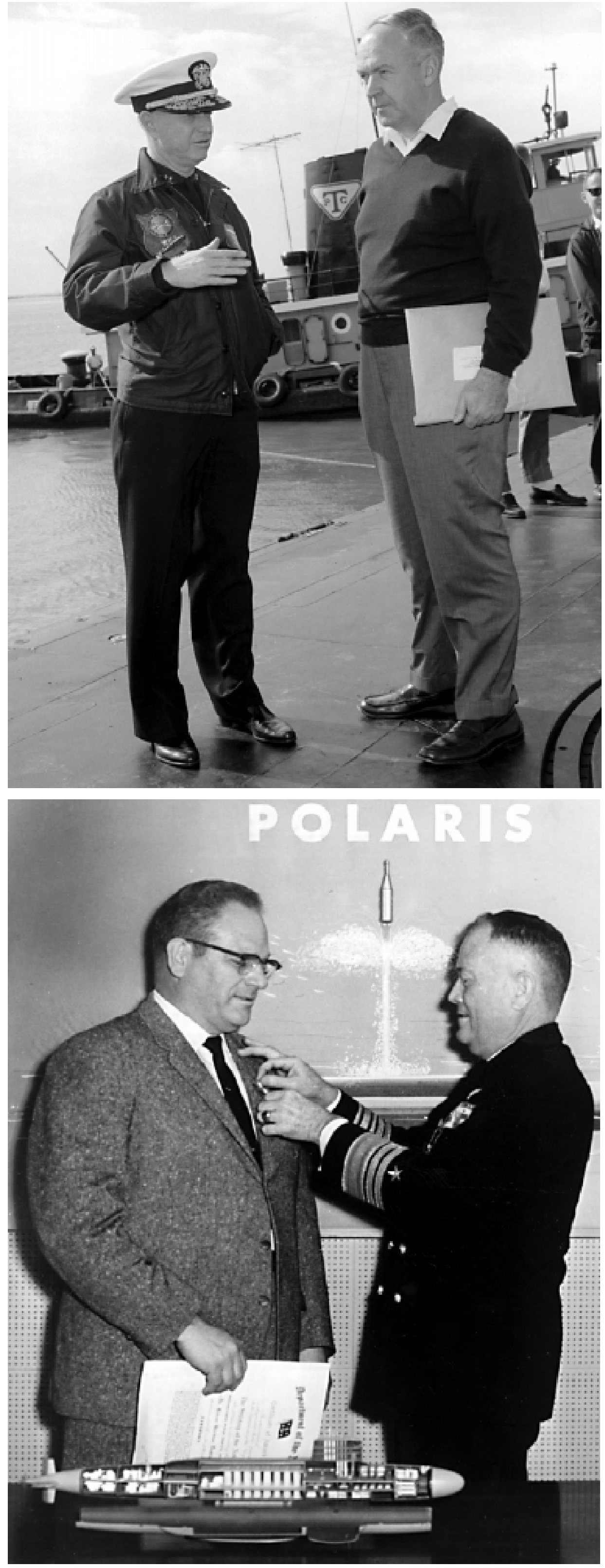

Figure 7. (top) Rear Admiral Levering Smith and Robert C. Morton, Supervisor of the APL Polaris Division, discuss results of a Polaris test missile launch aboard USS *Lewis and Clark* (SSBN-644) in Port Canaveral, Florida, 1966. (bottom) Dr. "Kirk" Dahlstrom is presented the Navy Distinguished Public Service Award by Vice Admiral William F. Raborn in 1961 for his "outstanding contributions to the successful development of the Fleet Ballistic Missile System."

demonstrate response time and produced a representative sampling of subsystem errors needed to ensure that system accuracy was being achieved while on patrol.

The APL FBM evaluation task expanded in 1965 to include support for a new Joint Chiefs of Staff directive for an annual assessment of strategic nuclear weapons systems by the CINCs responsible for their operational employment. The Weapon System Evaluation Group/Institute for Defense Analysis prepared a set of common guidelines for each CINC to use in operational test sizing, analysis, and reporting. Using these guidelines, APL assisted SPO in defining the FBM DASO/CET flight test programs, conducted mission planning and targeting, developed DASO/CET weapon system procedures, and evolved a detailed analysis methodology. The first comprehensive APL CINC Evaluation Report was completed for the Polaris A2 FBM Strategic Weapon System in 1966.

The continuing evaluation of the DASO, CET, and Patrol programs provides a crucial mechanism to monitor the deployed weapon system, identify deficiencies and trends, and recommend material, procedural, or training improvements needed to maintain the exceptional reliability and readiness of the FBM Strategic Weapon System.

On occasion, APL has undertaken an engineering development task to expedite a solution to a significant problem. For example, the Laboratory took this approach in 1963 to resolve major performance deficiencies in the SSBN hovering system. An exact replica of the SSBN pneumatic hovering controller was built and tested in a ship-motion simulator, which led to the discovery of an unexpected SSBN roll-coupling phenomenon. APL designed and fabricated an improved controller and successfully demonstrated the hovering performance improvements with this prototype installed in an SSBN for a DASO. A ship alteration design change (SHIPALT) was approved by the Navy, and kits were manufactured at APL and sent directly to the Fleet. A follow-on effort led to an APL design for an improved solid-state hovering controller that became the standard for new SSBNs.

In 1968, SPO asked APL to develop a program that evaluated the prelaunch survivability of the SSBN fleet by addressing technical issues related to submarine detectability. This effort, which began in the Polaris Division as the SSBN Security Program, established the basis for the creation of the third APL department to evolve from the Polaris FBM Program, the Submarine Technology Department. Two other non–weapon systems evaluation tasks began in the 1970s, the SSBN Sonar Evaluation Program and the Range Systems Program. Figure 8 depicts the evolution of the Strategic Systems Department programs. A detailed discussion of our current programs is provided in the next article of this issue.

SUMMARY

The Strategic Systems Department began on 1 August 1958 when the APL Polaris Division was founded to help the Navy develop the FBM Strategic Weapon System. The objective of this article was to detail the start of the FBM Program, the reasons why the Navy asked APL to help in its development, and some of our early contributions. I have chosen to elaborate on certain aspects of the Polaris propulsion developments because of the importance of the solid-propellant missile to the viability of this weapon system concept, and because the extent of APL's contributions in this field is not generally known. However, it was the inspired efforts of many people in many organizations, led by the talented Navy SPO management team, which achieved the numerous technical advances on a seemingly impossible schedule that made the FBM Strategic Weapon System a reality. Dr. Alexander Kossiakoff expressed it this way on 15 November 1977:

> I don't consider the word 'miracle' in reference to what Levering has done in bringing the Fleet Ballistic Missile system into being as an extravagant term. A man who combines the creativity and imagination of the engineer, the rigor and depth of understanding of the scientist, and the decisiveness and courage of the military officer can literally work miracles. Levering Smith is indeed such a man, and miracles he has indeed wrought.

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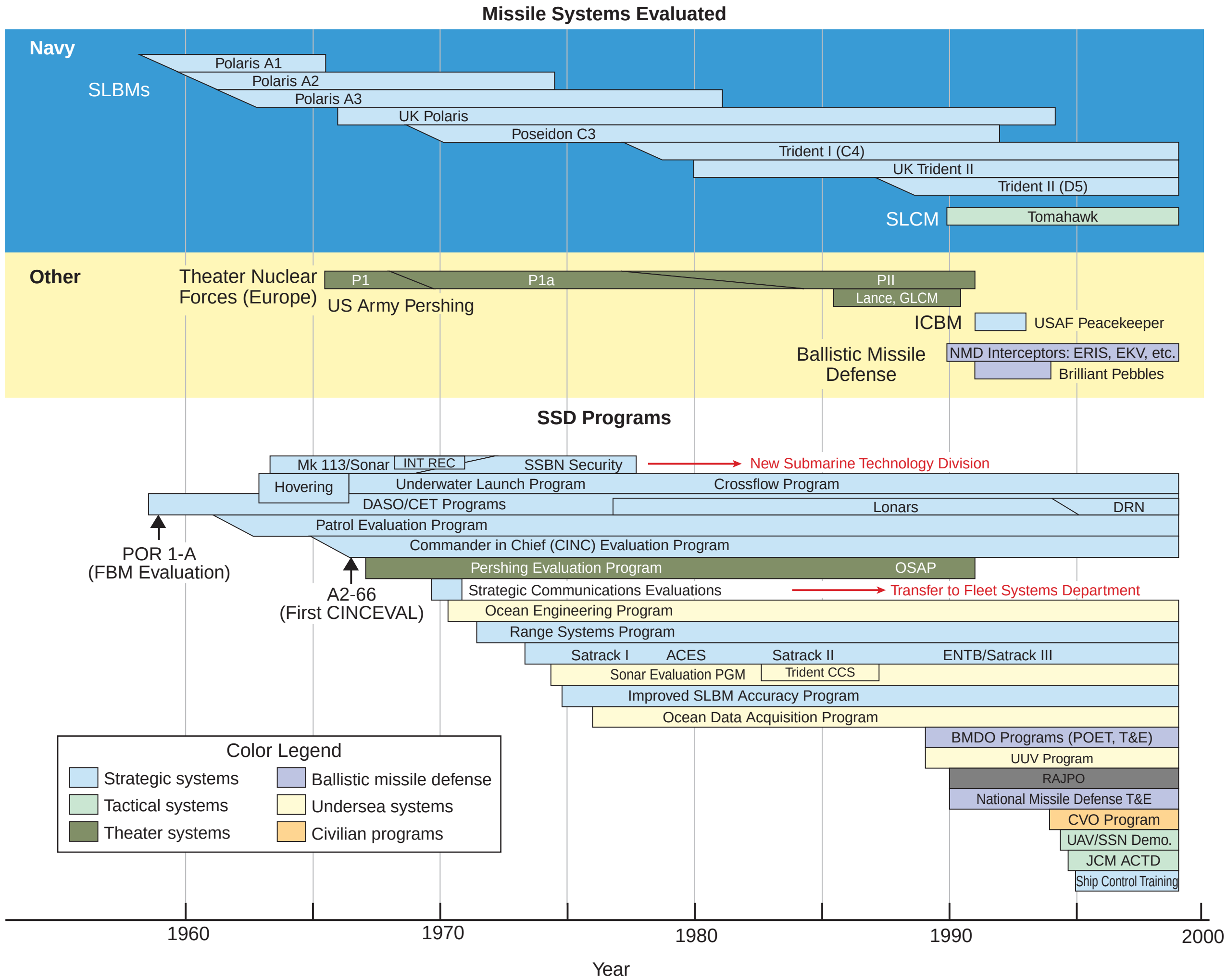

Figure 8. Evolution of the Strategic Systems Department (SSD) Programs. This chart summarizes the major systems for which SSD has had a significant test and evaluation role and the various programs which define SSD today.

THE AUTHOR

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