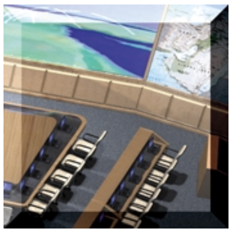

APL's Warfare Analysis Laboratory: Applications and Accomplishments

Russell E. Gingras

APL's Warfare Analysis Laboratory (WAL) is a dynamic, interactive systems analysis facility designed for requirements analysis, concept evaluation, planning, and simulation. People and organizations are brought together and led through a well-defined, yet adaptable, seminar process by experienced facilitators and staff. The WAL allows participants to examine and prioritize requirements for meeting future needs and to assess the capabilities and limitations of current, planned, or proposed systems and concepts. The blend of visualization, simulation, and information technologies with a structured analysis process provides an environment for the collaborative analysis of complex systems engineering and planning problems. A key attribute of the WAL is the technical and operational fidelity that is achieved by leveraging the breadth and depth of APL resources. In this article I describe the evolution of the WAL, the associated analysis process, examples of significant WAL applications, and the analytical and programmatic contributions of the WAL process to defense and nondefense problem areas. (Keywords: Analysis, Simulation, Wargaming.)

INTRODUCTION

From its establishment 3 months after the attack on Pearl Harbor, APL recognized the critical importance of systems-level requirements analysis and concept evaluation within the context of expected future operating environments. The engineering of very complex systems required a thorough consideration of operational needs, technical feasibility, affordability, and potential threats to the system. From this recognition, the systems analysis function was institutionalized at the Laboratory in 1948 and continues to this day. This capability was mainly applied to defense problems but has evolved to include uses in transportation, biomedicine, and other nondefense areas. The APL Warfare Analysis Laboratory (WAL) is a principal tool used in the systems analysis function.

A critical air defense problem emerged in the 1950s as the Soviet Union developed and fielded a new type of weapon, the anti-ship cruise missile. Launched from Soviet bombers and submarines, these missiles were designed to penetrate and overwhelm existing U.S. Navy air defenses. The Laboratory developed a computerized version of Navy air defense (called Program 323) that allowed more quantitative assessment than had been possible previously. This effort was one of the first digital computer simulations and may have been the first large simulation of air defense. As air defense issues were analyzed with Program 323, the requirement became apparent for more flexible analysis than that allowed by the constraints of the simulation and was coupled with the exigency for a more systematic and standardized approach. In response to this need to help the Navy understand the broad implications of the threat, APL conducted an analytical war game of a Soviet missile attack against a U.S. carrier battle group. This war game led to the development of a new analytical tool at APL that was the forerunner of today's WAL. On 11 October 1960, the Director of APL, Ralph E. Gibson, reported on this "war game":

> Nine months ago, a high-priority study was organized to carry out a comprehensive and objective study of the total anti-air warfare problem. . . . During the intervening period, important and far-reaching advances have been made in our understanding. . . . *In addition, a new technique has been developed for air battle analysis which encompasses the full scope of the problem and permits examination of a large variety of alternative situations in a comparatively short period of time* [emphasis added].

Later that year the Air Battle Analyzer[1] was developed as a formal analysis methodology to address naval anti-air warfare issues in a more flexible way than allowed by contemporary computer simulations. Through the 1960s and 1970s, the Air Battle Analyzer was used extensively to examine a variety of air defense problems and potential solutions, thereby facilitating an increased understanding of fundamental principles of air defense and requirements for future systems to meet those problems.

The Air Battle Analyzer was used effectively for 20 years to explore a variety of scenarios and system concepts. But as the complexity of these scenarios grew, a more capable facility for warfare analysis became increasing important to our ability to understand and respond to ever more challenging problems. In 1981, APL Director Carl O. Bostrom chartered the APL War Game Planning Committee comprising representatives from all of the Laboratory's technical departments to determine future APL needs for warfare analysis. The committee's report to the Director recommended a central facility to improve our understanding of sponsor needs that could be supported by the Laboratory. The resulting facility, the WAL, in its fourth location at APL, has been in operation for nearly two decades.

The capabilities of the WAL have been used for many important programs since its inception. Its specially designed collaborative analysis environment, along with its visualization and analysis support tools, has applied APL science and engineering expertise to aid senior DoD and government officials. Through personal participation in these WAL Exercises, called WALEXs, our sponsors have seen firsthand how the APL-developed analysis process and the WAL (designed to support this process) are used to more fully understand the scope of their problems and to more fully explore alternative courses of actions.

This article briefly describes a WALEX, summarizes representative applications of the WAL in the 1980s and the 1990s, and examines expected applications and challenges for the first decade of the 21st century.

WALEXs

WALEXs are structured, objectives-driven analysis seminars that use scenarios and operational concepts as the context for a given exercise. Each exercise has five components:

1. Objectives definition
2. Exercise design
3. Exercise preparation
4. WALEX execution
5. Analysis and reporting

WALEXs bring together and help bridge communications gaps among disparate elements of the research and development, operational, and acquisition communities to focus on a common problem, examine the requirements for new capabilities, and evaluate alternative solutions.[2] Through a combination of seminar wargaming supported by scenario visualization, collaborative decision support tools, models and simulations, and information databases, participants explore and analyze a wide range of problems.

WALEXs are used to address complex problems that cannot be defined precisely and for which explicit assessment algorithms typically do not exist for quantitative assessment. They are useful in developing a perspective about the boundaries of a problem and the interrelationships among problem elements. These exercises are generally used for

- Mission analysis to determine and prioritize future needs to support new and evolving missions
- Requirements analysis to develop technically feasible system requirements that are tailored to user priorities and future operating environments
- Concept evaluation to assess alternative system concepts and concepts of operation
- Strategic planning to achieve consensus on long-range plans for the implementation of complex systems and processes

A WALEX usually involves 20 to 50 people from a variety of organizations who have the expertise relevant to the solution of the given problem. Key factors for successful exercises are as follows:

- Establishment of an operational context or scenario for the problem that portrays the dynamic environment in which the system or process under examination must operate
- Technically and operationally credible information on the performance and employment of systems within various operational contexts
- Careful selection of WALEX participants and leaders to ensure that various perspectives and organizations, as well as needed expertise and authority, are represented in the discussions
- Application of a structured procedural discipline so that adequate data are collected, issues are identified and illuminated, and the rationales for insights, conclusions, and decisions are made explicit

EVOLUTION OF THE WAL

The First Decade

During the 1980s, the WAL underwent great improvements in terms of its physical facility and capabilities. It moved from its initial 600-ft^2 home with one large screen display (Fig. 1a) to one with two large screens (Fig. 1b), and then to a 2700-ft^2 location (Fig. 1c) with three large screen displays that served for a decade. (The latest WAL facility and its capabilities are described elsewhere in this issue.) The Navy and DoD used the WAL for analyses of missions, requirements, and system concepts. A few highlights from the first decade follow.

Figure 1. The Warfare Analysis Laboratory: (a) 1981 to 1983, (b) 1984 to 1989, and (c) 1990 to 1999.

Mission Analysis WALEXs

Air Defense. By the early 1980s, the long-range, anti-ship cruise missile threat to Navy ships had significantly increased. What was the best air defense architecture to respond to this severe and growing threat? This architecture included Navy carrier-based fighter aircraft, ship-based surface-to-air missiles, and electronic countermeasures systems. At issue was the best mix of these air defense capabilities to deal with the threat.

In 1981, the first major exercise conducted in the WAL examined the contributions of electronic countermeasures or jamming to carrier battle group air defense in future threat environments. This WALEX explored mission needs and operational benefits from denying information to an adversary such that its overall combat effectiveness would be significantly reduced. The first large multi-organization effort to use WALEXs was the Outer Air Battle Study. These exercises closely examined the requirements for future air defense missions and evaluated the relative effectiveness of long-range fighter aircraft and surface-to-air missiles. These WALEXs provided insight into the appropriate mix of hard kill (i.e., missile) and soft kill (i.e., jamming) defenses against air attack, thus helping to shape the architecture for future Fleet air defense.

Requirements Analysis WALEXs

Top Level Warfare Requirements. A key problem for military decision makers is determining which weapon systems are needed to achieve desired mission objectives. In assessing alternative concepts, one must know the required level of effectiveness to meet the objectives.

Top level requirements must meet needs across a spectrum of operational scenarios and threats. In 1987, APL assisted the Navy in developing a set of future Top Level Warfare Requirements. Several WALEXs were conducted to define future operational environments for the Navy. WALEXs were used with these scenarios to derive top level requirements and to compare the performance of alternative Navy systems and architectures against those requirements.

The following year, Navy leadership conducted their annual Program Objective Memorandum (POM) Wargame in the WAL. Over 50 senior Navy and Marine officers participated in determining future naval requirements and assessing the capabilities of the planned naval force against those requirements. These efforts led to a more focused and structured approach to the requirements and appraisal process in the Navy and have since gone through additional refinement.

System Concept WALEXs

Aegis and Tomahawk. To meet the quick-reaction demands imposed by submarine-launched anti-ship cruise missiles, an unprecedented level of computer-programmed decisions and responses was needed, with minimal human real-time intervention. These were implemented in shipboard combat systems in the form of automated doctrine statements. Anticipating the introduction of Aegis cruisers into the Fleet in 1983, the Navy sponsored a series of WALEXs to develop and test guidelines for configuring the Aegis combat systems' automated doctrine statements (a set of "if-then" statements enabling automatic target identification and weapon assignment). From these WALEXs, a tactical manual was developed that gave commanding officers information necessary to configure their combat systems in a wide range of operational situations. Subsequent WALEXs helped build an understanding of development needs associated with Aegis operations in multi-Aegis ship battle groups.

Likewise, the initial Fleet deployment of Tomahawk land-attack cruise missiles created a need to evaluate Tomahawk performance in various operational scenarios. A series of WALEXs was conducted to develop a set of scenarios that reflected authoritative views about the future use of this new weapon. From these exercises, technical and operational improvements to the Tomahawk Weapon System and its associated mission planning system were identified and evaluated.

Advanced Technology. Determining the expected military value of a new technology in its early stages of development is one of the most difficult problems faced by the defense research and development community. To properly allocate funding resources to technologies with the highest potential for significantly increasing warfighting effectiveness, new analytical tools and methodologies are needed. Therefore, the warfare analysis process was extended and generalized to an approach known as "technology gaming," which was shared with the Navy and the larger defense community.[2,3] This technique provided greater insight into which technologies would be most effective in future scenarios.

The Second Decade

During the 1990s, the WAL had a more prominent and visible role than before. The facility, which became operational in 1989, supported a wide range of organizations, helping senior decision makers and leaders tackle very challenging problems. Through the 1990s, WAL capability increased dramatically. It incorporated and applied group decision support technology, connected to external information links and distributed simulations, incorporated high-fidelity simulation federations in its exercises, and added three-dimensional scenario visualization to its displays. The WAL, as a facility, has served as a model for a number of others in the defense community, such as the Decision Support Center at the Naval War College. Exposure to advanced information technology tools by senior defense leaders in the early 1990 WALEXs contributed to the widespread incorporation of such capabilities in many domains.

One major change in the 1990s was the emphasis on Joint operations in the military.[4] Although most WAL activities originally focused on single-service needs, the emphasis of WALEXs changed to examining requirements, capabilities, and concepts for the overall Joint force. Consequently, there has been a much greater increase in defense-wide Army and Air Force activities associated with the WAL. The facility's analytical staff has expanded accordingly to include analysts with experience in all services and Joint operations.

Also increased has been the use of the WAL by nondefense organizations, principally in the areas of transportation and biomedicine. During the 1990s, WALEXs were used for mission, requirement, and concept analyses and other varied applications, for example, in support of distributed simulation and strategic planning.

In transitioning from Cold War applications focused on the Soviet Union, the WAL was used to examine important issues associated with regional threats in Northeast Asia, Southwest Asia, Africa, and the Balkans. Highlights from WAL use in the 1990s follow.

Mission Analysis WALEXs

Theater Missile Defense. By 1990, the need for defense against tactical ballistic missiles was being hotly debated. Some believed that the potential destructive power of these missiles relative to aircraft and artillery threats was not significant. Others believed that these missiles could have a disproportionate effect on a conflict, not only in tactical terms but in strategic terms as well. The need therefore existed to develop a common view of the nature of the threat and a U.S. military response to the threat. For this purpose, a 3-day Theater Missile Defense (TMD) WALEX was conducted in September 1990. Forty participants from 20 organizations took part in this Anti-Tactical Missile Program Review Panel sponsored by the Assistant Secretary of the Army for Research, Development, and Acquisition.

Specifically, this exercise examined whether all four "pillars" of TMD (active defense, passive defense, counterforce/attack operations, and battle management) were required for effective TMD. Extensive technical and operational information was prepared in advance for the WALEX. The Blue Team participants included four former commanders-in-chief, one from each service (Army, Air Force, Marine Corps, and Navy). The Red Team included several intelligence community experts on the Theater Ballistic Missile (TBM) threat. Results of the WALEX showed that the defense against the projected TBM threat required all four TMD pillars. The report generated by this exercise significantly influenced the subsequent Joint Requirements Oversight Council Mission Need Statement for TBM Defense.

Since 1990, many WALEXs have been conducted, both in the United States and Europe, to examine a variety of TMD issues for Army, Navy, and Ballistic Missile Defense Organization (BMDO) sponsors. The findings from the first dozen or so of these exercises were reported to the international BMD community. More recent TMD WALEXs are discussed elsewhere in this issue.

Joint Mission Area. After the fall of the Berlin Wall, Congress and the public expected a reordering of defense priorities to meet the more diffuse and uncertain dangers facing the post–Cold War world. The Navy, with much of its existing capabilities and plans shaped by the Soviet threat, established an aggressive process to bring about needed changes. In 1992, the Navy's Deputy Chief of Naval Operations for Warfare Resources, Requirements, and Assessments sponsored a series of WALEXs. The objectives were to reorder Navy priorities to better address post–Cold War requirements and to be more responsive to the increased emphasis on Joint warfighting.

During a period of 3 months, more than 30 Flag Officers participated in the Joint Mission Area Assessment exercises. Once required capabilities were prioritized, the officers took part in a series of follow-on seminars in the WAL to evaluate the capability of existing programs to meet those requirements. From these sessions, recommendations were made to restructure Navy programs to better meet anticipated future needs. Over the next several years, the WAL was used for annual assessments.

Mine Warfare. Naval mines are one of the oldest and most potent threats to ships and shipping. There is a continual need to ensure that existing planning and technology development programs will be adequate to deal with this silent threat. In 1993, the WAL was used for a series of exercises to assess the Navy's Mine Warfare Program as part of a congressionally mandated study. The Director of Expeditionary Warfare led the study and used the WAL to examine operational concepts for existing, planned, and proposed mine countermeasures (MCM) systems. These WALEXs involved examination of several scenarios where MCM capabilities were needed. Requirements were identified, programs were evaluated against those requirements, and ongoing research programs were also examined to determine if they met MCM deficiencies.

The entire mine warfare community as well as Navy warfighters were involved in these exercises. Results were sent to Congress and formed the basis of the overall restructuring of the Mine Warfare Program. More recently, WALEXs have been used to examine MCM requirements to support the Marine Corps in Operational Maneuver from the Sea. In addition, the U.S. Atlantic Command used the WAL for postexercise analysis of the Joint Countermine Advanced Concept Technology Demonstration.

Space Communications. The U.S. military is relying more heavily on space-based communications systems to meet future peacetime, crisis, and warfighting needs.

A key issue is the appropriate mix of commercial and military communications satellites to provide secure, reliable, and adequate communications for operational forces. Too much reliance on commercial capabilities could make our communications vulnerable to jamming or overload during a conflict. In 1995, the newly formed Space Architect Office sponsored a series of WALEXs to evaluate future architectures for military satellite communications to support deployed forces. The DoD Space Architect WALEXs evaluated four alternatives that had varying levels of dependence on commercial satellite services. They brought together Joint warfighters to examine requirements and capabilities for those architectures to meet their future needs. From these exercises and associated analysis, a preferred Military Satellite Communications (MILSATCOM) architecture was developed. This architecture was subsequently presented to the Joint Space Management Board as the preferred future MILSATCOM choice.

Requirements and Concept Analysis WALEXs

Space Control. During the 1980s concern about Soviet space reconnaissance and communications capabilities led to interest in developing a capability to negate hostile satellites. Would the adversary's space threat really affect our ability to win a war? If so, which satellites, and how quickly did they need to be negated? The cost of such a U.S. antisatellite capability would be heavily driven by the numbers of antisatellite missiles and system response times needed to meet the threat. In 1990, APL, working for an Army-led Joint Program Office, conducted a Cost and Operational Effectiveness Analysis (COEA) for a proposed kinetic energy antisatellite system through a series of WALEXs during which requirements were examined and alternative approaches were evaluated for meeting those requirements. At the end of the study, the Assistant Secretary of Defense for Program Analysis and Evaluation stated:

> I think the Army should be congratulated for the "blue sky" approach that it took to requirements in its COEA for the antisatellite system. It structured the analysis in a way that allowed people to look at this question of "requirements." It created a war game simulation, using past and present space commanders, to ask: "How would we really use this system? Which of its characteristics would be important? How would it be employed? What military outcomes are desired?" From that process came a different set of "requirements" than had been laid on the table at the beginning of the program. These requirements were somewhat simpler to meet. If the system does indeed continue, part of its success will be due to this careful examination of requirements at the start of the program.[5]

Cooperative Engagement. A significant, long-lasting problem in air defense has been an inability to achieve a single integrated air picture which would give commanders in geographically distributed locations identical information on friendly, enemy, and neutral air targets. Multiple air defense radars on different ships provided individual tracks that might be miscorrelated, leading to an air picture with duplicate and missing target track information. A new concept for treating this set of individual radar systems as a single distributed radar system, the Cooperative Engagement Capability (CEC), was developed at APL. CEC promised an unprecedented capability for a coherent air picture, and from that offered important new tactical options for the Fleet to exploit.

In 1994, CEC was ready to be introduced into the Fleet for initial testing and evaluation.[6] Prior to the first exercise, a WALEX was held with the Commander of the Dwight D. Eisenhower (IKE) Battle Group and the commanding officers of all combatant ships in that battle group. This WALEX brought together engineers who conceived, designed, and built the CEC prototypes and Fleet operators who would actually use the equipment. The purpose was to demonstrate via scenarios the operational payoff of operations with a CEC-equipped battle group. CEC performance in the different scenarios was calculated and portrayed via computer generated visualizations. Officers of the IKE Battle Group began exploring new tactics enabled by the CEC capability. The WALEX bridged the gap between CEC engineers and future CEC operators, providing both with important insights into the utility of CEC and future evolutionary needs for the CEC Program.

Following the CEC exercise, a series of air-directed surface-to-air missile WALEXs examined the system concepts and military utility of CEC in Overland Cruise Missile Defense. These WALEXs determined and communicated the value of connecting surface and air units via CEC to engage this new threat. These activities led to exercises for the Joint Requirements Oversight Council Review Board, which examined requirements for Overland Cruise Missile Defense.

Surface Combatants. By 2010, the expected service life of major classes of warships begins to end, forcing an evaluation of the need for a new class of surface combatant to sustain the necessary ship force levels. However, these ships, which would be the newest combatants built after the 84 Aegis cruisers and destroyers, would not necessarily be updated versions of previous classes.

The post–Cold War peacetime and warfighting requirements shifted Navy emphasis to littoral warfare. Thus, a new combatant would have to be designed to meet the new requirements while improving its capabilities and reducing its costs through new technologies. In 1996, the Defense Acquisition Board approved the 21st Century Surface Combatant (SC 21) Program to proceed to a Milestone I decision by conducting (1) an exhaustive assessment of Joint force requirements and deficiencies for 2015 and (2) an analysis of ship alternatives that would meet any deficiencies.

The 2-year SC 21 COEA involved over 100 people and 50 organizations. Part I of the study was an in-depth requirements assessment. Three WALEXs were held with warfighters from all services to examine future warfighting scenarios and to determine expected deficiencies in Joint force capabilities. For deficiencies, alternatives were identified and considered. Those best addressed by future surface combatants were highlighted. Additional WALEXs were conducted for operators to develop operational concepts for each alternative, play them out in different scenarios, and evaluate their capabilities and limitations.

The WALEX process allowed a wide range of stakeholders in the SC 21 Program to participate in the analytical process. It broadened the understanding of needs and potential solutions and built program support. Participation by operators from all services was essential to prove the varied perspectives that were needed to build a workable program. In January 1998, the Defense Acquisition Board approved the SC 21 Program for Phase II development. It has since become the DD 21 Program.

Area Air Defense Commander. Projecting power through the air is an integral component of U.S. warfighting strategy. Desert Storm involved over 2000 aircraft and even Operation Allied Force in Kosovo had more than 1000 aircraft involved in the region of operations. The presence of Air Force, Army, Marine Corps, Navy, Allied, Coalition, neutral, hostile, and unknown aircraft creates a very complex air picture. Control of the air war requires a sophisticated capability to plan and monitor the execution of the air campaign.

To provide this capability for the staff of the Joint Force Commander, a new prototype Command Center for the Area Air Defense Commander (AADC) was developed. This prototype was to provide a highly capable planning and execution capability for Joint Force staffs responsible for Theater Air Defense. A WALEX held in 1997 brought together senior operators from all services with air defense coordination experience to evaluate AADC requirements in operational situations typical of Joint theater operations. This exercise validated much of the early AADC design requirements and identified additional improvements that would increase its utility to the AADC. As a result of this WALEX, there was a renewed confidence within the air defense community that the proper set of operational requirements and functions was being addressed in AADC prototype development.

Varied Applications

Simulation. Modeling and simulation offers potential for more cost-effective training, analysis, and acquisition. Connecting multiple simulations to form a distributed force or system of systems provides an efficient and effective means for exercising advanced system and force concepts. In 1994, the WAL entered the era of distributed simulation when it was used as a node in a number of distributed simulation exercises for TMD and precision strike. An on-site gateway into the Defense Simulation Internet provided the WAL and other APL facilities with access to exercises. The facility functioned as the East Coast "viewport" for the Kernel Blitz 95 Exercise conducted by the Third Fleet off the coast of California.

The WAL gave observers a real-time feed of tactical and simulation data, merging real and virtual platforms that were part of the exercise within the Third Fleet Commander's tactical displays. The WAL has been used since then to support other military exercises and Advanced Concept Technology Demonstrations. Expanding the WAL's electronic links to a wider external environment is a primary goal of ongoing WAL development.

Strategic Planning. A continuing challenge to large, complex organizations is to develop an integrated long-term investment strategy in support of long-term strategic goals. In 1999, the NASA Science and Technology Integration Office conducted a WALEX to articulate a new process for developing their technology investment long-range plan. The exercise brought together enterprise managers (mission managers) with technology thrust area managers to better match NASA's technology development programs with anticipated mission needs in space science, Earth science, and human exploration of deep space. Over 50 key leaders from 8 major NASA centers used group decision support techniques to facilitate real-time collaboration and consensus building.

The WAL has also been used for a variety of other purposes, for example,

- Affordability risk assessments for the Joint Strike Fighter Program
- Requirements determination and prioritization for the Joint Warfare Simulation (JWARS) Program
- Concept of operations development and assessment for the Affordable Rapid Response Missile
- Strategic planning for the Commercial Vehicle Operations activity under the Department of Transportation
- Advanced Concept Technology Demonstration formulation for Joint telemedicine
- Operational concepts for the Joint Biological Remote Early Warning System (JBREWS)

WAL 2000: THE NEXT DECADE

Twenty years of experience with the WAL has led to the development of a next-generation collaborative analysis facility called "WAL 2000" (Fig. 2), the hub

Figure 2. The new WAL 2000.

for collaboration on a wide range of problems. WAL 2000 (described elsewhere in this issue) provides a major increase in capability by expanding links to the outside world and to the rest of the Laboratory. It nearly doubles the capacity of the previous WAL and is much more accessible.

WAL 2000 is designed to be a positive force for change, stimulating analytic adaptation to the problem set to be addressed. While continuing to assist DoD with its changing needs, the WAL is increasing activity with other government agencies and may be used by nongovernment organizations as well. Within DoD, new challenges in counterproliferation, information warfare, network-centric warfare, and space systems will be addressed. For other government agencies, WAL 2000 will assist in developing plans and programs in areas such as counterterrorism, law enforcement, transportation, health care, and biomedicine.

The challenge for WAL 2000 is to substantially increase its capability to rapidly incorporate and exploit new collaborative technologies and apply them to solving the even more complex problems of the 21st century. The three keys to the Laboratory's effective warfare analysis process remain (1) consistency in discipline, data validity, and analytic rigor, (2) a structured process for consensus building and issue exploration, and (3) collaborative use of information and people with multidisciplinary expertise.

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