Tactical Decision Aid for CEC Engage on Remote

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The Cooperating Unit Position Planner is a planning tool developed for calculating cooperative Aegis engagements against low-elevation cruise missile threats where the shooting ship may not hold the threat with its onboard sensors. The tool allows operators to create scenarios with up to eight Aegis cruisers, view engageability regions in near–real time, and then refine the scenario to enhance coverage against a threat. Battle Group Commanders can then plan ship positions to take advantage of the Cooperative Engagement Capability's remote engagement potential. The tool integrates several existing models for remote engageability, atmospheric radar propagation, and firm track performance; combines them with an up-to-date intelligence database; and provides a graphical user interface embedded in the Common Display Kernel software package.

INTRODUCTION

The Cooperative Engagement Capability (CEC) provides revolutionary air defense capabilities to Navy surface warfighting platforms by distributing sensor, weapons, decision, and engagement data among battle group members.[1] CEC operational principles of composite tracking, precision cueing, and cooperative engagements result in significantly extended battle spaces and engagement zones. Composite tracking allows tracks to be formed and maintained more accurately by merging sensor data from many platforms. Precision cueing allows for earlier target acquisition by one sensor based on information from sensors on other ships. With cooperative engagements, a ship can engage and fire upon a threat using remote data from another ship, even if that firing ship does not see the threat with its local sensors.

CEC's ability to perform Aegis engagements using remote sensor data provides a unique, distributed weapon system capability. Because of CEC, a commander can alter ship placements to increase the battle group's effectiveness against threats and to better protect the battle group's assets. These ship placements may not be standard or conventional. For example, CEC-equipped ships, known as Cooperating Units (CUs), can be placed farther apart than non-CEC-equipped ships. To assist the Battle Group Command and Air Defense Coordinator in planning CU positions, we have developed a CU Position Planner that runs on a CEC display console in the combat system of CEC ships. Using this display, an operator can create experimental planning scenarios and, within a few seconds, can view the battle group's effectiveness in engaging threats using CEC.

Aboard Navy ships, the CEC interfaces with radars, other sensors, the combat system, and ship personnel, among many other assets. Interaction with ship personnel is accomplished via the CEC display system. Some CEC display functions may be integrated with an existing combat system display, such as the Advanced Display System aboard Aegis cruisers, or may reside in stand-alone computer systems (Fig. 1). In either case, the displays must allow the operators to interact with CEC and to perform necessary CEC functions. In addition, these displays abstract and digest voluminous amounts of data and present these data to the operators to assist in their decision-making processes. These display tools are collectively known as tactical decision aids. The CU Position Planner is one such aid.

The Planner brings together (both in real-time software and preprocessed data files) several existing tools, adds new capabilities for integrating and merging those tools, and provides an advanced graphical user interface (GUI). The existing tools include atmospheric propagation models for determining radar performance in evaporative ducting environments over the ocean's surface, the accredited high-fidelity APL-developed AN/SPY-1B radar simulation for predicting SPY performance against low-flying threats, and a cooperative engagement model for determining engageability against those threats when using remote data. The CU Position Planner does not attempt to predict engageability using local data, but instead predicts engageability when sensor data originate from a ship other than the shooter.

The Planner is currently installed and operational aboard USS *John F. Kennedy* (CV 67), *Eisenhower* (CVN 69), *Wasp* (LHD 1), *Cape St. George* (CG 71), *Anzio* (CG 68), *Hue City* (CG 66), and *Vicksburg* (CG 69), and at the Surface Combat Systems Center, Wallops Island, and the Naval Surface Warfare Center, Dam Neck.

Figure 1. A typical stand-alone CEC display system. Shown here is a Sun Ultra 1 workstation running in a CEC development laboratory at APL. Shipboard systems are similar, with a trackball replacing the mouse.

OVERVIEW

The CU Position Planner allows the operator to define battle group scenarios by interactively adding and positioning Aegis cruisers (the only CU type for which the tool currently works), selecting a specific threat, and establishing a defended point which the threat is attacking and the CUs are protecting. Clicking a button on the tool's GUI initiates the engageability calculations and, within a few seconds, displays regions where a successful engagement can occur. These regions indicate where the given threat can be engaged by some CU in the battle group using remote (non-local) data. The operator can then experimentally rearrange the CUs to enhance engageability.

The problem of determining engageability for the entire battle group is broken down into successively smaller problems, the results of which are recombined to provide the final answer. Battle group engageability is determined by calculating engageability for each individual CU in the scenario and then combining those results graphically on the display. In this way, each CU is given the opportunity to be the shooter; i.e., battle ground engageability E for N CUs can be expressed as the union of CU engageability E_i for all CUs:

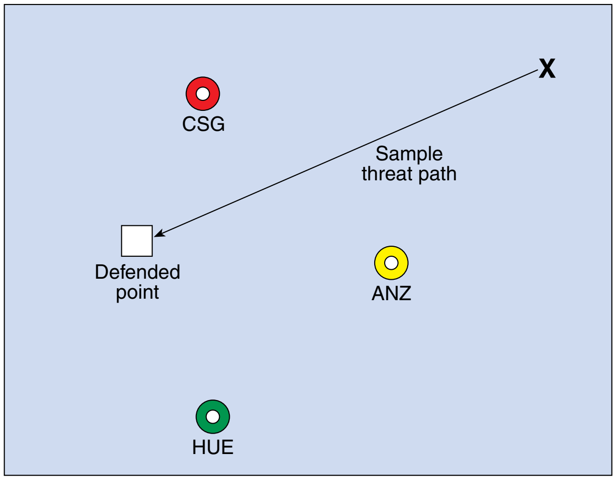
$$E = \bigcup_{i=1}^{N} E_i \ .$$

Individual CU engageability is further broken down by considering each of the other CUs in the scenario as remote data providers one at a time. That is, E_i can be defined as

$$E_i = \bigcup_{j=1}^{N} E_{ij} \ , j \neq i \ ,$$

where E_{ij} is engageability for CU_i shooting with remote data from CU_j. This approach can be seen in Fig. 2 in which three CUs—*Cape St. George* (CSG), *Anzio* (ANZ), and *Hue City* (HUE)— form the battle group scenario, which results in six individual engageability calculations.

For each shooter/provider pair, engageability is calculated throughout a 100 × 100 nmi square around the shooter and oriented toward the provider (Fig. 3). Points at 1-nmi increments are selected and tested for engageability, which results in 101 × 101 = 10,201 points tested for each pair. At each point a series of engageability tests is performed. If all tests pass, then the threat is



Individual engageability calculations		
Iteration	**Shooter**	**Provider**
1	CSG	ANZ
2	CSG	HUE
3	ANZ	CSG
4	ANZ	HUE
5	HUE	CSG
6	HUE	ANZ

Figure 2. Battle group engageability broken down into shooter/provider pairs. A sample scenario comprising three CUs, a defended point, and a nominal threat trajectory is shown. Engageability for the entire battle group is calculated by separately considering each CU as a shooter and, for each shooter, considering every other CU as a remote data provider, as shown in the accompanying table.

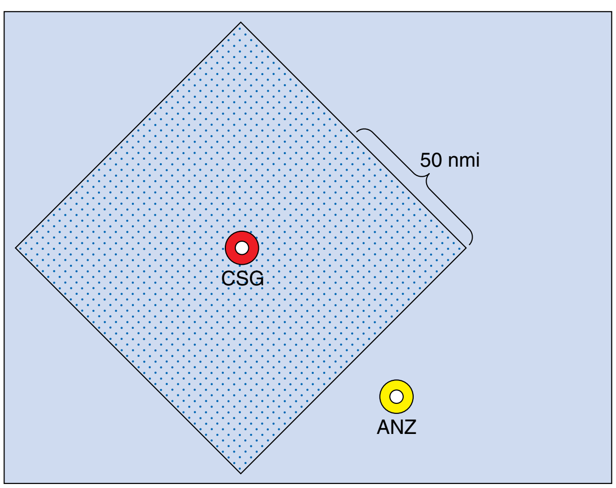


Figure 3. Sample points (spaced regularly every 1 nmi) in a sample region around a shooter. This represents iteration 1 from Fig. 2, with CSG shooting and ANZ providing remote data. An engageability calculation is performed at each point in the 100×100 nmi square around CSG. The sample region is oriented so that the provider is considered lying due east of the shooter.

said to be engageable at that point; if any one test fails, then the threat is determined to be not engageable at that point. These calculations take approximately 1 s per shooter/provider pair.

COMPONENTS

As battle group engageability is broken down into sets of smaller problems, engageability is eventually calculated at an individual sample point with a sequence of tests. These tests apply various radar and weapon system performance models, which are described here.

Firm Track

Because the CU Position Planner determines whether a shooting CU can successfully engage a threat when provided engagement support data from a remote CU, the remote data provider must be able to see the threat with its AN/SPY-1B radar. Output from APL's high-fidelity SPY firm track model is queried at each sample point to determine if in fact the threat can be seen by the data provider. A threat is said to be held in firm track if the radar has seen it several times and has identified it as a real object distinct from background clutter.

Before the CEC display software is delivered, the firm track model is run for a selected set of threats and results are stored into text files that are included with each software delivery. These files, queried at run time, are parameterized by threat type, atmospheric evaporative duct height (as specified by the operator), and the threat's cross-range distance from the providing CU. Cross-range distances, also known as closest points of approach (CPAs), are in 2-nmi increments. For each increment, two downrange distances are given that indicate where the threat will become firm track and where it will be dropped. It is between these two distances that the threat will be seen by the data provider's SPY radar.

A generic firm track table is depicted in Fig. 4a. The shaded regions indicate where the provider CU, which is in the center, will hold a threat in firm track for varying CPAs. Figure 4b illustrates how the firm track table is queried for a particular sample point. In this example, with CSG shooting on data provided by ANZ (iteration 1 from Fig. 2), the sample point in question is held as a firm track by ANZ. Thus, ANZ is able to support CSG's engagement.

Propagation

An engageability calculation at a sample point considers many factors, one of which is a determination of whether sufficient Aegis illuminator energy is received by Standard Missile-2 (SM-2). This illuminator energy is sent out by the shooting CU, reflected off the threat, and detected by SM-2. The CU Position Planner must determine how much of the illuminator energy can be seen by SM-2.

Illuminator energy is attenuated by several factors, including distance between shooter and threat, distance between threat and SM-2, and radar cross-section of the threat. Additionally, the energy can be both

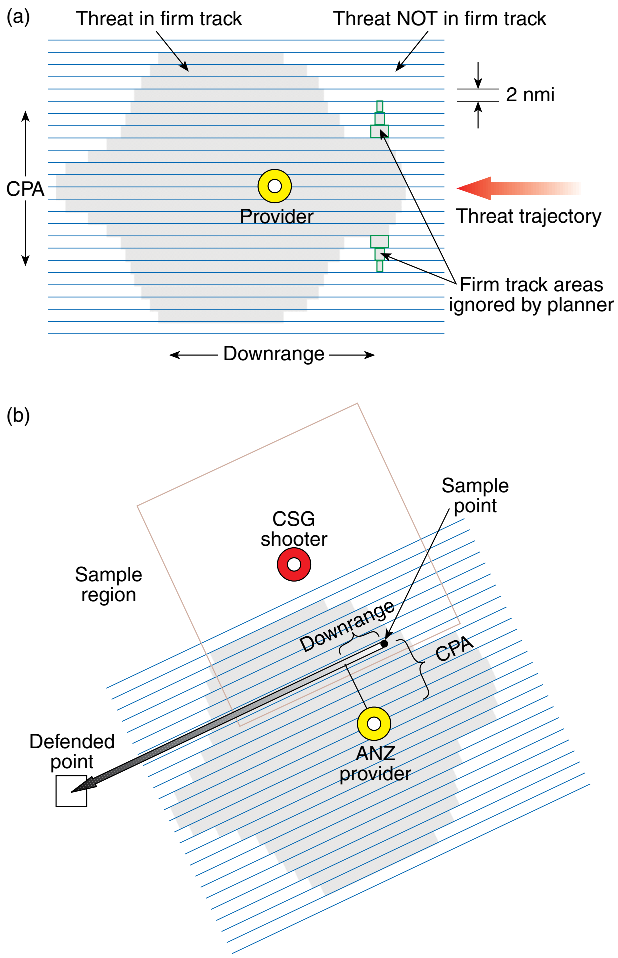


Figure 4. Firm track tables. (a) Generic table in which each shaded strip represents the area in which a threat, moving from right to left, is visible to the provider's radar. The actual table contains only the upper half, since the values are symmetric. (b) Table for ANZ with sample point in ANZ's firm track region. The sample region is shown around CSG, with one sample point highlighted. The table is reoriented for each sample point so that the strips are parallel to the threat's trajectory to the defended point.

weakened and strengthened at different points by propagation through the atmosphere near the ocean surface, as well as by reflections off the ocean surface. Output from the APL Tropospheric Electromagnetic Parabolic Equation Routine (TEMPER) radar propagation model[2] is used to determine this latter form of attenuation.

As with firm track data, TEMPER models are run for various atmospheric conditions, and the results are stored in text files and delivered with the CEC display software. The files are parameterized by threat altitude and the distance between the threat and the shooter's illuminator, and their values are queried at run time. Values in the files indicate whether the illuminator energy is increased (e.g., by constructive interference) or decreased (e.g., by destructive interference). Figure 5 provides a visualization of one such TEMPER propagation file.

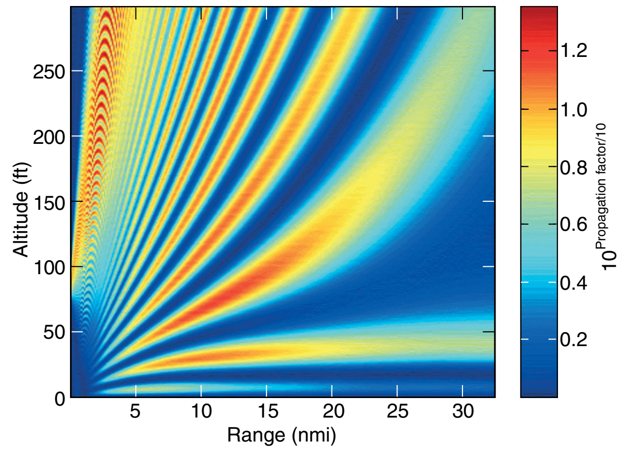


Figure 5. One-way propagation factor for a 22-m evaporative duct. This image illustrates how illuminator energy is both amplified and attenuated over the ocean surface. Note that the image is highly out of scale, with the vertical axis in feet and the horizontal axis in nautical miles.

Remote Engageability

The CU Position Planner does not attempt to determine engageability when the shooter is tracking the threat with its onboard radar systems. Instead, the tool's purpose is to show the user the enhanced engageability afforded by CEC when radar and sensor data are provided to the shooter from a remote Aegis cruiser. T. P. Nguyen of APL has described calculations that determine whether an individual sample point is engageable. A model that implements those calculations for remote engageability has been developed[3] using MATLAB (a commercial software package for mathematical numeric processing, visualization, and simulation). The MATLAB model was subsequently converted to C++ for integration into the CU Position Planner.

GRAPHICAL USER INTERFACE

The operator interacts with the CU Position Planner via its GUI (Fig. 6). The GUI allows the operator to enter environmental information, threat type and location, and anticipated operational area defined by the location of the defended point and the CUs constituting the battle group. As objects such as CUs are added to the scenario, they appear immediately in the display's Plan Position Indicator (PPI) window. Using the **Modify in PPI** buttons, the operator can reposition objects by simply clicking the mouse anywhere in the PPI. A special feature called **Get Real Time Position Data** can be used to automatically extract the positions of Aegis CUs and any aircraft carrier from the real-time data maintained by CEC. The **Save**…, **Restore**…, and **Delete**… buttons allow the user to maintain an archive of scenarios.

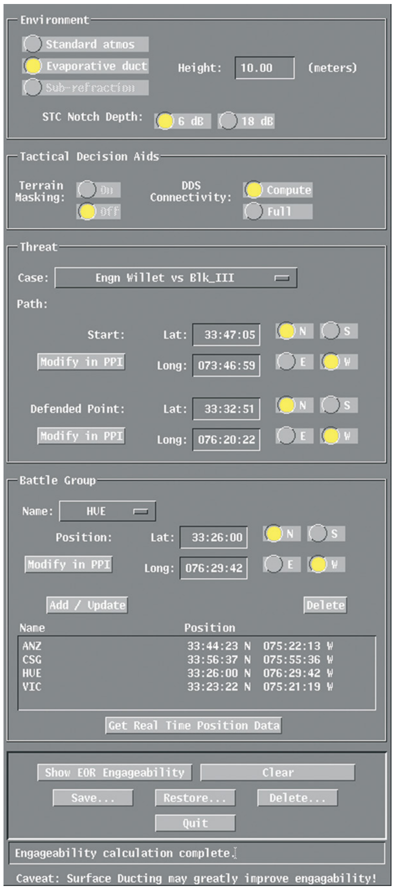


Figure 6. CU Position Planner graphical user interface.

INTEGRATION

The computer applications constituting the CU Position Planner are set up in a client/server paradigm. Figure 7 shows this architecture, in which circles are applications, rectangles represent UNIX shared memory segments, and arrows indicate general information flow. The GUI creates a scenario and stores it into a Common Display Kernel named buffer.[4] The server application, which performs the actual engageability calculations, reads the scenario with the assistance of a named buffer daemon (nbufd). The daemons provide access mechanisms for reading and writing named buffers transparently so that applications need not be concerned with whether a named buffer resides in local memory or in the memory of some other computer. (The server need not reside on the same computer as the GUI and PPI.) Results, stored as a sequence of latitude/longitude pairs indicating where an engagement against the user-specified threat will be successful, are stored onto the GUI's computer for processing and display in the PPI. The data generator application transforms the sequence of points (as well as other information from the scenario, such as CU positions) into a buffer of drawing instructions using the Graphical Entity Data (GED) language,[5,6] which is transferred to the PPI. The PPI application renders those drawing instructions as symbols and graphics into an X Windows display.

As the server breaks down the engageability problem into successively smaller steps, it eventually considers a single sample point (Fig. 3). A sequence of tests is performed on each sample point to determine if a threat can be successfully engaged at that point. The tests performed include

- Firm track, which tests whether the provider can see the threat (Fig. 4b)
- Illuminator accuracy, which checks to see if the shooter's illuminator can point at the threat with sufficient probability to support the engagement using the remote provider's data
- Illuminator power, which determines if there is sufficient illuminator power received at the SM-2 radome for the missile to successfully seek and engage
- Seeker accuracy, which determines if the SM-2 seeker can find the threat with sufficient probability for a successful engagement
- Doppler shift, which determines whether the SM-2 seeker will be able to distinguish the threat from background clutter

These tests are run in order. A sample point is said to be engageable if and only if all tests are completed successfully. If any test fails, the remaining tests are not performed, which saves on processing time.

As mentioned in the Components section, the CU Position Planner integrates a number of previously existing models and tools. The tools were designed independently by separate groups of engineers, and their outputs were not designed for integration into a single engageability tool. One problem resulting from this was the mixture of coordinate systems used by the various models. For example, firm track tables place the data provider CU at the

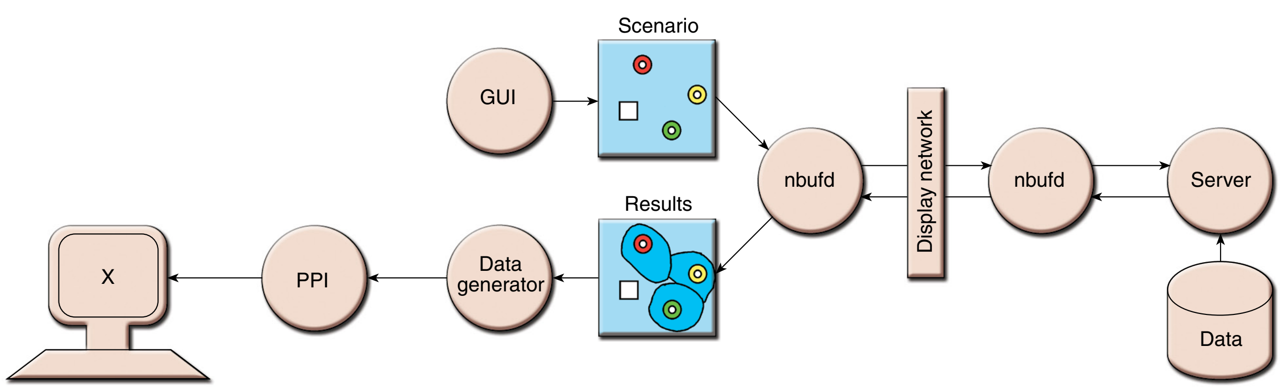


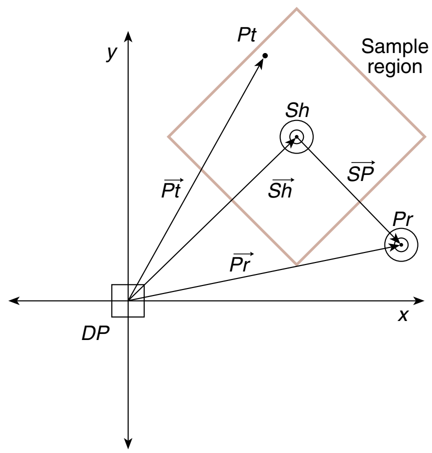
Figure 7. Applications constituting the CU Position Planner.

center, whereas the remote engageability MATLAB simulation locates the shooter in the center, with the data provider always positioned due east.

Rather than redesigning each tool to conform to a display-imposed coordinate system—a process that would have involved substantial risk—the CU Position Planner selects the location of the defended point as its center and converts sample points, shooters, providers, and other positions from that system to the coordinate system required by the various models.

The common coordinate system used by the Planner is shown in Fig. 8. Coordinates for engageability calculations for one sample point *Pt* for a particular shooter/provider pair are shown in Fig. 9. (Vectors from *Sh′* to *Pt′* and *Pr′* are defined in the usual way.)

For firm track calculations, the CPA and downrange for each sample point in the sample region must be calculated to determine if the sample point lies within the provider's firm track region. CPA and downrange calculations are shown in Fig. 10. CPA is simply the distance from the provider to the threat's trajectory. Downrange



DP = defended point at (0, 0),

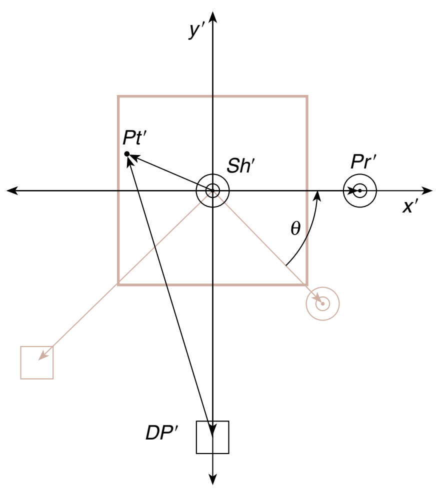
Pt = (x_{Pt}, y_{Pt}),

Sh = shooter's position (x_{Sh}, y_{Sh}),

Pr = provider's position (x_{Pr}, y_{Pr}), and

$\vec{Sh}$, $\vec{Pr}$, $\vec{SP}$, and $\vec{Pt}$ are two-dimensional vectors.

Figure 8. Common coordinate system with one engagement sample point *Pt*.



$\vec{i}$ = (1, 0),

θ = $\cos^{-1}(\vec{i} \cdot \vec{SP}/|\vec{SP}|)$,

θ = $-\theta$ if $y_{SP} < 0$,

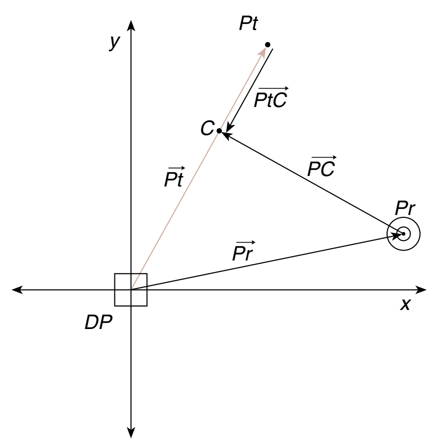
$\vec{DP}$ = $\mathrm{Rot}(-\vec{SP}, \theta)$, and

$\vec{Pt'}$ = $[(x\cos\theta - y\sin\theta), (x\sin\theta + y\cos\theta)] + \vec{Sh}$,

where

$\mathrm{Rot}[(x, y), \theta] = [(x\cos\theta + y\sin\theta), (x\sin\theta + y\cos\theta)]$.

Figure 9. Coordinate system for engageability calculations with the shooter at the center and the provider located due east. This system was chosen to match the remote engageability MATLAB model, which was originally designed with threats flying toward the shooter at the center.



$\vec{C}$ = $\mathrm{proj}(\vec{Pr}, \vec{Pt})$,

$\vec{PC}$ = $\vec{C} - \vec{Pr}$,

CPA = $|\vec{PC}|$,

$\vec{PtC}$ = $\vec{C} - \vec{Pt}$,

DR = $|\vec{PtC}|$,

S = $\vec{PtC} \cdot (-\vec{Pt})$, and

$$\text{downrange} = \begin{cases} DR \text{ if } S \geq 0, \\ -DR \text{ if } S < 0, \end{cases}$$

where

$\mathrm{proj}(\vec{A}, \vec{B})$ is the projection of $\vec{A}$ onto $\vec{B}$, and downrange values are positive if the threat is approaching CPA; negative if it has passed CPA.

Figure 10. Calculations for CPA and downrange for firm track determination. The CPA is the perpendicular distance from the data provider to the threat's trajectory. The downrange value indicates the threat's position relative to CPA. $\vec{PtC}$, the vector from the threat's current position to CPA, is slightly offset for clarity.

is the distance from the sample point to CPA. If downrange is positive, then the threat has not yet reached CPA; if negative, the threat has already passed CPA. Thus the calculated downrange value can be directly compared to the values in the firm track data table.

SAMPLE OUTPUT

Figure 11 shows an image of a CEC display PPI with results from a sample CU Position Planner scenario. The relative positions of the ships and defended point in this scenario are similar to those in Fig. 2, and the battle group has been placed off the coast of Puerto Rico. Threat, SPY, and SM-2 performance data are fictitious in the figure. Each white dot in the image represents a sample point that the tool has determined to be engageable.

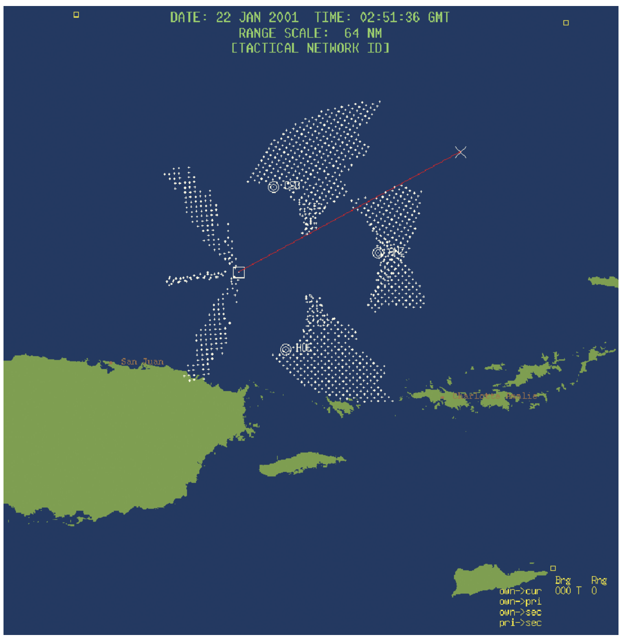


Figure 11. PPI image with sample scenario. CSG, ANZ, HUE, and the defended point are arranged similar to Fig. 2 off the coast of Puerto Rico. The white dots represent sample points that the tool has determined to be engageable.

FUTURE DIRECTIONS

Future engagement planning tools can build upon the CU Position Planner by overcoming many of its current limitations. New tools might allow for airborne CEC platforms (e.g., the E-2C) to act as data distribution system relays and to provide advanced track cueing. Other advances can be made in the area of greater threat coverage, in both breadth and depth. Deployed battle groups will require the addition of many more threats in the database as well as more robust and higher-fidelity data concerning those threats.

The tool's current design does not take into consideration the self-defense capabilities of CEC ships, or of other non-CEC ships in the battle group. Future work may involve integrating Planner capabilities with shipboard self-defense engagement capabilities to provide a fuller and more robust battle group engageability resource.

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