System Concept Development Laboratory: Tooling Up for the 21st Century

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Emerging threats, acquisition reform policies, and technological changes require new approaches to the development of advanced concepts in air and missile defense. Trends include proliferation of hostile cruise and ballistic missiles; acquisition policies involving extensive use of modeling and simulation; greater application of systems engineering disciplines and related tools; design to total life-cycle cost; and automated sensor, command and control, and weapons networks effecting battle force operation as a naval, Joint services, and/or multinational system of systems. Meeting the challenge of developing concepts for the next decades requires new engineering tools and approaches that apply proven systems engineering principles. A new System Concept Development Laboratory has been designed and recently placed online to meet the concept development needs. This laboratory features new capabilities in modeling and simulation, configuration management, collaborative engineering, element-in-the-loop stimulation and test, remote test support, and engineering facilities networking. These features are described and examples presented.

INTRODUCTION

This article describes how APL developed the System Concept Development Laboratory (SCDL) using systems engineering disciplines. Trends leading to the need for the SCDL are described first. The article then explains how the SCDL itself was "systems engineered." We begin with the overarching requirements for such a facility and then present a "concept of use," along with constraints and assumptions, based on systems engineering activities ranging from concept formulation through system test. We include corresponding functional layouts and scenarios of operation. The design of each of the as-built SCDL spaces is then presented in some detail. Finally, the potential evolution of this facility and of engineering tools in general is briefly discussed.

BACKGROUND

Advances in threats have driven U.S. systems to be increasingly complex, automated, and networked. Further, the reduction in U.S. forces and corresponding expenditures in the post–Cold War era has increased the need for greater performance from battle forces of smaller numbers and for operation with Joint and coalition forces. Complexity has increased with the use of very advanced technologies; the combination of complexity, automation, and networking has led to combat systems that interact via tactical data links (TADILs) and the Cooperative Engagement Capability (CEC), enabling a force of many ships, aircraft, and missile batteries to operate as a single distributed system. Emerging DoD policies toward reduction in government infrastructure and increased reliance on defense contractor engineering require new means for the government to maintain a "smart buyer" capability. Although APL and other organizations have played key roles in support of this need, DoD needs increased automation and quantification of requirements, better tracking of contractor progress, and more quantitative means to evaluate competitive approaches in complex system and operating environments.

TRENDS IN SYSTEMS ENGINEERING TECHNOLOGIES

Some of the specific systems engineering challenges and the technology employed to date by the acquisition community to meet those challenges are described below.

Distributed Engineering

Several developments over the past few years employed advanced, geographically distributed engineering facilities. For example, in 1990, as the Technical Direction Agent for CEC, APL devised an approach to connect land-based Navy test sites into an engineering configuration representative of a CEC battle group. This was necessary because CEC had to be verified in multi-unit configurations without tying up an entire battle group for engineering tests. In more recent interoperability improvement efforts, this idea was extended to the Navy Distributed Engineering Plant (DEP), which consists of land-based test and engineering sites representing battle group elements linked via land lines to emulate CEC and TADIL networks. The Navy DEP is a means to determine, and in some cases correct, problems in as-built combat system software before deployment. Efforts to extend the concept to a Joint services DEP and use it for testing earlier in a system's development cycle are in progress.

Wrap-Around Simulation/Stimulation

Work to more fully integrate automatic detection and tracking into the Terrier/Tartar air defense systems of the 1970s and 1980s required the development of wrap-around simulation programs (WASPs) to emulate elements built by contractors but not yet available for integration. This assured the maturity of interfaces and the early problem resolution of increasingly complex software. The WASP approach was necessarily extended to the development of CEC to support software testing and to test the many interfaces to CEC across different combat systems, each with unique interface requirements. We foresee the extension of this approach to test new elements of a battle force and to assess the products of competing government contractors.

Modeling, Simulation, and Visualization

As systems and networks of systems became increasingly complex, more sophisticated modeling and simulation (M&S) was required to predict performance and complement testing. Further, as is occurring in scientific fields such as organic chemistry and molecular biology, the ability for human visualization of complex interactions and architectures is becoming recognized as a way to gain insights into system behavior, and even to view the complex issues associated with evaluating and trading competing design features.

Rapid Prototyping

In determining the feasibility of a new technology or newly discovered device phenomena, the ability to rapidly prototype an element and test it in a virtual setting became more prevalent. APL facilities such as the Avery Advanced Technology Development Laboratory wind tunnels, the Guidance System Evaluation Laboratory (GSEL), and the Combat System Evaluation Laboratory (CSEL) are examples of this trend.

Collaborative Systems Engineering

As we teach in our JHU part-time graduate courses in systems engineering, much of this discipline is the methodical exercise of trade-offs, iterative design, interface control, and merging of considerations from many technical specialties.[1] This requires methods for collaboration, communication, and management of design progress. These methods are being pursued in such programs as DD-X development and Navy Theater Wide Ballistic Missile Defense. The concept of collaborative engineering is not new (e.g., Ref. 2), but the approach of using technology and automation to facilitate the effort is gaining ground and is actively being pursued by the Chief Engineer, Assistant Secretary of the Navy for Research, Development, and Acquisition. Consequently, networking of engineering teams and their products, including documentation, prototypes, and simulations, is of increasing interest.

Remote Test Support

In 1995, APL connected CEC through the International Marine/Maritime Satellite (INMARSAT) network to allow monitoring by, and advice from, Laboratory technical staff during tactical exploration exercises of the USS *Dwight D. Eisenhower* battle group while it was deployed in the Mediterranean. A more recent example is APL support of the Pacific Blitz 2000

Theater Ballistic Missile Defense and Air Defense Warfare exercises, during which APL monitored the test events, provided the assessment skills of subject matter experts, and collected data remotely, thereby saving travel time and equipment transport. We foresee an increasing need for this capability as a rapid means of accessing remotely located technical expertise and providing unique data reduction and analysis facilities.

OVERARCHING SCDL REQUIREMENTS

The ideas, challenges, and technical approaches noted in the preceding paragraphs were brought together in the concept for the SCDL. To meet the emerging engineering needs of the DoD community, APL had to improve its capability for system concept development and systems engineering by increased integration of prototyping, critical tests, data collections, simulation, and early design trade-off evaluation—all to be done in a collaborative environment. The need translated into developing and combining new systems engineering tools consistent with well-established systems engineering principles. The necessary systems engineering activities—formulating concepts, refining concepts through requirements analysis, validating concepts and reducing risk through critical experiments, integrating prototypes into representative operating environments, validating operation of prototypes through testing in natural environments, etc.—are described in Ref. 3 and shown in Fig. 1 with examples of tools and facilities.

Because existing facilities already served many systems engineering activities, the new facility concept was bound by the following constraints:

- Existing APL and DoD facilities had to be used to the greatest extent practicable.
- Analogous activities within the DoD community had to be anticipated.
- Growth had to be provided for.
- Needed tools had to leverage current APL tasks to allow evolution of new approaches and tools without disruption of ongoing sponsored efforts.

The primary requirements of the SCDL were to support all systems engineering activities and ensure access to the resources needed. These requirements led to a design requirement for a single facility with collocated tools and access to assets needed for the systems engineering activities. Access to APL resources, DoD sites, and contractor facilities from the single facility required high-bandwidth networks within the APL campus and to external facilities. The SCDL would host a minimum of assets so as to leverage existing systems and resources within APL and DoD.

SCDL CONCEPT

In systems development, a system concept and corresponding "concept of operations" (use) are often developed in parallel; this same process was applied to SCDL development. The new facility was to support the systems engineering activities depicted in Fig. 1. Beginning at the top left, concepts for employing technology to meet warfighting demands are established, assessed against certain criteria, and ultimately retained for elaboration or discarded. This activity is predominantly analytical and collaborative. To support such efforts a war room space in the new facility was defined. To support multiple projects, or the numerous phases of a single project, electronic means to allow many war room efforts to share the same resources were also prescribed.

As war room efforts involve synthesizing answers using many diverse inputs and views of problems and solutions, a means to show multiple graphical images and electronically link them to background information was defined. The space needed to support this part of the SCDL concept was termed the Electronic War Room. Because of the strong connection between concept formation and warfare analysis, this (and other SCDL spaces) was interfaced with the APL Warfare Analysis Laboratory (WAL).[4]

Following concept formulation (Fig. 1) are evaluation of concepts

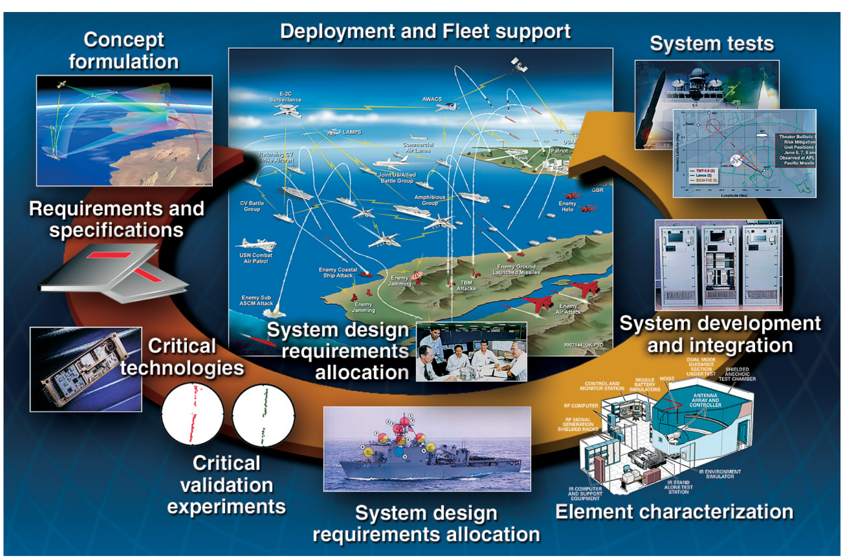

Figure 1. Systems engineering phases and activities. Development of a major new system begins with concept studies and subsequently includes requirements definition, critical risk reduction experiments, element design, element performance characterization, system development and integration, field testing, and deployment and in-service support.

and establishment of initial requirements. Since virtually all new warfighting capabilities integrate with deployed, legacy systems, a means for easy access to documents describing such systems was needed. Consequently, a library capability was defined where documents would be stored electronically and readily accessed. The Electronic Library thus became a requirement of the SCDL; the library capability was anticipated as a combination of a CD jukebox, PC terminals, and software to manage and access the library contents.

The need for exploring potential performance, and hence effectiveness, through models and simulations is tied to concept evaluation and requirements analysis. At this early stage of a concept's evolution there is little if any hardware or software to be tested; thus detailed analyses are done via models. Because the models must represent elements in the absence of real hardware, software, or test data, they must have a substantial level of fidelity (the model is initially the only representation of the physical environment and the system elements to be built). To support this need a System Element Modeling and Visualization (M&V) space was defined for the SCDL. This space would contain powerful computers and graphics capabilities to accommodate a very wide range of high-fidelity models planned and currently in use. Later, to precisely specify the computers for this space, computing requirements (e.g., memory and processing speed) were established to execute extant radar, missile six-degree-of-freedom (6-DOF) simulations, and weapon system models in an end-to-end configuration and to support several mission areas simultaneously.

Moving downward in Fig. 1, critical experiments are often performed to obtain data for analysis and/or to reduce risks associated with an advanced concept. Some critical experiments are performed in the field using prototype capabilities integrated on a trial basis with existing warfighting systems. Participation in a critical experiment requires the presence of many engineers, scientists, government sponsors, and testers at the sites. In consonance with the requirement for the new facility to provide ready access to resources—in this case, the fielded elements of critical experiments—a capability to remotely participate in the experiments and examine experimental data in real time was needed. Thus the Test Participation space in the new SCDL became a requirement. The intent of this space is to "bring the field to the engineers." Although testers are still present at the field sites, the Test Participation space allows APL, government, and contractor staff to participate first-hand in the field exercises from the APL location. The goals of this space are to expedite the analysis of data collected in the field, bring more analysts to bear on problems, and reduce overall travel and field support costs. To this end, test conductor audio, test range instrumentation, and combat system data would be provided in real time to the Test Participation space. Field test data would be stored and analyzed in the Electronic Library and also used as inputs to models in the M&V space.

The next phase of bringing a concept to a realization, assuming goals of critical experiments have been met, is interaction with industry and acquisition-oriented Navy activities to transform the concept from an experiment to an engineering development activity. This effort requires exposing industry and government to the concepts and working with them to transform system requirements and experimental results into a system design. Ultimately, the implementation of elements so designed is inserted into the acquisition stream. To accomplish these tasks a great deal of collaboration is needed; results of analyses and critical experiments are explained, and the engineering performed to develop robust elements to achieve the concept and properly integrate new and legacy elements. The Electronic War Room, Electronic Library, and to some extent the System Element M&V spaces would support these efforts. Later, as industry produced an engineering development model, the Test Participation space would be used to monitor and/or control developmental tests performed at contractor sites.

Continuing to the right in Fig. 1, system elements are developed and integrated with legacy warfighting elements. For specialized elements such as a missile seeker, performance validation and characterization of elements also take place (as in APL's new GSEL). Integration examines the behavior of the elements in an environment reflecting the actual interfaces to other elements. Ultimately, the activity examines the behavior of the total system, which includes the newly developed elements. A critical aspect of systems engineering is to integrate the parts, many of which comprise legacy systems that have undergone only minimal changes, such that the benefits of the newer elements are fully achieved in the operational environment. The government DEP, described earlier, may be the surrogate battle force for such integration testing. The Test Participation space would support tasks where system elements and test tools at multiple sites must be networked, and where element data captured during integration tests must be forwarded in real time to APL for analysis. The System Element M&V space would also support this activity when high-fidelity software-based models are needed.

Lastly, an engineering development model or its equivalent is brought into the field, installed in its actual operating environment, interfaced to the required existing systems, and tested. This testing is rigorous in an engineering sense, usually with a test plan, test procedures, and a reporting process. The Test Participation space would support this effort by allowing engineers and analysts to view tests and associated real-time data. The Electronic Library would support data analysis and retention, and the Electronic War Room would support hot washups along with collaborative preparation of report materials.

Figure 2a illustrates the expected APL on-campus interfaces. In consonance with the requirement that existing laboratories and facilities be leveraged, the APL complex would not replace individual facilities and laboratories, e.g., those used in system modeling and analysis, test and evaluation, and element-in-the loop tests. Instead, it would allow these facilities to be electronically linked and interactive, providing a greater capability to design and characterize systems comprehensively and efficiently, and to fill apparent gaps in access to design and specification data. The present network (Fig. 2a) can accommodate the other principal APL facilities. This was considered especially important as new tasks were emerging to ensure that the air defense mission would be interoperable with other missions, such as strike warfare, in which a number of combat system elements must be shared. Figure 2b indicates the original intent for the SCDL to be a primary APL facility interface to the combat system development and test sites of the Navy (and eventually the other services). As will be seen later, such interfacing is presently under consideration within tasks to support Naval Sea Systems Command DEP and the associated Naval Collaborative Engineering Environment of the Chief Engineer, Office of the Assistant Secretary of the Navy for Research, Development, and Acquisition.

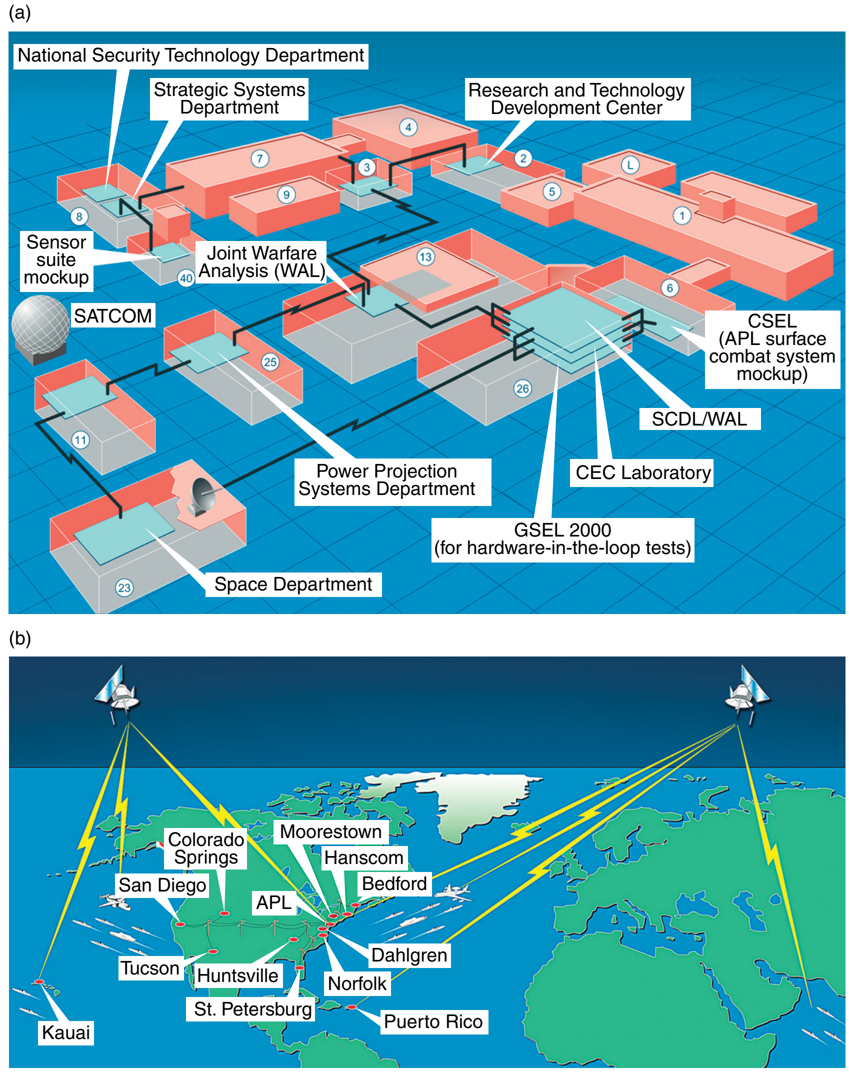

Figure 2. Concept for interfaces to the SCDL. (a) For on-campus interfaces, connectivity is via secure communications gateways. SCDL also supports links to smaller simulation and model development laboratories. (b) For external interfaces, connectivity is via commercial, terrestrial, high-capacity networks; military and commercial SATCOM; and military surface/air networks such as Link-11, Link-16, CEC, and the Global Command and Control System (GCCS).

Figure 3 illustrates four initial concepts of use:

1. Virtual element-in-the-loop experiments
2. Distributed M&S in support of warfare exercises
3. Remote test participation applied to network tests and data collection
4. Combat system element-in-the-loop testing with WASPs and remote sites

These will be referenced below as the SCDL areas are described in detail.

On the basis of SCDL requirements, projected use concepts, and substantial input from Air Defense Systems Department systems engineering users of the layout and equipment, a final concept for meeting the above requirements was developed; this is shown in Fig. 4 as the as-built laboratory configuration along with names of the SCDL spaces. At this point in the effort it was determined, again in design and use discussions within APL, that the Joint Warfare Analysis Department (JWAD) would host the Force-on-Force area of the SCDL as more closely related to their warfare assessment business area. This would be supported by other activities and, with their WAL, provide JWAD with a unique capability for more automated and visualized WAL activities in support of analysis of alternatives. The WAL is on the third floor of Building 26 adjacent to the SCDL.

The following sections describe the SCDL spaces in more detail.

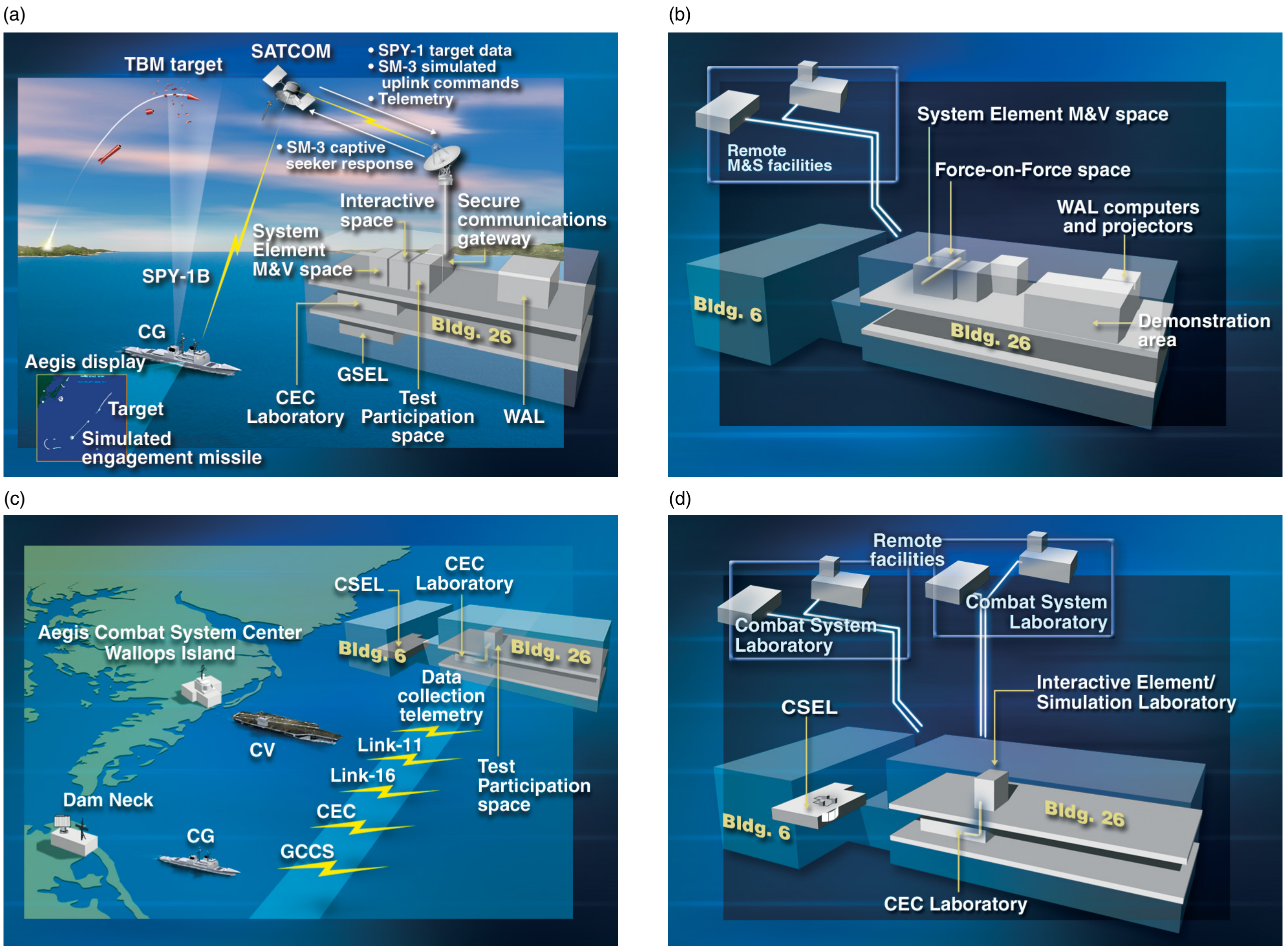

Figure 3. Four SCDL use concepts: (a) A virtual element-in-the-loop experiment executes an engagement of a Theater Ballistic Missile target using a 6-DOF missile model and Standard Missile-3 (SM-3) seeker in the GSEL, linked via SATCOM to an Aegis cruiser tracking the target. (b) A WAL Exercise (WALEX) is conducted using models resident at APL coupled to models at remote facilities. (c) A test is conducted in real time with at-sea participants, combat system elements, and CEC linked to APL Buildings 6 and 26. SCDL connects to land sites via land lines, to ships at sea via satellite links, and to combatant combat systems via actual military networks. (d) Hardware-in-the-loop elements at multiple remote facilities are integrated as a battle group using CSEL and SCDL to test combat system functions.

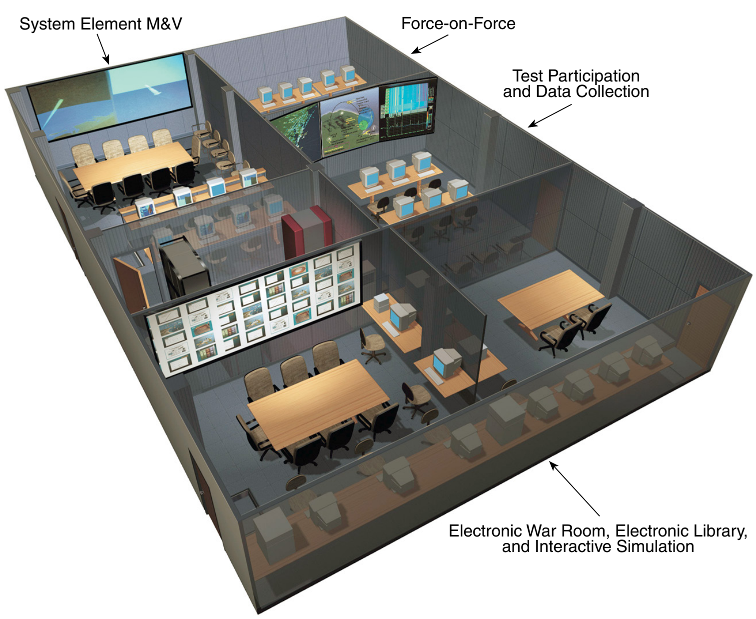

Figure 4. As-built SCDL layout.

Electronic War Room and Library Space

The Electronic War Room and Library space provides the basis for war room activities performed during most stages of concept exploration. War room efforts consist of gathering data associated with aspects of a concept, devising or identifying key characteristics of a concept, analyzing trades at a fairly high level, and producing conclusions that are often presented in the form of a "roadmap." A roadmap usually comprises a report and an annotated slide presentation. Frequent and broad collaboration among industry, laboratory, and government scientists and managers is the rule. This SCDL space provides the databases and repository for development-oriented information, including mission needs statements, operational and system requirements, technical risk reduction, concept definition, and program and system documentation. The central theme of this space is integrated electronic databases, presentation tools, and collaboration.

The space supports these activities by providing an information repository, a state-of-the-art presentation capability, video teleconferencing (VTC), and computer-based multisite collaboration tools. The repository is a DVDRAM jukebox capable of storing roughly 1.5 terabytes of data. Its intent is to host historical program-related documents and presentations, system specifications, interface specifications, test data associated with factory tests or at-sea exercises, test reports, and planning information for pertinent programs. The repository is essentially the library to which analysts can go to find specific system data needed for evaluating proposed concepts. In addition to the DVDRAM jukebox, the library contains PCs for viewing information, printers, and document management software for retrieving library articles given keyword, author, or content.

The Electronic War Room and Library space supports direct collaboration between APL staff and engineers at remote sites. It contains a standard PictureTel VTC unit operating with up to three 128-Kbits/s ISDN phone lines. Several PCs are configured with computer-to-computer collaboration software, principally Microsoft NetMeeting. A virtual private network supports online conferencing using servers at government and contractor sites. Finally, a SIPRNET node allows e-mail, FTP, and browser connection to selected sites and nodes on the classified Secret-high network.

The space also hosts an electronic presentation capability consisting of a PC, a special graphics board, and three large-screen displays; this setup allows a PowerPoint file to be displayed in a format three times as wide as the normal view. Thus a single wide-aspect slide, three slides simultaneously, or three times as many slides in the sorter view can be shown. This capability is extremely helpful when analyzing disparate information, organizing presentation material, and presenting complex ideas using multiple slides. There is also a capability for hypertext links within presentations. The Electronic War Room and Library is one classified space. A divider separates the War Room and Library areas, allowing long-term flexibility in configuring the space. Figure 5 is a photograph of the completed space.

Figure 5. SCDL Electronic War Room space. A 5 × 17 ft screen driven by a special graphics board supports war room and collaborative engineering. VTC links to outside meeting participants. Presentations are shared using collaborative conferencing software.

System Element M&V Space

The System Element M&V space provides the means for analyzing candidate warfighting systems and/or subsystems via simulation. Such analysis efforts establish possible configurations of sensor, weapon, communication, and computing capabilities to support a warfighting concept; capabilities may comprise extant systems, modifications of extant systems, systems under development, or altogether new systems. The rule is generally some combination of all these. For all but the simplest concepts, far too much hardware and/or software would need to be built to examine concepts at this early stage using actual element prototypes. While systems engineering eventually calls for the use of prototypes to demonstrate feasibility or to retire developmental risks, prototypes are too costly for initial concept analysis as the concept's potential capabilities are invariably changed and refined. Thus, M&S is chosen to represent the candidate system capabilities, elements, or functions. (Building appropriate models is not necessarily an inexpensive endeavor.)

Because the models or simulations are the only representations of system elements at this early stage (i.e., no elements are yet built for which performance characterizations can be made), their fidelity must represent capabilities at levels commensurate with the analyses being performed. For example, to examine a concept that prioritizes a ship's defense against enemy aircraft based on the aircrafts' closest points of approach (CPA), an aircraft model driving the concept algorithms could simply include Cartesian position, velocity, and acceleration. The resultant model would simulate aircraft motion using three degrees of freedom and may be considered operating at a medium-fidelity level. On the other hand, if the concept relied on how well a radar tracked one of these aircraft (to be processed by the CPA algorithm), one would need to represent radar tracking in both clear and clutter environments. In this case the aircraft model would not only need to simulate aircraft motion but also the aircraft characteristics to which the radar processing is sensitive, as well as the radar signal processing up to a certain point (for example, the clutter rejection algorithms being studied). These level-of-fidelity considerations influenced decisions on the computing capabilities of the System Element M&V space.

The space provides powerful computers capable of executing a broad variety of models ranging from those operating at the radar signal processing level to lower-fidelity mission-level models. The former are generally computationally intensive, requiring high-end capabilities such as the Silicon Graphics multiple processor shared memory supercomputer. The latter applications involve moderate computation requirements and are often Monte Carlo in nature, requiring many executions of the same problem. The System Element M&V space supports these applications using a multiple PC cluster, where each PC solves a problem independently of the others.

For the computationally intensive models, potential users of 6-DOF missile aerodynamic models, detailed radar cross-section models, and radar signal processing models were surveyed. These staff members were queried about the computers and operating systems they used as well as those that should be available in a new facility if possible. They were already executing their models in extant laboratories, so inquiring about their desires was an effective method for determining their plans for growth. Responses showed that a wide range of high-end computers and workstations were being used. For the above reasons, and furthermore to support a business case for integrating the models in an end-to-end sense within a single facility, it was decided to procure an equally diverse set of computing assets. This would allow for the broadest range of user applications as well as desired visualizations (see the article by Colbert and Ralston, this issue). Figure 6 is a photograph of the M&V space showing visualization and conference areas and user console stations. The M&V space supports individual analysis and development in addition to the end-to-end model integration.

Figure 6. SCDL System Element M&V space. A 5 × 17 ft screen supports three pictures generated by three separate high-fidelity models, and/or multiple views of data generated by a single model. High-end Silicon Graphics computers, Sun workstations, and a 32-PC cluster support a wide variety of engineering-level models and associated visualizations.

Test Participation Space

The Test Participation space provides the means for monitoring and potentially controlling tests conducted at government test sites, industry facilities, and other laboratories. This allows APL analysts to obtain data from the test assets of these sites in real time or near–real time. For control of test assets from APL, the control data would be sent from APL to the remote assets in real time. Test assets consist of an operating environment and at least some real-time hardware-in-the-loop (HWIL) combat system elements.

For tests conducted at a test range, all elements of the systems are usually present, including sensors, control systems, weapon systems, and tactical operators; test scenarios define controlled aircraft, drones, and missiles that represent threats. For tests conducted at laboratory and contractor facilities, the combat systems of interest are usually HWIL elements, while real-time stimulators provide the controlled environment to the elements under test. Such stimulators represent (i.e., simulate) the controlled aircraft, combatant sensors and weapon systems, and tactical communication. The test data of interest include the time/space/position information (TSPI) of the controlled (or simulated) threats, the sensor reports generated for these threats, the tracks generated by combat system elements for the threats, the combat system and operator decisions determining how the threat is engaged, designation to weapon systems, and the TSPI of weapons as they engage a simulated threat. In a laboratory environment this information could consist of simulated threat positions, simulated sensor reports, TSPI generated by a missile simulation, and simulated TADIL messages.

The Test Participation space provides radio connectivity to field sites, operator console stations for viewing monitored data in real time, software programs to tailor views of monitored data, a Link-16 TADIL (TADIL-J) capability, a threat generation capability, and software connectivity to CEC, Ship Self-Defense System (SSDS), and tactical missile defense HWIL laboratories at APL. The space will support the Navy and Joint DEPs once a Secure Defense Research and Engineering Network or Defense Information Systems Network–Leading Edge Services node is available at APL.

Figure 7 shows two kinds of tests involving the Test Participation space and remote sites. Figure 7a depicts a land-based battle force exercise, where a ground truth test target scenario is sent in real time from APL to remote stimulators that drive ship combat system elements under test, and real-time test data are sent from the remote sites to APL. Figure 7b depicts connection to a site where a factory acceptance test is being performed using stimulators to drive the articles under test; ground truth test targets generated at APL drive stimulators that interface to the articles under test, while detailed data from instrumentation embedded in the tested articles are sent to APL.

APL used the Test Participation space to support the Pacific Blitz Battle Management Command, Control, Communications, Computers, and Intelligence (BMC4I) Theater Ballistic Missile Defense exercise conducted in June 2000 at the Pacific Missile Range Facility (PMRF). The main role of the SCDL was to support the Data Analysis Group in examining the effectiveness of TADIL-J messages during the exercise. Information sent from the field to APL in real time included the data link messages generated in response to the Tactical Ballistic Missile threat, test range radar data for the threat, and the test conductor's voice circuit. APL analysts assessed the data link message content using the test range radar data as ground truth. Availability of the voice circuit aided in determining the sequence of events and correlating anomalies (about which there were test conductor comments) with the data collected.

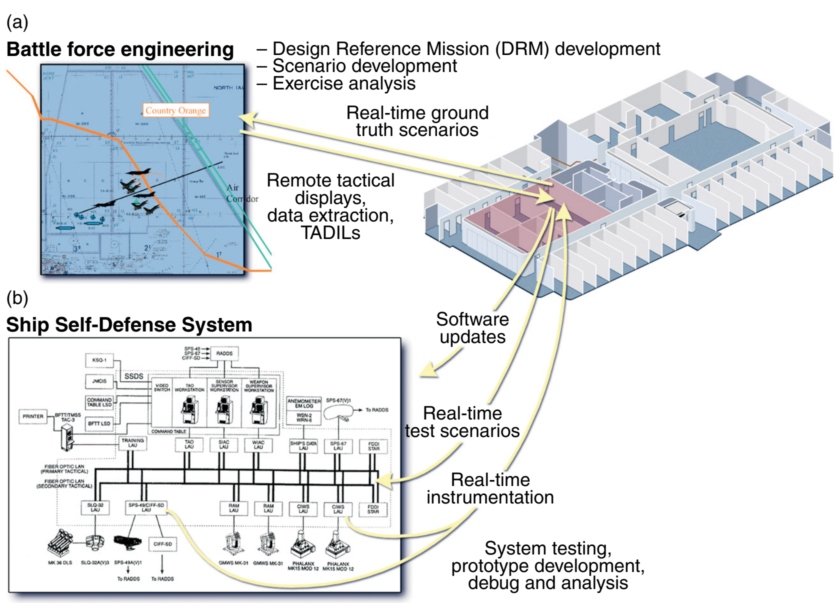

Figure 7. SCDL distributed engineering applications. (a) A battle force engineering application uses scenarios derived from a Design Reference Mission. SCDL creates scenario ground truth data and passes these data in real time to remote combat system sites. Data extracted in real time from sites are passed to SCDL for analysis. (b) For analysis of SSDS performance using HWIL elements, SCDL creates real-time test scenarios and receives data from instrumentation within the tested elements.

The subsequent Coral Talon II exercises conducted in February 2001 built on the Pacific Blitz BMC4I configuration by adding Theater Ballistic Missile Defense System Coordination Center software for displaying and analyzing data link messages in real time, and the Area Air Defense Commander three-dimensional Earth-view display software for improved, three-dimensional rendering of the test range data.

In January 2002, in support of the Flight Mission SM-3 test event, the Test Participation space received real-time video and voice communication from USS *Lake Erie* (CG 70) sent via the Pacific Missile Test Range. Shown in real time were the target launch from PMRF, the target's camera video, the SM-3 launch from *Lake Erie*, and infrared imagery from the kinetic warhead prior to intercept. Also shown were PMRF range displays (participant locations) and a virtual intercept using the system test bed at the missile prime contractor site in Tucson, Arizona. Further, telemetry from the missile was received on *Lake Erie*, and the telemetry along with *Lake Erie* Aegis Weapon Control System data were transmitted to APL, Tucson, and PMRF in real time via satellite relay.

FUTURE EVOLUTIONS

The Virtual Battle Force

Efforts are under way at APL to further leverage and extend the capabilities of the SCDL/WAL complex and network. Several APL business areas are developing an approach for the JWAD Force-on-Force Laboratory as a bridge between the SCDL and the WAL to model for the first time a battle force at the detailed model and simulation level. In the concept, each workstation will represent a combatant and will host the detailed models of that combatant. For example, each Aegis ship would be represented by one workstation with models of AN/SPY-1 Firm Track, SM-2 6-DOF, CEC, Tactical Tomahawk Weapon Control System, Tomahawk 6-DOF, etc. Terrestrial and space-based communications would be represented in workstations networked to the combatant workstations to represent battle force architecture. This virtual battle force would be the baseline force-level model product of SCDL activities and would represent force capability in certain types of WALEXs.

Extended Laboratory Facility Network

As new APL facilities are constructed, opportunities will develop to further leverage and contribute to the capabilities of the Building 26 SCDL/WAL complex in conjunction with other major facilities such as the Air Defense CSEL. In particular, a new building, Building 17, will house the business areas of Strike Warfare, Information Operations, and Defense Communications. Plans are already in place for the new facilities spanning these areas to network with the Building 26 complex to extend the SCDL/WAL into national and other theater warfare areas. We expect that as additional new APL-wide facilities are planned, they will be systems engineered into our new-generation engineering capabilities.

The National and Allied Engineering Community

As we are already beginning to observe for certain sponsored activities, our facilities will be increasingly integrated and used in conjunction with other government facilities to further our national large-scale engineering capabilities. As we begin a new century with advances in national defense presently beyond the horizons of our thinking, we stand ready to respond to the national need with advanced, collaborative, system-of-systems engineering with facilities such as the SCDL.

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