Bringing Science and Technology to Bear on the Navy's Needs

William H. Zinger

Throughout history, the outcome of conflict has been heavily biased toward the party with the best and most effective technology. The Air Defense Systems Department undertakes to assure that the most current and appropriate science and technology advances are successfully applied to naval systems to secure a favorable outcome from any conflict that would require defense against air and missile attack. An approach to executing this undertaking is in place that embraces the codified systems engineering process and extends throughout the life of the equipment.

INTRODUCTION

The Air Defense Systems Department (ADSD) can trace its roots back to original World War II air defense activity that led to the founding of APL in 1942.[1] Over the years, the successful application of science and technology to improve naval capability has resulted in the identification and, ultimately, understanding of new layers of operational problems. Consequently, the breath, depth, and scope of the Department's work has expanded, as depicted in Fig. 1, to embrace all elements of air defense—from the sensors, control system, and weapons of individual units to the networked interconnection of multiple units in a theater. This broadening of scope and perspective has been roughly concurrent with the rise of systems engineering as a recognized and codified discipline.

The success of a systems engineering endeavor applied to a practical problem is at risk if those involved lack detailed knowledge of the workings of a system's components. While the Department has moved to an increasingly broad perspective of what an air defense system is, it has not lost sight of this risk. This issue of the *Technical Digest*, along with the subsequent two, is devoted to articles illustrating efforts in place in ADSD to assure that science and technology are being applied to the Navy's air defense needs at all levels—from materials and numerical methods technologies through Joint service integrated air defense systems engineering. This first issue concentrates on Navy air and missile defense interceptor engineering. Articles describe the Standard Missile family of weapons, their use in air and missile defense, activities under way to assure the desired outcome if they have to be used in conflict, and the application of science and technology to identified risk items. The second issue will deal with the ship combat systems needed for successful conduct of air and missile defense. Single-ship command and control, weapon control, and sensor developments will be covered in that issue. In the third issue, force-level

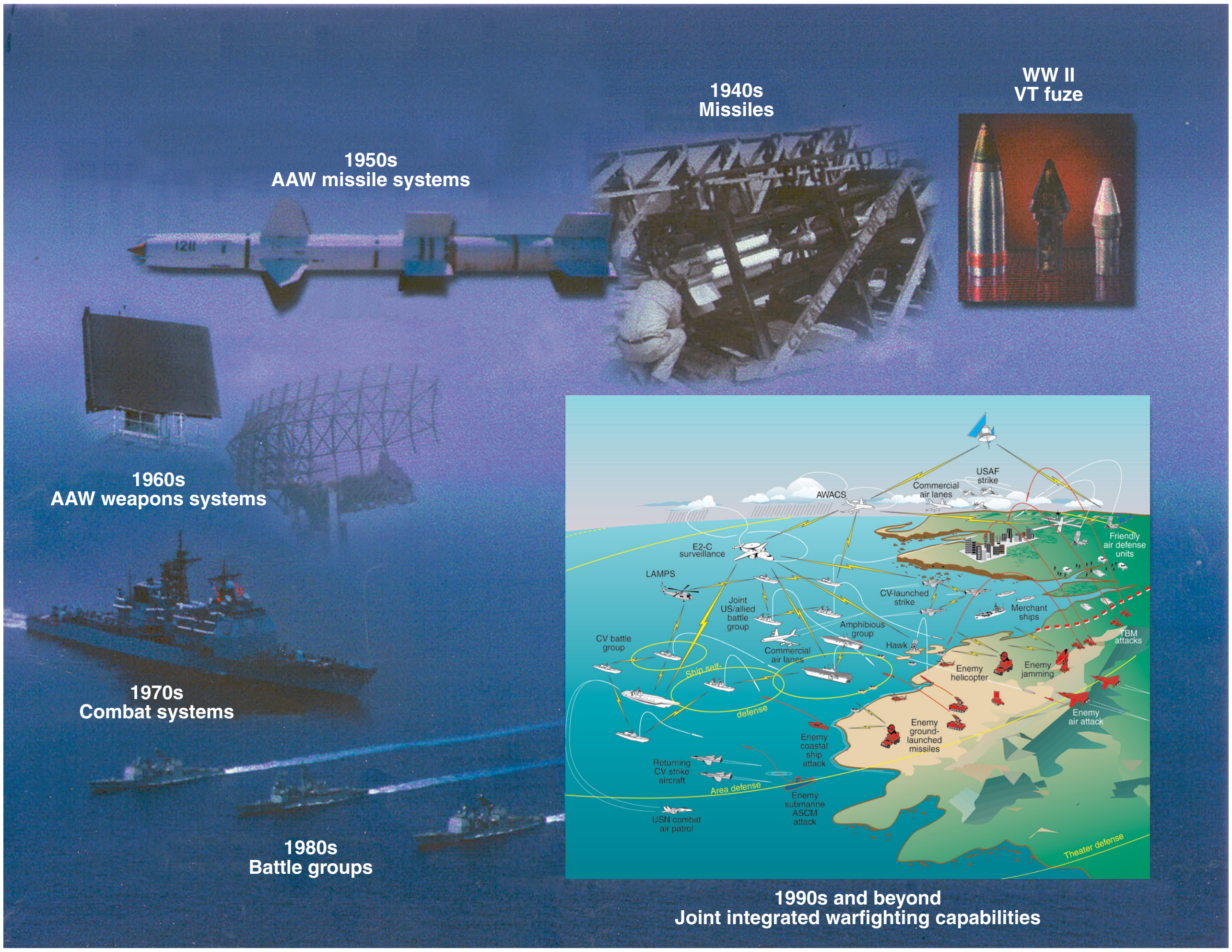

Figure 1. Air Defense Systems Department heritage.

developments, including command-level planning and execution aids for air defense, sensor netting as exemplified by the Cooperative Engagement Capability (CEC), and engagement coordination across multiple air defense units will be discussed.

Organizations must be able to articulate what they do and how they go about it. Many years ago ADSD examined processes and approaches to tasks that had been particularly successful. We looked at the activities in our heritage and found that we performed best, both from the sponsor's point of view and in terms of staff satisfaction, when the work could be categorized as problem solving and the solution required the application of science, technology, and the principles of scientific investigation. The Department had developed an approach that was being applied fairly consistently, even though the steps had not been formalized in writing. Doing so not only provides a framework for explaining to others what we do but also improves our focus in program planning and execution.

PROBLEM-SOLVING APPROACH

The following discussion outlines the steps we have identified and found to be required to successfully produce a new or significantly improved naval capability through the application of advancements in science and technology. This sequence begins with initial conditions set by the history of naval activity up to the entry point.

- Recognize and quantify needs
- Develop operationally responsive system concepts
- Perform critical experiments
- Transfer operationally validated technical approaches to producers
- Continue insistence on at-sea test operations, both technical and operational

"Need" is the operative word in the first step. The costs for equipment and training are generally large enough to require a compelling need to be established before the Navy is ready to consider change. There is a continuum of change in science and technology, and each change represents an opportunity, not only for the Navy but also for potential adversaries. Usually, the opportunity is related to a new or increased capability that can counter an adversary's incorporation of new technology; sometimes it allows for cost reduction in acquisition or operations. Recognizing the need is essential in using science and technology to assure a preeminent naval air defense capability. Most often, the needed capability is not totally new, but the parameters that characterize it must be changed to guarantee adequate performance against expected or observed increases in adversarial capability. In either case, the functions associated with these needs have to be identified and the associated parameters quantified. Thus the enumeration and quantification of the parameters necessary to secure a successful air defense outcome is the first step in the systems engineering process. (The formalization of this process is discussed in the article by Krill, this issue.) Quantification relies heavily on analysis, supported by modern numerical methods and by modeling and simulation. Many of the articles in the *Digest* issues devoted to ADSD discuss developments in these methods and show their application to quantifying design parameters.

After the technical objectives have been identified and quantified, the next step can be taken, i.e., science and technology are applied to fill the capability need. Operationally responsive system concepts that may be able to provide the functional and parametric capability must be invented. The notion of operational responsiveness is not trivial in the context of the application of science and technology; it relates back to the previous discussion of need—the reasons for considering new concepts. Concepts are operationally responsive only if they offer the functional and parametric capabilities considered necessary to restore dominance over the threat. They are not operationally responsive if they have a strong element of infusing new science and technology primarily because it can be done.

There is also a reason that "concepts" is plural. At this stage, a proposed solution may incorporate a considerable amount of judgment and extrapolation. Further, neither the risks (both technical and schedule) nor the cost may be well known. A range of concepts must be evaluated. Again, analysis, modeling, and simulation tools must be applied—this time to the proposed concepts—to measure them against the needs and as one means of making comparisons among them.

In addition to the parametric aspects of the analysis, technology experts evaluate the concepts from a feasibility perspective, assigning risk factors to new technology applications. Risk assessment will have both an absolute component based on the likelihood that the concept will function as expected and a schedule-related component based on the likelihood that the requisite engineering and testing can be completed on schedule. Typically, one concept is selected to go forward, with another one to two pursued at a low level of effort as fallback options.

One of the key consequences of the concept definition process is the identification of technical risk areas. Mitigation of technical risk is most effectively done through the design and execution of critical experiments. The approach, technique, or item is generally declared a risk because analysis, modeling, and simulation have been extended somewhat past the point at which the underlying physics, chemistry, or materials properties are well understood. Often, transient conditions contribute to the uncertainty that the process is properly characterized. The dynamic range of scale of these critical experiments, performed over weeks, is quite large, ranging from the examination of stress in a crystal during a thermal transient, through the construction and test of a hot gas control valve, to the collection of large-scale clutter measurements involving aircraft, ships, and ground sensors.

The application of science and technology to critical experiments is necessary at several levels. The subject of the experiment is often an important feature of the concept, but one that is somewhat immature in its technical development, thereby requiring considerable design activity to approach a working model. The critical parameters that will determine whether performance within the concept's construct will be as needed must be determined, and the measurable quantities established from which those parameters would be derived. The performance parameters of the concept's operating regime often exceed the limits of available instrument systems, resulting in a science and technology evolution to develop instrumentation to collect the data that will support characterization. Sometimes the nature of the data requires advancements to convert them to the physical parameters of interest in a timely manner. Several articles in this issue deal with critical experiments and experiment instrumentation.

The technology applications developed by the Laboratory are only useful to the Navy if an industrial agent can produce them. Consistent with this precept and with APL's university affiliation, transfer to industry of the technology necessary to produce operationally validated concepts is a key ADSD theme. The most effective transfer mechanism has proven to be joint, collegial participation. Involvement as early as the concept development phase is most beneficial, but often industry is excluded from initial activities because these activities are intended to lead to a competitive procurement. Other approaches used to foster technology transfer include classes and seminars, conferences, and information exchange meetings; provision of documents; and participation of industrial agent interns on Laboratory design and analysis teams. APL staff members are encouraged to publish and to offer papers at symposia as a transfer mechanism to a broader audience.

Not surprisingly, much of the application of science and technology centers on risks identified during concept development and in the early stages of detailed engineering. Activities directed at understanding and altering the level of risk represent excellent opportunities for technology transfer. Work is usually done by teams that include people from industry, and the joint analysis, experiment design, experiment conduct, and data examination activities result in an advancement in knowledge for all parties, with industry well prepared to execute.

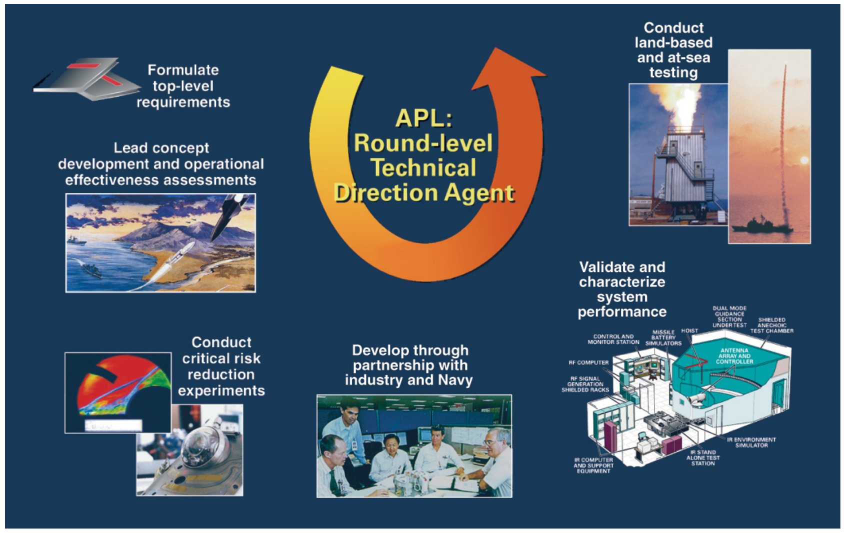

Figure 2. Application of ADSD's approach to Standard Missile.

The completion of this cycle, i.e., an examination of the Navy's use of the industrial translation of a concept, also lays the groundwork for reentering the sequence some years later with an update of air defense needs. The Department has a long tradition of being at sea with the Navy to test new concepts, introduce new production capabilities, and study naval operations in threat-representative training situations. These activities are at the heart of the ability to apply science and technology to operationally responsive system concepts.

Being at sea in the operating environment with the ultimate user of the technology offers invaluable insight into both the existence and often the cause of shortfalls in models of the environment and equipment. Errors in modeling generally result in fielding gear that does not fully meet requirements. Additionally, human factors associated with the use of the equipment can have a surprisingly negative impact on the actual in-practice capability of an otherwise sound design. This type of problem—and whether it is associated with a need for design or training adjustments—can only be identified through at-sea test operations with the users. For these reasons, ADSD emphasizes critical experiments at sea whenever appropriate and participation at sea with full system tests and follow-on training exercises.

EXAMPLES

The application of ADSD's approach to satisfying naval capability needs through the use of science and technology has been illustrated in some key programs, two of which are presented here. Figure 2 illustrates its application to the Standard Missile Program.[2] The activity begins with the formulation of top-level requirements. Next, some concepts are developed and parameterized in enough detail to allow for a relative performance comparison through simulations of operational effectiveness. The risks associated with these concepts are enumerated. In the Standard Missile illustration, the infrared window, one of several identified risk items, is shown. Risk reduction work comprises supersonic wind tunnel tests, including the development of instrumentation, use of computational fluid dynamics, crystallography, axis-dependent crystal stress measurements, and transmission measurements from the risk reduction flight test. Through this work a crystal orientation and mounting approach is found that allows the thermal and aerodynamic shock to be absorbed by the window without fracture, and a cooling approach is developed that provides adequate target contrast without lossy deposit accumulation.

This work, like other innovations, includes a technology transfer–enhancing intellectual partnership with industry. In the case of Standard Missile, samples of the industrial agent's guidance section product are tested and characterized in ADSD's Guidance System Evaluation Laboratory. Finally, full-up missile rounds are fired against threat-representative target drones as the last stage in proof of the concept. Data collected from the flight are compared against the models used during concept definition and development. Any discrepancies are pursued and corrective action taken.

Another example, Fig. 3, illustrates application to the CEC Program.[3,4] In this case, the critical technology example is the solid-state transmit/receive (T/R) module. Here, the risk is twofold: (1) delivering the technology in production quantities in time to save significant weight and money in the second-generation development models, and (2) avoiding the cost of qualifying a traveling wave tube for carrier landing. APL developed the specifications and awarded a competitive

Figure 3. ADSD's CEC development role.

contract to develop a T/R and to show the production cost. There were a number of critical algorithms in the concept that were based on assumptions about the devices that would collect and provide data to the CEC and about the environment in which it would all operate. These assumptions were validated through several at-sea data collection experiments. The objective of CEC was to connect a number of existent combat systems by a radio channel into a single distributed combat system. The allocation of requirements between new CEC equipment and the existing combat systems proved to be a significant part of the CEC activity. At later stages of development of the capability, this allocation process reappeared in the form of increased difficulty and, therefore, time in the integration phase.

CONCLUSION

The articles in this and the next two issues of the *Johns Hopkins APL Technical Digest* have been selected to highlight important new contributions to naval air defense at every stage—from identification of the need for new or improved capabilities to at-sea testing. Whether the topics involve interceptor engineering, the ship combat system, or engineering at the force-wide level, they are all based on the application of science and technology advances that have been successfully applied to naval systems using ADSD's proven systems engineering approach to meeting the Navy's needs.

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THE AUTHOR

WILLIAM H. ZINGER is a member of APL's Principal Professional Staff and Associate Head of the Air Defense Systems Department. He obtained a B.S.E.E. from the University of Pennsylvania in 1961. Since joining APL in 1961, Mr. Zinger has worked on the design and testing of Fleet radars and related electronics and has been associated with Aegis and its AN/SPY-1 radar since program inception. He served as the Technical Director of APL's Cooperative Engagement Capability effort and led the merging of the Ship Self-Defense System effort with CEC. More recently, he has been associated with the definition of ship radar approaches for next-generation surface combatants, including NTW capability. He is engaged in international efforts in this regard. Mr. Zinger holds a number of U.S. patents. His e-mail address is william.zinger@jhuapl.edu.