The Prototype Area Air Defense Commander Capability

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The Area Air Defense Commander (AADC) of a theater of operations has the responsibility of allocating and coordinating air defense assets to maximize their effectiveness in countering enemy air and ballistic missile attacks. Air defense must be planned and executed in environments wherein critical data elements and battle conditions change frequently and unexpectedly. As part of a continuing effort to give the commander the ability to generate plans and execute them in such environments, APL has built a prototype capability consisting of a set of integrated information management, analysis, collaboration, and display tools. These tools enable the AADC, for the first time, to develop and execute timely air defense plans that optimize theater combat power in a dynamic environment.

INTRODUCTION

The mission of the Area Air Defense Commander (AADC) is to protect defended assets (DAs) that are vital to theater operations against missiles and aircraft. DAs typically include airports, seaports, critical government installations, and concentrated civilian populations. These assets are selected, often in consultation with higher authority, by the Commander of the Joint Task Force (CJTF) and are assigned to the AADC to defend in a given priority order. The resultant product is a Defended Asset List (DAL).

Although the AADC is assigned air defense weapons to protect DAs, there is always a shortage of weapons, leaving more DAs than weapons available for defense. A capability was needed to develop plans that would provide efficient, effective, synergistic air defense solutions in an environment threatened by Theater Ballistic Missiles (TBMs), aircraft, and other offensive weapons, some of which could be weapons of mass destruction.

In developing the Theater Air Defense (TAD) solution, the air defense planner must digest a myriad of information pertaining to enemy weapons and their employment, friendly weapons and their employment, the physical area of each DA, and the priority of each DA for air defense. Laboriously building a TAD plan, which can take hours or days, will not suffice in today's dynamic, frequently changing environment. The new capability must produce, in minutes, solutions for various contingencies and phases of the campaign. During attack, this capability must also provide a real-time capability to audit the battlespace by assessing performance of the air battle and assigning friendly weapon engagements where shortages exist.

The Navy's requirement to initiate first-on-scene, integrated TAD has led to the development of a prototype AADC capability for evaluation in an Aegis cruiser and a command ship. This capability was developed at the direction of the Assistant Chief of Naval Operations for Surface Warfare (N86) and the Program Executive Office for Theater Surface Combatants (PEO(TSC)). Its principal goals are to

- Verify and refine requirements of the Operational Requirements Document
- Define engineering requirements for production
- Develop common tactics, techniques, and procedures in air defense and airspace management
- Develop new standards reflecting advanced technology
- Help in the development of Joint services architecture
- Help in defining hardware and software requirements for collaborative planning

THE PROTOTYPE AADC CAPABILITY

The prototype AADC capability optimizes air defense weapons system performance at the operational level of war. When appropriate, it also supports trade-off analysis at the tactical level of war. The prototype provides two capabilities:

1. Continuous, dynamic, synchronized, collaborative, wargamed, predictive TAD planning in an environment where critical data elements change frequently. The normal operational environment for the prototype AADC capability requires the capacity to simultaneously work variants to plans, develop multiple courses of action (COAs) for follow-on plans, develop long-range plans for all phases of the campaign, support component commander requests for information, and provide responses to the CJTF in support of optimizing the allocation of air defense assets throughout the theater. The AADC can produce TAD stationing plans within minutes, inside the enemy's decision cycle. This rapid planning capability is needed to generate products that enable collaboration of prospective plans with supporting air defense units, component commanders, and other organizations needed to execute an air defense plan.
2. Continuous, reliable visualization of the battlespace for unambiguous situational understanding to enable the AADC to audit the battlespace and execute real-time command and control as necessary. The real-time battlespace "picture" is fully comprehensible by all levels involved in decision making. This is accomplished by visualizing the operational picture in three dimensions, overlaid with an array of on-call visual aids (e.g., airspace coordination order, ballistic missile flight projections, surveillance contours) and supported by decision aids that help optimize engagement of the enemy.

These two capabilities are provided within the prototype in two separate manned spaces: a planning module and a current operations module.

THEATER AIR DEFENSE PLANNING

The air defense planning process involves the placement and coordination of friendly air defense assets in a theater of operations for defense against ballistic missile and air attacks. The prototype AADC capability is a set of tools used by air defense planners that enables, in minutes, the development of multiple, feasible air defense plans in response to a rapidly changing planning environment. Tools for plan generation, collaboration, evaluation, and analysis are embedded within the prototype. With this capability, the AADC staff can make informed decisions concerning the allocation of assets.

Manning

The prototype AADC planning module supports an air defense planning team consisting of 13 AADC staff officers: 5 planners; a head planner; a 3-person intelligence team; land, maritime, and air liaison officers; and an information manager. The head planner uses the guidance of the commander to task the planners in developing and evaluating COA alternatives. While the planners are continuously developing these alternatives, the intelligence team gathers information about the location and likely intentions of the enemy. New intelligence estimates are used by the planning team to develop COA alternatives responsive to the new threat. Information comes into the prototype via e-mail and voice, and through active collaboration of the liaison officers with the land, maritime, and air component commanders. This high volume of information is sorted and prioritized by the information manager, who ensures that data relevant to the AADC mission are communicated to the head planner. This particular manning configuration is the result of the Joint exercise experience of staff officers who have used the prototype at APL and at sea.

Planning Module

The planning module (Fig. 1) consists of a central conference table surrounded by five multipurpose planning consoles, a video-teleconferencing system, and a large-screen display. The head planner station at the head of the conference table has a pop-up LCD display and a pull-out keyboard to monitor and evaluate plan development by the staff. The head planner has control of the large-screen display, which can be used to show the planning console displays.

Each planning console is equipped with a 24-in. monitor, keyboard, mouse/trackball, STU-III secure phone, headset with microphone, and secure radio. A keyboard/video/mouse switch gives each console operator fully functional access to Silicon Graphics (SGI) workstations for planning, and general-purpose embedded PCs for other related tasks. This flexible equipment suite is necessary to give planners fast and easy access to

Figure 1. The prototype AADC planning module.

communications with land, maritime, and air component commanders, as well as intelligence sources, to maintain current awareness of the operational environment.

Planning Environment

The data elements needed to properly execute air defense planning reside in a plan database that defines the DAs, friendly air defense assets, and the likely positions and intentions of the enemy. The DAL is a prioritized list of DAs with specified levels of protection. The list, as noted previously, comes to the planning module from the CJTF and consists of units, cities, or geographic areas (e.g., air/sea ports, government installations) that must be defended against ballistic missile and air attacks.

The enemy order of battle (EOB) is a set of threats with associated geographic uncertainty areas characterizing the types of weapons available to the enemy and the likely numbers and locations of those weapons. In addition to needing the numbers and locations of enemy weapons, planners have to know the capabilities and intentions of the enemy to deliver those weapons. This is an enemy course of action (ECOA), and it includes raid-size limits characterizing the magnitude of attacks likely from each enemy threat to each DA.

To counter the enemy threat, the CJTF allocates defensive units to the AADC, which are entered as the friendly order of battle (FOB). The FOB includes Aegis ships with Area Air Warfare (AAW), Navy Area Defense (NAD) or Navy Theater Wide (NTW) capabilities; Patriot or Hawk battalions; Theater High Altitude Air Defense (THAAD) batteries; and various aircraft.

The COAs developed by the AADC staff must represent the current operational reality of the battlefield, where data elements can change frequently and unexpectedly. The DAL can come into the prototype as a formatted text message which can be parsed automatically, or via e-mail, voice, or any of the built-in collaboration tools. EOB and ECOA information is gathered by the AADC staff through its three-person intelligence cell via collaboration and electronic requests for information. FOB weapons loads and status are obtained through collaboration with the land, maritime, and air component commanders.

The breakthrough of the prototype AADC capability is the ability to assess the possible effects of new information in minutes as opposed to hours or days. For example, DAs may be added or removed, DA priorities may change, or level-of-protection requirements may vary. New intelligence estimates based on battle damage assessments or reports on enemy locations may affect the EOB. The ECOA may change when the battle escalates or when it is suspected that weapons of mass destruction will be used. When a critical data element changes, the prototype allows the AADC to respond quickly and to reallocate resources as appropriate.

Plan Generation

Once planning data have been acquired, plans can be generated automatically. The automatic planner reads in DAL, EOB, ECOA, and FOB data and produces stationing assignments of FOB assets to DAs and threats, optimizing theater combat power. DAs are covered by the automatic planner in priority order to the required raid size and probability of kill (P_k) specifications, while making maximum use of friendly assets without overcovering any DAs or threats. The automatic planner evaluates thousands of unit placement possibilities in parallel, solving the theater-wide optimization problem within minutes. Plan alternatives can be generated simultaneously from multiple workstations to account for multiple contingencies or varying theater conditions. The large number of plans generated can be evaluated and compared simultaneously through collaboration among Regional Air Defense Commanders, the CJTF, and others to produce the single most synergistic air defense plan possible in a short period of time. The rapid generation of air defense stations for a complex Joint operations area (JOA) is facilitated by a Cray-linked 24-processor SGI Origin 2000 server. This automatic planning tool uses parallel algorithms for asset allocation, coverage evaluation, and unit stationing against short- and medium-range TBM threats, air-breathing threats (ABT), and Anti-Ship Cruise Missile (ASCM) threats.

A distinguishing feature of the prototype automatic planner is its ability to generate areas of maneuver (AOMs) surrounding the optimal positions of friendly assets. An AOM for a unit is the set of stationing locations where the unit can achieve the desired level of protection on its assigned threats and DAs. The responsibility for handling the tactical details of stationing the unit is left to those who know the most about it—the commanders in the field. The AOMs are also assessed, in advance, through collaboration with the supporting commanders to validate stationing options and give movement-order warnings. This capability is key to producing a feasible plan that will be accepted by both the AADC supporting commanders and the CJTF.

The prototype AADC capability uses high-fidelity models of air defense sensors, weapons, and threats to provide the performance information needed to generate and evaluate friendly asset stations. Because the AADC functions at the operational level of war—synchronizing friendly forces throughout the theater across all phases of the Joint campaign—these models were produced to account for the effects of system configuration and operating environment in providing realistic predictions of air defense system performance. For example, terrain blockage for radars at all potential station locations is computed using elevation data based on Digital Terrain Elevation Data Level 1 produced by the National Imagery and Mapping Agency (NIMA).

The models in the prototype must provide performance results within fractions of a second to facilitate the quick generation of air defense plans. Consequently, friendly weapons performance models, such as the large and complex six-degree-of-freedom (6-DOF) models developed at the Laboratory for Standard Missile variants, have been run offline to generate time-of-flight and probability-of-kill tables for the full battlespace of each weapon against the short- and medium-range TBM, ASCM, and ABT threats contained in the prototype. Data from these tables are integrated with online output from sensor and weapon control system models to produce engagement performance predictions against any of the full set of air defense threats.

Stationing units capable of engaging TBM threats in the upper tier (i.e., Aegis NTW and THAAD units) and lower tier (i.e., Aegis NAD and Patriot units), or units capable of engaging ABT threats (i.e., Aegis AAW, Patriot, and Hawk units) involves a combination of a localized and theater-wide evaluation of thousands of potential locations in the JOA. This search is performed using the high-fidelity models of friendly and enemy weapons systems along with terrain data. It requires the computation of hundreds of weapons performance contours, several for each potential unit location. Sets of such locations that achieve similar coverage are intersected to form hundreds of candidate AOMs for each unit in the plan. Mathematical programming techniques[1] are used to choose the best AOM for each unit.

The planning techniques are formalized in a mathematical framework that accounts for the many different threat and unit types handled by the prototype. The numbers of different elements in any plan are defined as follows: P = number of air defense units, M = number of DAs, and R = number of threat areas.

These elements are referenced by index. For example, the plan contains unit 1 through unit P, DA 1 through DA M, and threat 1 through threat R. Instances of these items are referenced as unit p, DA m, and threat r, where it is assumed that p ranges from 1 to P, m ranges from 1 to M, and r ranges from 1 to R. The enemy attacks DA m from threat area r with a raid of magnitude t_{mr}. Of course, $t_{mr} \geq 0$, and if DA m is outside the geographic area that can be reached by threat r, then $t_{mr} = 0$.

The enemy has a limited capacity to simultaneously attack either a single DA or multiple DAs from either a single threat area or multiple threat areas. These limits are defined by the following inequalities:

$$\text{for every } m \text{ and } r,\ t_{mr} \leq E_{mr}\,, \tag{1}$$

$$\text{for every } m, \qquad \sum_r t_{mr} \leq D_m\,, \text{ and} \tag{2}$$

$$\text{for every } r, \qquad \sum_m t_{mr} \leq T_r\,. \tag{3}$$

The numbers E_{mr}, D_m, and T_r (for every m and r) come from intelligence data as part of the ECOA. Inequality 1 represents raid-size limits on threats going from individual threat areas to individual DAs. Inequality 2 represents raid-size limits on the total number of threats going simultaneously from all threat areas to the same DA. Inequality 3 represents raid-size limits on the total number of threats coming simultaneously from the same threat area and going to all DAs. An *admissible attack* is a set of $m \times r$ numbers $\{t_{mr}\}$ that satisfy inequities 1–3, representing a simultaneous attack of one or more DAs from one or more threat areas, within all specified enemy raid-size limits. An important feature of this threat characterization is that it does not specify the precise attack plan of the enemy, but rather a set of possible ECOAs. This gives air defense planners the flexibility necessary to define threat scenarios when the enemy's attack plan is not precisely known.

The automatic planner computes candidate AOMs for every unit in the plan by evaluating friendly weapons performance in the JOA. The number of candidate AOMs found for unit p is denoted N_p. The complete set of candidate AOMs (involving all units) is characterized by a binary-valued function $a(m, r, p, j)$, where j ranges from 1 through N_p. We set $a(m, r, p, j) = 1$ if unit p being inside AOM j implies that it would be able to engage (at the required probability of kill) the threat t_{mr}. In this case, we can expect that if the corresponding AOM is chosen for the unit and $t_{mr} > 0$, that is, if the enemy attacks DA m with threats from threat r, then unit p would be able to engage those threats. If the unit is unable to engage such threats when it is inside AOM j, then $a(m, r, p, j) = 0$.

Of course, more than one threat or DA may be involved in an attack, and more than one unit may be involved in the defense against the attack. Unit AOMs are therefore selected so that they complement each other, ensuring that threats are not overcovered at the expense of leaving other areas uncovered. To this end, we define another binary-valued function $x(p, j)$, which is an AOM *selecting function*. We set $x(p, j) = 1$ if the candidate AOM j of unit p is selected for the plan, and $x(p, j) = 0$ otherwise. Only one AOM can be selected for each unit, requiring for all p,

$$\sum_j x(p, j) \leq 1 . \quad (4)$$

The planning problem is to determine the function $x(p, j)$ (i.e., to select AOMs) to cover the threats and DAs in the plan.

For a given attack to be considered covered, unit capabilities must be assigned to the incoming threats in such a way that every threat is engaged to the required probability of kill. Unit capabilities are expressed in terms of a raid-size handling capacity U_p. The value of U_p depends on the unit's ability to sustain simultaneous engagements and on the weapons load of the unit (which comes from the FOB). Let $t = \{t_{mr}\}$ be any admissible attack. Let $s_t(p, m, r)$ be an integer-valued *assignment function* that specifies for the attack t how many engagements unit p assigns to t_{mr}. For the attack t to be covered by a particular selection of maneuver areas, this assignment function s_t must satisfy the following properties:

$$\text{for all } p, \sum_{j,m,r} s_t(p, m, r) \cdot x(p, j) \cdot a(m, r, p, j) \leq U_p, \quad \text{and} \quad (5)$$

$$\text{for all } m \text{ and } r, \sum_{p,j} s_t(p, m, r) \cdot x(p, j) \cdot a(m, r, p, j) \geq t_{mr} . \quad (6)$$

The term $x(p, j) \cdot a(m, r, p, j)$ is equal to 1 if and only if AOM j of unit p is selected and the unit can engage the threat t_{mr} while inside AOM j. The first of these two properties is the requirement that the total number of engagements assigned to threats by unit p does not exceed the unit's capability to simultaneously engage those threats. The second of these two properties is the requirement that there be a sufficient number of engagements assigned so that every threat is engaged.

For a specific attack t, the determination of the existence of an assignment function s_t that satisfies Eqs. 5 and 6 is equivalent to checking for the existence of a solution to a certain linear programming problem. Of course, in order for the DAs in a plan to be considered covered, *every* admissible attack must be covered. To accomplish this, the coverage evaluation module of the automatic planner runs hundreds of linear programs that estimate worst-case attack situations, comparing the results to the capabilities of units stationed to counter each attack according to Eqs. 5 and 6.

Additional factors that extend the model stated above are as follows:

- DAs must be covered in priority order.
- The raid sizes against clusters of DAs can be limited.
- A higher probability of kill can be achieved by assigning multiple engagements to the same target.
- Some units can simultaneously engage TBMs in the upper tier, TBMs in the lower tier, and ABTs.
- Partial area coverage of a DA is possible.
- Partial coverage of threat areas is possible.
- Probabilities of kill can be partially achieved.

Furthermore, the automatic planner characterizes (for every considered set of selected AOMs) the set of admissible attacks that are *not* covered. This information is used in a sequential algorithm that makes the final determination of the selected AOMs in the plan. Once the AOMs have been finalized, automated analysis provides a coverage summary that can be displayed on the planning workstation. These summary data account for the complete set of ECOA possibilities as defined in the EOB and ECOA, and they show the locations of areas of no coverage and areas of partial coverage. A quantitative analysis of the risk associated with a plan can then be produced with the wargaming tools embedded in the prototype AADC capability.

Wargaming

The wargaming tools provide Monte Carlo evaluations of a plan. The risk associated with a plan is based on the number of threats that are expected to leak through friendly defenses (i.e., *leakers*). Leaker statistics are acquired via a set of randomly generated threat scenarios selected from all admissible attacks. Threats are launched from randomly selected launch points within their defined threat areas and are flown along simulated trajectories to randomly selected impact points within the defended areas under attack. An optimum force-on-force engagement schedule that best achieves the required probability of kill against all threats simultaneously—all within the capabilities of friendly radar, launcher, illuminator, and missile systems—is continuously generated and executed throughout the simulated attacks. Defensive surface-to-air missiles (SAMs) are launched in accordance with the engagement schedules. When a threat intercept occurs, a kill or a miss event is randomly generated according to the probability of kill associated with the location and kinematics of the intercept.

The number of threats expected to leak through friendly air defenses is the primary wargaming result. For each DA, statistics on the number of threats flown, the number of SAMs fired, and the number of ABT, ASCM, and TBM leakers are indicated along with the reason for each leaker. A threat can leak through without ever being engaged if it impacts an uncovered portion of a DA, or if it is part of a mass raid that overwhelms the engagement capacity of friendly air defenses. A threat can also leak through because it is underengaged, i.e., the raid sizes are large enough to prevent sufficient missiles from being launched to achieve the required probability of kill. Of course, a fully engaged threat can also leak through since probability of kill is never 100%. This comprehensive leaker characterization is used by the decision maker to evaluate the risk associated with a plan.

The prototype provides graphical tools for comparing leaker statistics from multiple plans. An example of this comparison appears in Fig. 2. This visualization gives the decision maker the ability to rapidly understand differences among plans.

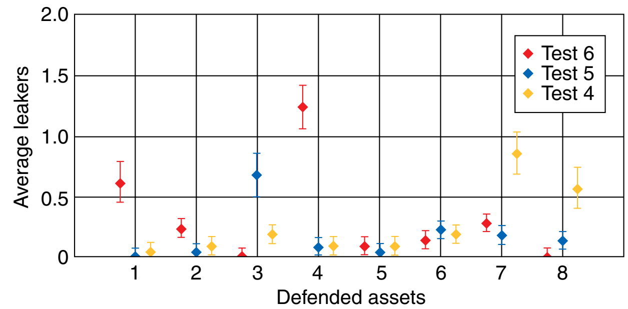

Figure 2. Wargame result comparison graph generated by the prototype AADC capability. Each of the three test plans being compared has eight DAs. The expected total number of leakers (TBM, ABT, and ASCM) is shown for each DA, with an associated confidence interval. (Average leakers per DA, ±1 σ.)

Collaboration

A crucial element of the plan generation process is continuous collaboration among the AADC planners and component commander planning staffs to ensure the feasibility of friendly unit mission and stationing options. Collaboration also links air defense planners in the theater, thus ensuring that all commands involved in the execution of a plan are also involved in the development of that plan.

Collaboration tools embedded in the prototype provide textual, graphical, and voice communications among planners and external sites over the Secret Internet Protocol Router Network (SIPRNET) using the COMPASS (Common Operational, Modeling, Planning, and Simulation Strategy) collaboration capability. An online chat capability is coupled to a graphical "whiteboard" that facilitates interactive screen image transfer and annotation for planners at remote locations. The prototype can also export geographically referenced plan items (e.g., threat areas, weapons performance contours, and AOMs) to an external site, where they are correctly located and drawn on the mapping system. SIPRNET voice is used with these tools to provide robust communications to computer users at external sites. An embedded Web browser is used to access SIPRNET Web sites for information relevant to AADC operations. The prototype AADC capability also maintains a Web site where planners can make their documents accessible to other activities.

AADC CURRENT OPERATIONS

AADC current operations involve a round-the-clock audit of the theater battlespace. Potential threats are constantly evaluated, and the performance of theater forces in protecting DAs is constantly assessed. During an air battle, weapon engagements may be assigned where shortages exist and duplicate or unnecessary engagement assignments may be negated. To support this, a continuous, reliable visualization of the battlespace is presented, driven by an integrated, real-time database of radar contacts or tracks from all contributing sensors in theater. Ideally, each actual aircraft in theater will be represented by one and only one track in the database. Additionally, each will be continuously evaluated for identification of intent (friendly, hostile, commercial, or unknown). The prototype AADC current operations module can accept these integrated battlespace data from a number of data links to produce the battlespace picture. Several decision aids are also available to support threat evaluation, performance assessment, and engagement activities.

Current Operations Module Manning

The current operations module is configured to support five officers: three watch-standers, a battle-watch captain, and the AADC. Experience in the field has confirmed that this is sufficient manpower to monitor and control a theater-wide battlespace, given a capability such as the prototype AADC to provide a single, integrated battlespace picture that is comprehensible by all decision makers. Though tasking responsibilities are determined by the commander in the field, it is envisioned that two watch-standers will be assigned as liaisons to Regional Air Defense Commanders in the theater while the third watch-stander will serve as the Joint Interface Control Officer (JICO). The JICO ensures that high-quality track data are entering the system through management of the data links and their contributors. The battle-watch captain and AADC maintain situational awareness over all regions in the theater and execute decentralized command and control as necessary.

The officers are supported by three consoles, a two-seated elevated battle-watch command dais, an HDTV projector that produces a large 8 × 4.5 ft depiction of the real-time battlespace, a large banner board for surfacing alerts, two smaller banner boards to indicate current weapons status of the regions, and status monitors that display friendly unit readiness and data link input quality. Figure 3 shows a typical operations module layout.

Each console of the prototype current operations module is driven by a two-processor SGI Onyx 2 workstation, and all are supported by SGI Origin 2000 servers for decision-aid processing. Consoles are equipped with a 28-in. HDTV monitor for display of the three-dimensional (3-D) real-time battlespace picture, a variable action button array for frequent or critical actions, a trackball, a spaceball (a 6-DOF input device) for 3-D view control, a microphone for speech recognition, a 14-in. LCD display for detailed actions and office applications, a secure telephone unit, and a secure radio set. The battle-watch command station is similarly equipped, except it uses the HDTV projector instead of a 28-in. monitor. The HDTV projector is equipped with a video switch that allows the battle-watch captain to show any of the four stations' 3-D displays on the large screen.

Display of the TAD Picture

The main component of the current operations module is the display of the battlespace. This display provides unambiguous situational understanding to decision makers at all levels, enabling them to monitor and control the battlespace as necessary. From information presented on the display, a commander can identify and evaluate potential threats and the friendly force's ability to counter them.[2]

The prototype AADC battlespace display offers an interactive 3-D perspective of sensor data overlaid with an array of on-call AAW visual aids. The representation closely resembles the external reality of aircraft, surface ships, and land-based units operating around the land masses of a theater, modified from a realistic rendering as needed to promote rapid comprehension of tactically relevant information (Fig. 4). With a spaceball, the user can navigate by directly manipulating the view to examine the representation from any position above the Earth's surface. As the user's view changes, the representation rapidly updates or animates, enhancing the sense of realism, control, and comprehension of spatial relationships in the battlespace.

Instead of using a traditional flat map projection, the prototype AADC display shows the Earth as a sphere

Figure 3. The prototype AADC current operations module.

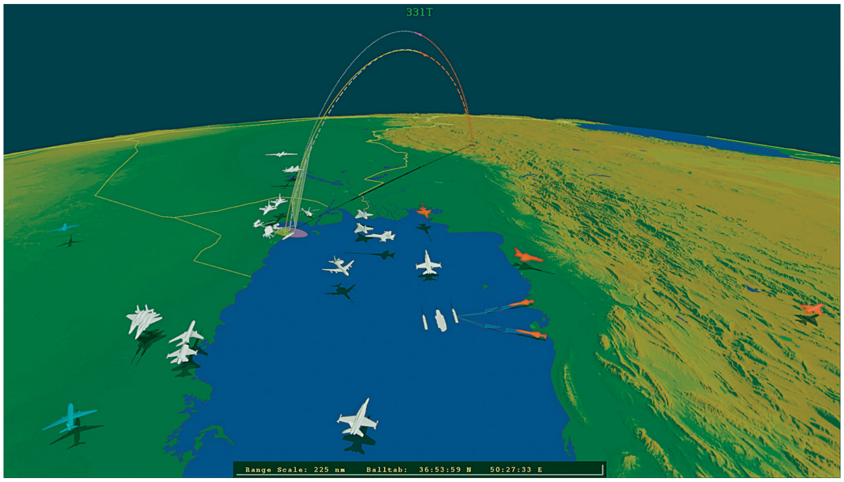

Figure 4. The prototype AADC capability's 3-D perspective display of the TAD picture.

with oceans and land masses. The land masses include graphical depictions of detailed coastlines, national boundaries, lakes, rivers, cities, commercial airways, and elevation terrain derived from the NIMA. Terrain is rendered as mountains and valleys on the Earth's surface. Airways (updated monthly) are presented as transparent strips overlaid on the Earth's surface and are invaluable in judging whether an air contact is a commercial airliner.

The prototype AADC current operations display shows air, maritime (or surface), and land contacts detected by force units using realistic 3-D icons that reflect the position and heading of the contacts in 3-D space. The contacts or tracks can originate from organic real-time sensors, satellite-based infrared sensors from the Defense Support Program (DSP), and sensors detecting electronic intelligence (ELINT) emissions. Real-time tracks are shown as solid objects to emphasize that their positions are based on hard data that are constantly updated. DSP and ELINT tracks are shown as transparent or ghostly objects to emphasize that their positions are estimated or based on dated information. The shape and color of each symbol denote tactical identification such as airliners, fighters, and tankers. The shape of friendly aircraft (e.g., whether a track is shown as an F-14 or an F-16) is further distinguished by automatically correlating real-time track information with missions in the air tasking order (ATO). The ATO is produced by the Joint Forces Air Component Commander and indicates when particular types of aircraft will be flying and what interrogation, friend or foe (IFF) codes they will respond with when interrogated. Track symbols are also drawn with a pitch to indicate whether an air contact is ascending, descending, or flying at a steady altitude. Each symbol has a corresponding shadow drawn with the appropriate shape and orientation. Rather than showing where a shadow from the Sun would fall, however, the shadow's placement indicates the track's "ground truth," that is, the position on the Earth's surface over which the track is flying. The distance between the shadow and the track supports coarse judgments and comparisons of track altitudes. Protruding from each shadow is a vector, called a velocity leader, which is a rough indicator of speed.

AAW visual aids that can be overlaid onto this picture by the prototype AADC capability include airspace coordination order (ACO) areas, ballistic missile fly-out projections, ongoing engagements of threats, and the current defensive counter air plan. ACO areas are specifications for the use of airspace for such factors as combat air patrol stations, carrier battle group operating areas, and minimum risk routes that are received textually in standard military message traffic. ACO messages are automatically parsed and the areas are depicted on the display as transparent volumes in 3-D space. TBMs are rendered as air tracks with the addition of estimated launch and impact points along with flight paths. All ongoing engagements of threats by friendly units reported on the data links are displayed as pairing lines between the threat and the shooter. The expected threats, the DAL, and the unit lay-downs and AOMs from the current defensive counter air plan can all be overlaid on the current track picture. The results of decision aids for threat evaluation, weapons assignment, performance assessment, and rapid replanning can also be overlaid graphically.

The high-level system architecture of the prototype AADC graphics display software supports the high-speed rendering of all these data. A multiprocessing computer system is used and the software elements are partitioned to allow simultaneous rendering, display object generation, and event handling. To maximize graphics throughput, idle time and processing time have been eliminated or reduced in the rendering process. By dividing display object generation among several processors and partitioning the resulting objects, the renderer can begin drawing data as objects become ready instead of waiting until all are available. Through the use of shared memory, communications paths from the data generation processes and the renderer have been removed, eliminating message interrupts and processing within the renderer. External event handling (e.g., spaceball actions) has been relegated to another process, further streamlining the renderer. The prototype AADC display generation design also supports fine-grained preemption of drawings to ensure adequate response to the decision maker. Fine-grained preemption lets the user interrupt the system while a scene is being drawn to allow immediate response to new commands.

Threat Evaluation and Weapons Assignment

In addition to the display of the theater air picture, the prototype also provides three decision aids for threat evaluation: threat ranking, alert conditions, and deep history. A theater air picture may consist of hundreds of air contacts. Successful threat evaluation is largely determined by knowing what to examine first. To cue the decision maker, the current operations module's threat-ranking decision aid periodically evaluates every real-time track. Every 4 s it develops a rank ordering of the top 20 tracks exhibiting the greatest likelihood for hostile intent. When developing the rank order, the threat-ranking algorithm evaluates track heading, speed versus range, closest point of approach, and speed versus altitude with respect to the DAs in the current active defensive counter air plan. Decision makers can bias this ranking by indicating that they want tracks located in specified geographic entities (e.g., a known chemical weapons site) to appear higher or lower in the rank order.

Another decision aid to cue the decision maker is the user specification of alert conditions. Each set of alert conditions delineates criteria that a track must satisfy for the generation of an alert message. Track characteristics that can be evaluated for alerts include identity, category, geographic location (e.g., an airway), range, closest point of approach, speed, altitude, attitude, and heading. Alert conditions can be used to detect both hostile situations and unwanted friendly actions such as the violation of airspace restrictions.

A large part of threat evaluation is knowing where an air contact originated and what it has done. A deep history capability within the prototype integrates data from unit sensors, the local combat system, and data links for a 1-h composite track history for every track. Each track's history indicates where and when all tactically significant events have occurred. History data are displayed as 3-D flight profiles trailing user-selected or "hooked" tracks on the 3-D battlespace picture. History trails consist of a series of dots, one for each track update received on a data link. Each dot is colored according to the track identity at the time of the update. When a track is dropped and then reacquired, the deep history aid is able to correlate the dropped track with the new track. The old history trail is combined with the new trail to form one continuous trail. Gaps in trails caused by gaps in radar detection data are filled in with 3-D splines of estimated flight paths. Trails may be annotated on the display with boxes of amplifying data for certain events such as which unit is responsible for an identity or track number change.

If, following a thorough threat evaluation, a decision maker deems an action necessary, the current operations module provides a trial engagement tool to aid in weapons assignment. The weapons assignment capability provides for theater-wide engagement planning of user-selected threats using a probability-of-intercept leveling algorithm. The algorithm surveys all available shooters in theater and computes a trial theater-level engagement strategy that assures at least a minimum cumulative probability of intercept against all user-selected threats concurrently, subject to time and equipment constraints. The minimum cumulative probability is dictated by the decision maker in the defensive counter air plan. The probabilities of intercept of an engagement strategy are calculated from models of weapon performance. The results of the computation are integrated graphically into the 3-D battlespace picture and are updated every second. The weapons assignment capability does not make any decisions about which threat tracks to engage, nor does it issue any force orders over the link to execute engagements. It presents only engagement recommendations to the user for threats that he has selected for engagement.

Performance Assessment and Rapid Replanning

The prototype AADC current operations module provides the decision maker with tools to assess the AAW capability of the theater assets to protect DAs against predicted threats. The same high-quality models used for performance prediction in the planning process are utilized in the prototype to display the predicted detection and engagement performance of actual units in theater at their current real-time locations. This aids the decision maker in assessing the adequacy and limitations of the current air defense plan and determining the impact of units not on station with respect to that plan.

Because things do not always go as planned, the current operations module includes a rapid replanning capability to support decision makers in adjusting air defense assets to counter unforeseen events. Equipment failures, schedule changes, shifting priorities, and casualties can all render the current air defense plan and any contingencies inadequate for the situation at hand. Immediate, near-term adjustments may be required while a new air defense plan is developed. The rapid replanning capability supports decision makers in making these near-term adjustments through a what-if decision aid. This aid allows decision makers to drag and drop units on the battlespace display and instantly view resulting detection and engagement performance predictions. Thus, near-term adjustments of the air defense plan can be made with the benefit of solid data.

INTEROPERABILITY

Even the best engineered system can be rendered useless if it cannot interoperate with the other systems in its environment. The prototype AADC capability was designed from the start to work effectively with a broad range of existing military systems and applications (Table 1). Further, it is extensible to operate with future systems and applications. The overall strategy was to assure that results could be rapidly and accurately disseminated throughout the command structure and that information developed and resident in existing systems could be seamlessly imported into the prototype.

The prototype AADC capability is interoperable in terms of communications, single integrated air picture, the Joint Planning Network (JPN), intelligence, collaboration, sensor/weapon capabilities, and missile warning. The prototype receives real-time tracks from available tactical digital information links (TADILs) and CEC (Cooperative Engagement Capability). The capability exists for force orders (e.g., assign weapons, break engagements, etc.) originating from the current operations module through decision-maker action to be sent out over the TADILs. DSP missile warnings and electronic intelligence information are received via an interface to a ship's Tactical Receive Equipment and Related Applications (TRAP) System.

The prototype also generates, receives, and automatically decodes U.S. Message Traffic (USMTF) messages. Message processing supports the automatic importation of air tasking and airspace orders as well as CJTF guidance. It also allows plan data to be easily distributed to other systems. Through these messages the prototype AADC capability interfaces with JPN applications such as the Joint Defensive Planner (JDP), Global Command and Control System (GCCS), Theater Battle Management Core System (TBMCS), and Contingency Theater Air Planning System (CTAPS).

Table 1. AADC interoperability.

AADC capabilities	Existing systems/applications
Communications	USMTF record traffic
	Tasking/mission/JFC guidance
	ATO/ACO/TACOPDAT
	JICO
	TADILs Link 11/16
	CEC via TADILs
Single integrated air picture	HDTV operational displays, battlespace visualization
	Identification
	NIMA DTED/world-wide/cities/topography
	Overlays/graphics/air routes/tactical areas
	JICO interaction
	Operator-defined alerts
	Replay
JPN	TBMCS/CTAPS (ATO/ACO)
	GCCS (operations area)
	JDP (TACOPDAT exchange)
Intelligence	EOB/ECOA
	RFI/EEI
	TRAP/GALE
Collaboration	SIPRNET/ISDN
	COMPASS, whiteboard, e-mail, Web with component commanders/liaison officers
Sensor/weapon capability	DSP/TADILs/CEC
	E2/E3
	Weapons sensor terrain masking
	Patriot/SM-2/SM-3
	THAAD
Missile warning	DSP

CONCLUSION

The prototype AADC capability gives decision makers a set of easy-to-use advanced tools for developing and executing air defense plans in a rapidly changing environment. The prototype has been installed at APL and in two ships, USS *Mount Whitney* (LCC 20) and USS *Shiloh* (CG 67). Through several Joint TAD exercises with participation by the prototype AADC cell at APL and at sea, the prototype functionality has been refined, taking into account feedback from staff officers. Its functionality has proven to be an invaluable tool for the AADC in performing his warfighting responsibilities. Use of the prototype has demonstrated that "computer-assisted planning not only provides a quantum leap in tactical-level planning capability, but also more importantly enables effective operational and strategic-level planning for all phases of an operation or campaign."[3] Additionally, it has been shown that "the clarity of the 3-D display in the operations module enables the watch officer to significantly reduce time spent gaining situational awareness and dramatically increases time spent on decision making, direction, and coordination."[3]

The baseline requirements for the prototype AADC capability have been defined and it is currently in transition to production. The installation of the first-production AADC capability is expected to occur in FY2005 as part of the Cruiser Conversion Program.

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ACKNOWLEDGMENTS: In addition to the authors, the prototype AADC team includes Timothy P. Boyle, John C. Briscoe, Mark E. Byrkit, Richard L. Cannon Jr., Daniel J. Christine, Jeffrey G. Cooley, LTG Marvin L. Covault USA (Ret), William C. Critchfield, Henry F. Dirks, Ed B. V. Doran, Maj Gen Lee Downer USAF (Ret), Marvin E. Drewry, John G. Elder, Kellie M. Etheridge, Fredrick R. Facemire, Nancy M. Finta, Russell W. Garrett, Janet M. Goodman, Craig Harris, Keith A. Hirt, Edgar G. Jacques, James R. Lamping, Gregory A. Miller, James T. Miller Jr., Francis W. Murray, Larry W. Nemsick, Hyon W. Park, Michael A. Pratscher, Robert D. Rein, John F. Ritter, Dale R. Shiflett, Michael A. Simeone, Johnnie M. Sims, ADM Leighton W. Smith USN (Ret), Mark A. Swana, James M. Tepe, David A. Wallace, Thomas Wienke, and Arthur N. Willoughby.

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