Strategic Systems and Beyond: Guest Editor's Introduction

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THE STRATEGIC NUCLEAR DETERRENT

The term "strategic" denotes something of great importance within the integrated whole; the verb "deter" means to discourage or prevent from acting. There are many examples of strategic weapons in the history of arms, but it was the development of long-range ballistic missiles armed with nuclear warheads that added a global dimension to the strategic equation. The United States had been unprepared for World War II and was dealt a devastating blow by the sneak attack on Pearl Harbor. The national leadership was fully aware of the role that technology played in establishing a decisive edge in that conflict and vowed never again to be caught unprepared to deal with a formidable aggressor. These lessons were distilled into a national policy to develop a strategic nuclear deterrent force that could protect the United States and its allies from future aggression. This force evolved into the strategic "triad" composed of an air, land, and sea-based leg of the deterrent.

The U.S. Air Force became a separate military service in 1946, and the Strategic Air Command (SAC) was chartered to develop the long-range bomber, with bases here and abroad, as the primary nuclear deterrent. The wartime cooperation between the western allies and the Soviet Union soon began deteriorating, leading to the onset of the Cold War. The large standing Soviet armies that remained in Eastern Europe created an unsettling situation which prompted the formation of the North Atlantic Treaty Organization (NATO) in 1949 as a counterbalance to that threat. Once the Soviets exploded their first atomic weapon in 1949, ending the U.S. nuclear monopoly, our need for a robust and survivable nuclear deterrent became critical. By 1953, intelligence reports of long-range Soviet missile tests began emerging. This development was viewed as having a high potential to put SAC bases at risk and undermine the U.S. deterrent. The Eisenhower administration reviewed the state of U.S. missile technology and initiated the development of long-range land-based ballistic missiles to augment SAC.

Ballistic missiles are characterized as intercontinental-range (ICBM), intermediate-range (IRBM), medium-range (MRBM), or short-range battlefield missiles (SRBM). The definition of a strategic missile evolved into "the ability to strike at the heart of a nation at will"; during the Cold War this meant the ability to strike military, economic, and political targets on Soviet soil. Thus the distinction between a strategic and a tactical nuclear missile became reliant on its basing location. Mobile land-based missile systems intended for deployment in Europe, or some other area of conflict, became "theater" weapons. It wasn't until the Eisenhower decision to develop a 5500-nmi ICBM and a 1500-nmi IRBM that the land-based leg of the strategic deterrent triad became a reality. Initially, no plan existed for a Navy ballistic missile based at sea.

The first-generation U.S. ICBM and IRBM designs were liquid-fueled missiles based above ground. Like the SAC bases, they were vulnerable to attack and required lengthy delays to fuel and prepare for launch. Subsequent designs addressed these drawbacks by going to silo-basing, using storable cryogenic fuels, or adding mobility. The "survivability" features of a system became a crucial metric for strategic nuclear deterrent weapons. The Navy capitalized on this issue to promote a novel idea for a mobile, stealthy submarine-based IRBM. This visionary concept became known as the Fleet Ballistic Missile (FBM), leading to the first-generation submarine-launched ballistic missile (SLBM), Polaris. There were compelling advantages of the SLBM over a land-based IRBM:

- No negotiations were needed for Polaris launch sites, in the United States or abroad.
- Whereas liquid-propellant missiles could not be launched immediately, a solid-propellant Polaris was always ready for launch. Each Polaris had its own launcher.
- Every unidentified submarine at sea was a potential FBM, which created serious antisubmarine warfare and intelligence problems for the Soviets.
- Because the FBM could be launched at Eurasia from all directions, Soviet missile defenses had to be complex, versatile, and expensive.
- A Polaris was less vulnerable than a land-based missile because its location could not be pinpointed in advance, it was not easily sabotaged, and it could not be affected by (enemy) weapons aimed at other (nearby) targets.
- Use of the FBM afforded greater physical safety for the United States and friendly nations, whereas land-based missiles would draw enemy fire to U.S. and Allied centers of population like a magnet.

The Navy FBM Program, beginning with Polaris and continuing with Poseidon, Trident I, and Trident II, produced the premier leg of the U.S. strategic nuclear deterrent. The SLBM has been in a constant state of evolution since the start of the Polaris Program in 1956. Each generation enhanced the capability or survivability of its predecessor to keep ahead of Soviet developments and provide an assured deterrent. The increased range for each SLBM allowed the strategic SSBN submarine to operate in a larger portion of the ocean, further complicating Soviet antisubmarine approaches. Poseidon was the first strategic MIRV (multiple independently targetable reentry vehicle) weapon system, allowing coverage of widely dispersed targets with a single missile while defeating potential terminal defenses. The improved accuracy of Trident I was further refined to provide a prompt, hard-target attack capability for Trident II. The FBM Strategic Weapon System (SWS) will continue to be a cornerstone of U.S. defense policy for many years to come.

THE STRATEGIC SYSTEMS DEPARTMENT

This issue of the *Technical Digest* celebrates the 40th anniversary of the Strategic Systems Department. On 1 August 1958, APL established the Polaris Division under Dr. Richard B. Kershner to assist the Navy in developing the first-generation FBM SWS. This issue is dedicated to the four APL leaders pictured on our Dedication page. Their wisdom and inspiration guided our course from Polaris to Trident. Their technical contributions, as well as their leadership, have been recognized at the highest levels of our government.

The FBM Program has been extremely important to the Laboratory, having provided the impetus for three of our technical departments, Strategic Systems, Space, and Submarine Technology. The Navy Special Projects Office (SPO), under Rear Admiral William F. Raborn and his Technical Director, Captain (later Vice Admiral) Levering Smith, led the Polaris development. They knew APL and had great respect for the staff and our contributions to the Navy. APL was invited to help SPO develop Polaris. The family of organizations that SPO assembled to design, build, and maintain the FBM SWS is shown on the inside back cover of the issue. One underappreciated reason for the long-term success of the FBM Program has been the Navy's ability to keep this family together, dedicated to the continual improvement of the deployed systems and their successors.

The development of the first-generation Polaris navigation, fire-control, launcher/ship, and missile subsystems required a remarkable number of concurrent technology advances. APL was asked to provide independent and objective technical advice during the design and development phases and to plan a comprehensive operational test and evaluation program that would validate the subsystem and integrated weapon system designs. The staff drew heavily on in-house expertise in missile technologies, instrumentation systems, and systems integration and testing to conduct trade-off studies and advise the Navy. The ability to design and build prototype hardware at the Laboratory is a special asset that was exploited to benefit the FBM Program. Several APL engineering developments led to important technology breakthroughs. Later, this in-house engineering capacity was used to expedite solutions to fleet problems and to produce prototype equipment that satisfied special needs. But it was the test and evaluation task that became the long-term

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FBM effort for the Laboratory. The complexity and features of each new generation of SLBM and SWS presented a new and challenging menu of test and evaluation issues. Many problems were encountered, isolated, and effectively resolved in the course of 40 years. Our support for the Trident SWS remains ongoing.

SSD took on the evaluation task for another important strategic weapon, the Army Pershing, in 1965. This mobile weapon system was deployed in the European theater and presented its own unique set of test and evaluation challenges. SSD operated the only foreign APL field office, in Heidelberg, Germany, for 25 years to monitor and evaluate Pershing. The 1979 NATO decision to deploy the advanced Pershing II (PII) and the Air Force Ground Launched Cruise Missile (GLCM) to counter a massive Soviet nuclear missile buildup is viewed by many as the crucial final step that led to the end of the Cold War. The survivability of those theater-strategic deterrent weapons became extraordinarily important to the United States and its NATO partners. Survivability was vital to the credibility of the deterrent. The Laboratory was asked to plan and conduct the Operational Survivability Assessment Program to validate this survivability and to identify potential vulnerabilities. The mobile PII and GLCM systems moved freely on roads and through the towns in their areas of operation. They were highly visible to the public and highly political, often appearing in the headlines and on the covers of print news media throughout Europe. Because of this attention, planning and executing tests for these weapon systems was an entirely different experience than that of our Navy test programs. PII and GLCM were ultimately withdrawn from Europe and destroyed under the provisions of the 1987 Intermediate-range Nuclear Forces (INF) Treaty.

SSD activities in support of these weapons systems are broad and include

- Planning ground and flight test programs
- Planning individual flight test missions
- Assessing range safety issues
- Identifying data and instrumentation requirements
- Developing novel instrumentation
- Defining detailed analysis methodologies
- Producing test procedures
- Participating in field tests with the system operators
- Conducting data reduction and analyses
- Formulating recommendations for improvements
- Reviewing analysis results with the operational commanders

The ability to participate in this end-to-end system evaluation provides unique insight and a highly effective method to identify and resolve problems. Our contributions have been recognized as a significant factor in maintaining the high level of readiness and exceptional reliability of these strategic systems.

Beyond the core SWS evaluation task, SSD expertise is being applied to the evaluation of submarine sonar, range safety and flight test instrumentation, emerging national missile defense systems, unmanned undersea vehicles, unmanned aerial vehicle control systems, onboard ship-control training systems, engineering development of specialized submarine sensor platforms, novel submarine communications antennas, biomedical technology, and civilian commercial vehicle operations safety systems. In the articles that follow, we have selected a sampling of topics to give the reader insight into our accomplishments and current activities.

THE ARTICLES

The articles in this issue are organized into three general groupings: Programs, Technology and Applications, and System Demonstrations. In the first three articles, we present a discussion of past and current SSD programs. The opening article by Watson details the origin of APL's involvement in the FBM Program. It discusses the U.S. National Ballistic Missile Plan and the beginning of the Navy's Polaris IRBM concept. The Laboratory contributed several breakthrough technologies vital to Polaris. The article focuses on certain propulsion developments to clarify the historical record on the extent of APL's early contributions. Polaris was the first solid-propellant strategic missile, a feature central to the FBM concept. Many state-of-the-art advances were needed to make Polaris possible; these are already well documented in a variety of references and are not repeated here. The primary APL FBM task, that of planning the operational test and evaluation program, evolved into a much larger and longer-term activity than had been contemplated. It expanded to include deterrent patrol evaluations, SSBN sonar systems, strategic communications, and the range safety and instrumentation systems needed to support the flight test programs. The requirement for a "cradle-to-grave" FBM evaluation has generated a continuing core activity that has sustained SSD support for 40 years. A figure showing the evolution of SSD programs is included as a lead-in to the next article.

The second article, prepared by multiple authors, is a composite snapshot of our current SSD programs. It provides an overview of activities in five areas: strategic weapons systems, tactical systems, undersea systems, ballistic missile defense, and civilian programs. The topics provide a measure of the breadth and depth of SSD expertise. The third article, by Mentzer, is a historical retrospective review of the unique test and evaluation aspects of land-mobile missile systems deployed in the European theater. APL's responsibilities in this program were far ranging, including the design, fabrication, and operational installation and maintenance of the Pershing instrumentation system used on alert missiles.

The next grouping of six articles provides an in-depth look into specific technologies and applications. Thompson, Levy, and Westerfield review the APL development of a novel precision trajectory analysis system, called SATRACK. SATRACK uses Global Positioning System (GPS) satellites and a detailed weapon system error model to perform precision trajectory reconstruction and error state estimation. GPS signals originating from multiple satellites are received at the missile in a special device called a translator, shifted in frequency, and relayed to a ground station for recording. Postflight processing of the recorded GPS data is input to a large Kalman filter, allowing initial condition and in-flight error state estimation. The requirement for the SATRACK system derived from the improved accuracy objectives specified for the Trident I and Trident II SWS. An approach was needed to perform an end-to-end (launch-to-impact) measurement of flight test errors to understand the sources of inaccuracy, should system improvements be warranted, and to project demonstrated performance confidently into untested regimes where the system might be used. SATRACK was the first committed user of the GPS constellation; several APL GPS "firsts" have evolved from this pioneering activity. SATRACK also provided the first GPS-based real-time range safety system, replacing radar and beacon tracking approaches for SLBM flight tests. SATRACK continues to be an important element in the ongoing Trident SWS evaluation.

The SATRACK system is ideally suited to support precision analyses of ballistic missile intercept systems, including interceptor warhead lethality assessment. In the second article, Thompson and Westerfield discuss the evolution of the family of APL-designed and fabricated GPS translators used in the FBM Program and national missile defense experiments. The existence of the unique APL SATRACK postflight processing facility, and an experienced staff of analysts, has been leveraged to support these new applications. For example, a special test conducted for the Navy involved the experimental use of a GPS translator in a reentry body deployed from a Trident missile. In addition, a novel, suitcase-sized, portable signal recording system for GPS translators has been developed and demonstrated. (In a companion article, which appears in the System Demonstrations category, Thompson discusses a high-precision GPS sled test demonstration that validated an important capability for future intercept mission analyses.)

The next article is an example of SSD analysis expertise applied to submarine defensive systems. South et al. describe pioneering advances in technologies for passive sonar data recording systems, programmable signal processing systems, and improved sonar displays. SSD-led engineering developments have produced four suites of Trident special-purpose acoustic recording system (TSPARS) instrumentation for installation on SSBN submarines. TSPARS continuously records raw acoustic sensor data from all SSBN passive sonar sensors throughout an entire patrol. The patrol data are processed at the Laboratory using the Trident Sonar Evaluation Program Processor/Analyzer system called TSPAN. This article discusses the evolution of TSPARS and TSPAN capabilities.

Biegel et al. next describe the extension of SSBN launcher/ship subsystem evaluation expertise to developing a PC simulation-based submarine ship control training device. The interactive 6-degree-of-freedom ship control simulation embedded in the device was produced by SSD to support the overall FBM SWS evaluation. This portable, PC-based training device allows crewmembers to undergo independent, self-paced training while aboard ship. Realistic ship control displays are driven by the simulation in response to a selectable menu of ship handling scenarios, both with and without casualties inserted.

The next article is an example of an SSD analytical development that has widespread applications to many engineering problems. Spall describes his simultaneous perturbation stochastic approximation (SPSA) method for difficult multivariate optimization problems. In most practical problems of this type, a mathematical algorithm must be used to iteratively seek out the solution. SPSA uses a novel gradient-approximation technique that requires only two measurements of the objective function, regardless of the dimension of the optimization problem. This results in a major decrease in the time and cost to solve optimization problems having a large number of variables.

The final article in the Technology and Applications grouping by Criss, South, and Levy describes an APL-developed technique for rapidly determining accurate target location coordinates for use with precision guided munitions. The technique, called MICE (multiple image coordinate extraction), applies photogrammetry principles using imagery and GPS data to extract target coordinates to within a 5-m CEP (circular-error probable); it can also be used to determine the size and relative distances between objects in the imagery. The technique is versatile in that it does not require the use of classified geodetic databases to register coordinates, and it can be integrated into imaging platforms using electro-optical or infrared sensors, with either video or still cameras. This article describes experiments using imagery from the Predator unmanned aerial vehicle (UAV). SSD is currently exploring the utility of this technique to emerging precision strike and reconnaissance missions of the military services.

The final section describes two SSD system demonstrations. In both, a novel idea was taken from the conceptual stage through experimental design, including hardware fabrication, to a successful demonstration of a significant new capability. Vigliotti details the submarine/UAV interoperability demonstration. This 1996 experiment demonstrated the ability of a submerged submarine to take real-time control of a Predator UAV and its payload to support a Special Operations Forces training exercise. SSD outlined the experiment, conceived the UAV control system concept, designed and fabricated a special submarine antenna and radome, led the development of the control system installation for the submarine, and planned and successfully conducted the at-sea demonstration. All of this was completed within a 10-month span. With this new capability, a stealthy submarine can extend its “eyes” far out to sea and inland to support new reconnaissance, surveillance, strike, and battle damage assessment missions.

In the final article, Thompson describes an Independent Research and Development project that demonstrated the ability to use translator-based GPS signals to achieve a measurement accuracy of 2 cm in realistic missile intercept test environments. The experiment was performed on the High Speed Test Track at Holloman Air Force Base, New Mexico. The technique used demonstrated for the first time that APL wideband GPS translator instrumentation could provide sub-GPS wavelength trajectory measurements. This test validated the ability to use a single instrumentation system to perform precision intercept, warhead lethality, and interceptor guidance evaluation for theater and national missile defense programs.

SUMMARY

We hope you find the articles in this issue informative and stimulating. Our goal is to provide a sampling of topics to give a sense of our past accomplishments and the importance of our continuing mission. Over the course of these 40 years, our staff has contributed immeasurably to the success of the FBM and Pershing strategic programs. New challenges are on the horizon, and the Strategic Systems Department looks forward eagerly to applying its considerable talent to these emerging national problems.

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