Guest Editor's Introduction

Robert T. Lundy

In today's world, it is axiomatic that U.S. forces must conduct hostile engagements in coordination with coalition forces for mutual support and mission effectiveness. This requires integration of U.S. and coalition air and missile defense systems. Effective operations depend on the synergistic application of sensors, force-wide gridlock alignment, jam-resistant communications, positive identification, and coordinated or cooperative execution. Above all, it requires that battle force combat systems be interoperable and engineered so as to maximize offensive and defensive capabilities.

Battle force systems are being modified almost continuously in order to maximize support for all defended assets. System engineering these multiple systems or families of systems resident in Joint and allied ships and aircraft is a major challenge. The process for change is slow and complex. It requires sophisticated solutions, but is absolutely essential for survival and mission execution in the face of the ever-evolving threat. Problems in implementing solutions relate to the size and complexity of the disparate air defense systems and communications among them. The changes typically provide improved capabilities which become inadequate over time owing in general to changes in the threat brought about by improved technology and by divergencies in the combat system's development plans.

The modern era of battle force engineering began with the introduction of Terrier, Tartar, and Talos surface-to-air missiles and the Naval Tactical Data System with Link-11, introduced to the Fleet in the late 1950s and early 1960s along with improved command and control display systems. The integration of these "stovepipe" systems was an initial step toward overcoming inadequate communications, automation, and limited-range weapons. These early systems were integrated but not systems engineered, and required excessive manual operation. APL's work with combat systems, missiles, tactical data systems, and automation was addressed in two earlier *Technical Digest* issues (Vol. 22, No. 3; Vol. 22, No. 4) and is the subject of this issue as well.

In December 1969, the Radio Corporation of America (RCA; now Lockheed Martin) was awarded a contract to design and produce an engineering development model of a new system (now Aegis). The model for this advanced surface missile system (ASMS) had been characterized in the ASMS Report by a special task force led by RADM F. Withington, former Commander of the Bureau of Ordnance, who had been recalled to active duty to chair the ASMS assessment team. (The ASMS Report was later known as the Withington Report.) Aegis was the first system designed as a complete shipboard air defense weapon system embodying those features demanded to counter the threat and correct operational limitations in the Terrier, Tartar, and Talos systems.

USS *Ticonderoga* (CG 47), the first Aegis ship, was a major success, both technically and operationally. Technically, combat system elements were systems engineered and automated, resulting in vastly improved shipboard integration and interoperability among the shipboard combat system elements. Operationally, the Aegis system minimized reaction time, provided improved electronic countermeasures resistance and midcourse guidance to the missile, extended detection ranges, and increased engagement time, fire power, and engagement range. Fast launching increased firing rates, and accurate, fast digitized data provided automated testing and improved maintainability. As Technical Advisor for this program, APL provided technical oversight support to the Navy's Program Office and conducted critical experiments to mitigate risk and help ensure the program's success.

This first Aegis cruiser, commissioned in 1983, was delivered on schedule and within cost. At the time, it was the most powerful air defense ship ever produced. Although it added measurably to battle group effectiveness, it was not optimized for battle group/force operations and thus did not initially offer the leverage needed to be the battle force multiplier envisioned. This capability awaited the Battle Group Anti-Air Warfare (AAW) Coordination (BGAAWC) and Force AAW Coordination Technology (FACT) programs and their spin-off and successor programs, Cooperative Engagement Capability (CEC) and Area Air Defense Commander (AADC), respectively. Developments in these programs greatly improved battle group interoperability and performance.

FOUNDATION

This issue of the *Digest* discusses the Laboratory's foundational engineering efforts to enhance battle force effectiveness and performance.

RADM R. P. Rempt's letter to the Director of APL introduces this issue of the *Digest*. He notes that air defense battle force engineering at the Laboratory, which began in the early 1960s, evolved through Vietnam, the anti-ship cruise missile threat of the Cold War, Desert Storm, and now the war on terrorism. RADM Rempt also observes that the excellence and technical leadership role of APL for over 40 years has led the way to today's excellence in air defense and that the complexity of today's world will require the Laboratory's experience and expertise to develop and deploy the best engineered systems in the world.

ADM L. W. Smith (Ret.), in his article "Challenge and Change: Assessing Technology Needs for Future Naval Operations," describes the complexity and future of military operations from the perspective of a Joint Forces Commander (JFC). He outlines the significant issues and challenges faced by the JFC in planning, intelligence, training, and logistics for effective operations. ADM Smith concludes that these issues and challenges can only be surmounted practically by technological innovations that keep us on the competitive edge. In engineering terms this means systems engineering of the battle force.

RADM W. E. Meyer (Ret.), in his anecdotal article entitled "Our Navy—Like Our Lives—Is Continuous," shares his observations on technology, people, spirit, leadership, interoperability, patriotism, and transformation. This follow-on to his article in Vol. 22, No. 4 of the *Technical Digest* concludes that the Aegis epoch will span approximately 85 years, giving it about 50 years to go.

A. Kossiakoff, APL's Chief Scientist and former Director, notes that the Laboratory's foremost mission has been the application of advanced technology to air defense. He offers a perspective on the key attributes of APL that have evolved over 60 years to make it preeminent in air and missile defense. He cites several historical and current examples of how these attributes will help to carry out APL's missions of public service and air defense and how they satisfy the Laboratory's goal of making "Critical Contributions to Critical Challenges."

THE ARTICLES

The first series of articles relate to specific systems engineering projects that have been approved for Fleet introduction.

E. P. Lee et al. discuss the history and development of the BGAAWC/FACT programs and how these incremental and significant systems engineered battle group/force projects knitted the families of weapon systems together. These efforts provided mutual support to combatants and led the way toward interoperability as well as a more effective air and missile defense of Army, Navy, Air Force, allied, and coalition partners.

J. H. Prosser et al. describe the prototype AADC system. The system includes a set of integrated information management, analysis, visualization, and collaborative tools that allow the warrior to plan and then control battle force actions in order to maximize battle force effectiveness.

C. J. Grant examines sensor netting and integrated fire control implemented in the CEC program. His article also recounts the highly successful Technical and Operation Evaluations recently completed. In this connection, RADM Rempt noted that CEC completed the most complex and extensive evaluations ever conducted to ensure that this revolutionary system was certified as ready for war.

The next five articles describe CEC in terms of its development and key features.

W. G. Bath discusses the issues faced by engineers as they apply radar technology to the sharing of sensor data. Critical trade-offs were made in the CEC design to provide the most feasible, correlated sensor picture to all participants in the CEC network.

C. R. Moore et al. address a low-cost antenna array development which also improves radar performance. The approach envisions a life cycle that adapts commercial developments to military use while resolving size, weight, and mast blockage problems.

J. M. Gilbert's article discusses the multigraph edge-coloring problem, which has immediate application in scheduling CEC network communications. Using the mathematical theory behind this problem and edge-coloring optimization algorithms, available network bandwidth and sensor netting performance can be improved substantially.

C. J. Duhon then addresses CEC tactical decision aids and their application in the CEC decision-making process. The capability of ships to engage targets they have not acquired with their own sensors permits more effective stationing of the ships to maximize defensive coverage.

D. M. Sunday et al. discuss the E-2C Hawkeye Combat System display. They briefly describe the E-2C 2000 upgraded combat system and focus on APL's innovative and cost-effective graphical unit interface for the E-2C Advanced Control Indicator Set display. These units feature a unique architecture that incorporates commercial off-the-shelf hardware and software and permit selective display of maps, graphics, and text readouts from the E-2C mission control computer.

Another series of articles focus on distributed weapons coordination. These articles build on earlier CEC work and concentrate on future battle force operations that require innovative air and missile defense developments to stay ahead of the threat. They also discuss modeling that may lead the way to future cruise and ballistic defensive needs and to cost savings in their development.

An article on the conceptual framework of distributed weapons coordination by K. E. Shafer et al. addresses the systematic approach APL is taking to formulate and comparatively assess weapons coordination alternatives for the theater missile defense problem.

Several articles on modeling follow. Modeling is used for all equipment and software development efforts; models are cost-effective and result in improved products.

The article about ACES (APL Coordinated Engagement Simulation) by M. J. Burke and J. M. Henly describes a comprehensive force-inclusive simulation that analyzes engagements of multiple threats. The simulation involves multiple units with varying capabilities that apply various methods of coordination.

E. M. McDonald et al. write about new approaches to modeling networks within the ACES simulation. These networks can be modified to vary and analyze the characteristics of future networks that could impact engagement coordination.

C. W. Bates et al. discuss the high-fidelity modeling methods used to generate radar tracks unique to each sensor in an ACES simulation.

An article by J. F. Engler Sr. et al. on a methodology for scenario selection to facilitate performance analysis of Theater Ballistic Missile Defense (TBMD) engagement coordination concepts describes ongoing analysis efforts that support engagement modeling and simulation by specifying criteria for selecting scenarios that stress various aspects of the TBMD problem.

Tactical Ballistic Missile Defense engagement coordination schemes are compared by S. Moskowitz et al. They report on the results of ACES simulations that test the effectiveness of various coordination doctrines applied to massive tactical ballistic missile raids.

The next three articles address the extent to which simulation, stimulation, and visualization laboratories are used in the application of systems engineering concepts to solve air and missile defense problems.

First, J. A. Krill and A. F. Krummenoehl describe APL's new System Concept Development Laboratory, which has been designed to apply systems engineering principles to concept development activities: modeling, simulation, configuration management, collaborative engineering, element-in-the-loop simulation, and testing. The article includes a discussion of new concepts about the remote test networking of disparate engineering facilities.

The next article in this grouping by D. E-P. Colbert and R. E. Ralston describes the emerging role of advanced visualization techniques in the development of missile systems and the analysis of a missile and its systems throughout its trajectory.

In the last article of this group, B. L. Ballard et al. present simulation and modeling approaches that are used to support tactical system development. The article demonstrates the very important role of APL-developed real-time simulators in CEC, Patriot, the Ship Self-Defense System, and Marine TPS-59 radar.

THE FUTURE

In the concluding article of this issue, R. W. Constantine and R. J. Prengaman look into the future of air and missile defense, which is expected to require APL's expertise and leadership. "The Road Ahead" notes the commonly held belief that the threat is getting more diverse and severe and must be engaged overland, beyond the horizon, and at extended ranges and altitudes. This capability will require new shipboard radar technology and new approaches to missile guidance as well as an emphasis on networking airborne and land sensors. The path toward distributed air defense systems, and net-centricity specifically, requires the careful systems engineering of U.S., Joint, and allied air defense battle forces.

Some systems were brought together during the CEC Operational Evaluation in 2001. For the most part, they operated synergistically because of the essential systems engineering testing and corrections that were made. The AADC system has been demonstrated in several battle force exercises with similar positive results. We can conclude that without force-wide systems engineering, emerging, advanced, automated combat systems and networks based on current technology will not be effective against the threat. In recognition of these experiences, new, coordinated efforts by the Navy have been initiated to develop the overarching framework for engineering the battle force in all air warfare areas. APL is a participant in these efforts.

The Laboratory's future is inextricably tied to evolving battle force air and missile defensive systems. APL is accordingly committed to maintaining superior facilities and personnel to continuing a preeminent role in all aspects of air and missile defense. The Laboratory is pursuing the road ahead with all of its challenges and potential solutions. Our dedication to maintaining a superior staff and facilities augurs a bright future.

THE AUTHOR

ROBERT T. LUNDY is the Chief of Staff for Air Defense Programs in the Air Defense Systems Department and is a member of APL's Principal Professional Staff. He has extensive experience in air and missile defense with 25 years of experience as both a project and program manager. He received a B.S. from Northwestern University and has done graduate work in communication engineering and operations research. Mr. Lundy served 29 years in the Navy as a surface line officer, commanding two surface combatants and two naval research and development laboratories. He retired as Captain in 1972. He spent the next 5 years with ITT Electro Physics Laboratory developing an over-the-horizon radar. He joined APL in 1977 as Project Manager of the Battle Group AAW Coordination Program developing incremental capabilities in air defense that evolved into the Cooperative Engagement Capability Program. Mr. Lundy was Program Manager for the CEC Program from its inception in 1987 to its initial operational capability in 1996. He has been in his current position since that time. His e-mail address is robert.lundy@jhuapl.edu.