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VERTICAL-SENSING EFFECTIVENESS AND CONOPS TOOL FOR OPERATIONAL REQUIREMENTS (VECTOR) (PREPRINT)

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14. ABSTRACT
The ability to attain information superiority over an enemy and to quickly exploit it will be the core of the continued success of U.S. forces. Speed of command and decision-making will not only affect the outcome of future battles but drive the outcome of future battles. The Military Transformation Vision for the Department of Defense allows for an increased competitive advantage by creating future concepts of operation that will aid in the speed and effectiveness of defeating future enemy threats. At the core of the transformation vision is the Network Centric Warfare (NCW) concept of high quality shared awareness. NCW will better facilitate both the allocation and application of forces.

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Vertical-sensing Effectiveness and CONOPS Tool for Operational Requirements (VECTOR)

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BIOGRAPHY

Mr. James M. Catanzarite, Jr. is a Principal Engineer at General Dynamics (GD) in Dayton, Ohio and leads the Vertical-sensing Effectiveness and CONOPS Tool (VECTOR) team. He has over 8 years experience in the areas of airborne radar, signal and image processing, and modeling, simulation and analysis (MS&A). He earned his BEE from the University Of Dayton (UD) and his MSEE from Johns Hopkins University (JHU).

Mr. Gary Green is a Program Area Manager at GD in Dayton, Ohio in charge of Systems Analysis Programs within the Tactical Systems business area. He has over 20 years experience in MS&A primarily in the areas of GPS/Nav and combat ID, and is an original developer of the GPS Interference and Navigation Tool (GIANT). He earned his BEE from the University of Dayton and is a certified Project Management Professional (PMP).

Ms. Denice Jacobs is a Principle Electronics Engineer leading the Navigation Warfare (Navwar) in-house research team at the Sensors Directorate, Air Force Research Laboratory, Wright-Patterson AFB OH. She has been instrumental in the development of world-class M&S inventions, including the Antenna Wavefront Simulator (AWFS), GIANT, the Virtual Flight Test (VFT), AWFS Next Generation (ANG), and VECTOR.

ABSTRACT

The ability to attain information superiority over an enemy and to quickly exploit it will be the core of the continued success of U.S. forces. Speed of command and decision-making will not only affect the outcome of future battles but *drive* the outcome of future battles. The Military Transformation Vision for the Department of Defense allows for an increased competitive advantage by creating future concepts of operation that will aid in the speed and effectiveness of defeating future enemy threats. At the core of the transformation vision is the Network Centric Warfare (NCW) concept of high quality shared awareness. NCW will better facilitate both the allocation and application of forces.

General Dynamics, under the sponsorship of AFRL/SNR, have completed a series of studies that evaluate the impact of sensor and reference system information and accuracies upon warfighter effectiveness. These studies required a unique simulation methodology that has become, by design, a new M&S tool. This paper introduces this new tool called VECTOR. Consistent with the studies' methodologies, VECTOR leverages other simulations such as the Theater-wide Information Management SIMulation (TRIMSIM) for combining reference errors, GIANT for geometry, navigation errors and weapons effects, and the Global Architecture Combat ID Effectiveness Requirements (GLACIER) tool for the combat ID function. VECTOR considers all reference system position, velocity, attitude, frequency and time (PVAFT) parameters for the complete evaluation of the impact of them on NCW. With future planned upgrades, VECTOR will provide a user with the capability to evaluate and visualize all aspects of an NCW scenario: reference errors, ISR sensor errors, data links, combat ID, and pilot/operation decision rules.

NETWORK-CENTRIC WARFARE

Network-Centric Warfare (NCW) is the emerging concept of operations for the U.S. Armed Forces. It will provide a decisive warfighting advantage through the increased speed of command from timely and high quality shared awareness. NCW physically consists of the Global Information Grid (GiG) and data fusion algorithms. As a concept, it enables rapid warfighter decision-making and collaboration among the disparate platforms of all branches of the military. This collaboration not only leads to a quicker and more accurately executed kill chain, but also to a decisive information superiority gain over an enemy even before a war begins. NCW is a paradigm shift from present-day platform-centric operations to network-centric operations.

From Military Transformation: A Strategic Approach, the new rules governing warfare in the information age are: fight first for information superiority, noncontiguous operations (dispersed forces), deep sensor reach, and speed of command. Deep sensor reach and noncontiguous operations allow for time-sensitive and time-critical (TS/TC) targets to be quickly located and eliminated. NCW not only decreases kill chain prosecution time, but provides for the attack of targets that were heretofore not engaged. Through the sharing of targeting information, hit reports or BDA, intelligence, resources, and command, a competitive advantage can be gained, fewer resources expended, and the safety of our warfighters improved.

MOTIVATION

Our forces have evolved from dropping ballistic bombs, to man-in-the-loop (MITL) weapons, to GPS/INS (Global Position System/Inertial Navigation System) coupled munitions. These improvements have greatly improved upon the navigation component of munitions overall target miss distance error, which is comprised of navigation, target location (TLE), and guidance error components. Looking to the future of networked operations for the prosecution of TS/TC targets, target locations will be determined with sensors, permitting the quick tasking and retasking of aircraft in flight, and to the eventual transmission of target coordinates to munitions in flight.

In the 2003 timeframe, AFRL/SNR recognized the corresponding need for a mission tool to evaluate system-level & individual requirements and utility of:

- Position, velocity, attitude, frequency, and time (PVAFT) errors (reference, sensor, data link, terrain);
- Data links (connectivity, timing, content, fusion);
- NCW-enabled rules-of-engagement (ROE).

VECTOR

VECTOR

"Vertical-sensing" refers to the sensor-to-shooter process of find, fix, track, and target, which is also the F2T2 portion of the kill chain. It infers the expansion of horizontal integration from surface to space.

VECTOR is conceived as a repeatable constructive software simulation tool to:

- Evaluate C4ISR & evolving network-centric architectures and operations;
- Determine requirements, define performance, and evaluate utility for reference, correlation & sensor errors…singularly and in combination;
- Provide multi-level metrics...individual and system…for the determination of the dominant drivers and for traceability of cause and effect;
- Link technology, performance, and air-to-ground warfighter effectiveness to focus developments and support transition.

DEVELOPMENT APPROACH

The objective of our initial development approach was to have a tool working and being applied to a real program or problem, as soon as possible, with the minimum amount of resources expended. Methods for meeting these objectives included a focus on the overall architecture, an "apply while building" approach, and the use of existing codes.

The overall architecture was first developed to consider the requirements for the inclusion of sensor platforms (space, air, surface), munitions, targets, terrain, reference systems (PVAFT/PNT), sensors, data links, and pilot decisions iterated over time with variable time increments. A key to the architecture development at this step was to anticipate a design that would produce results that would not vary as a function of any artificial ordering of the entities within a scenario.

Available software codes were identified for immediate inclusion within the VECTOR architecture. Non-encompassing requirements included:

- Proven simulations (validated, verified, accredited);
- GOTS/COTS available;
- Source code access;
- Original developer availability.

The set of software codes utilized in the development of VECTOR Spiral 1 is shown in the figure below along with the primary source or developer sponsor.

The Theatre-wide Reference Information Management SIMulation (TRIMSIM) provided the algorithms for fusing PVAFT errors from multiple sources. The AFRL version of the GPS Interference and Navigation Tool (GIANT) provided the geometries, coordinate systems, Navigation (GPS/INS) algorithms, and weapons effects. It is noteworthy that VECTOR Spiral 1 will maintain full backwards compatibility with AFRL-GIANT, to include the current interface to the AFRL/SNR GPS Virtual Flight Test Facility. The Global Architecture Combat Identification Effectiveness and Requirements (GLACIER) tool provides CID algorithms. Satellite Toolkit provides an automated post-run scenario visualization capability through special user-selectable output files. The application of these existing codes shortened development times by years, and reduced costs by millions.

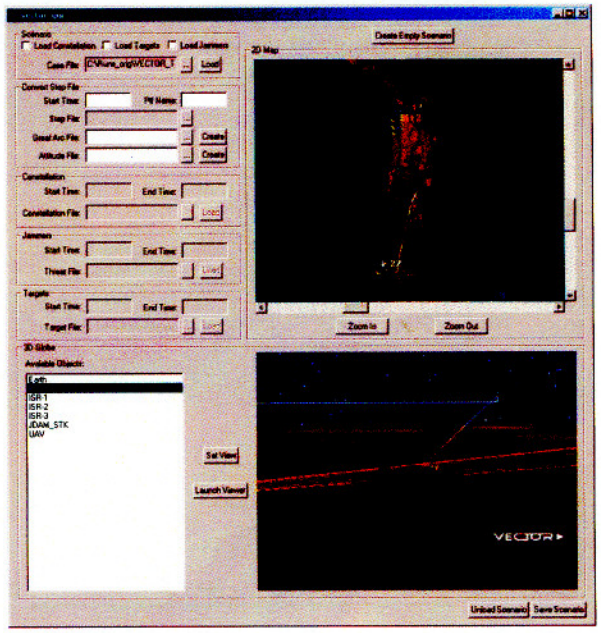
There remain several key functional areas for which existing source codes have not either been selected or candidates been identified. For future interfacing to the next generation GPS VFT, and to permit future VECTOR runs to include platforms whose routes are not preprogrammed in response to operation decision logic, a high rate and high fidelity flight generator (6 degrees of freedom) is required. Three candidates have been examined and we are very close to making a selection. The remaining needs include:

- Data links;
- Space-borne sensors (other than GPS);
- Other GNSS;
- Information Fusion;
- Sensor Management;
- Operator decision logic.

The authors would very much appreciate any feedback from readers (potential VECTOR team members?) who have or may be aware of codes that could be integrated to help fulfill the needs listed above.

VECTOR is designed to be an integrated system-of-systems simulation package. The software is modular and consists of "black box" modules interfaced by a data link. This architecture provides a robust way to model all types of network-centric systems from the simple to the very complex. The sensors included within the Spiral 1 version of VECTOR include: SAR, FLIR, GMTI/HRR, and several ESM types. These sensors are modeled very simply in terms of detection of track, and reference errors are inputs. However, GLACIER integration during CY07 will improve upon the combat ID fidelity, and higher fidelity detection and track modules can be easily added as required for the particular application.

Finally, with respect to the eventual release of VECTOR to other users. A GUI that interfaces both to the VECTOR input data base and for the control of the STK replay/visualization is under development. Initial development efforts have been in the area of STK visualization which will be included in Spiral 1. Front-end GUI development will occur in CY07. An example of the back end GUI for Spiral 1 is shown below.



GENERAL CAPABILITIES

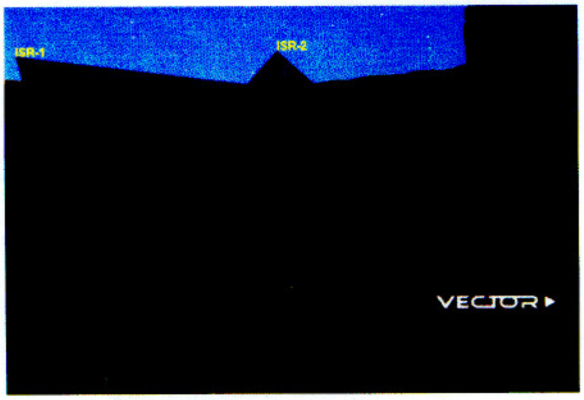
VECTOR's capabilities are summarized in the table below. Not all of the capabilities listed in the table have been fully implemented as of the date of this paper. We have a detailed Spiral release schedule beginning with Spiral 1, December 2006.

Multiple platforms & targets
Multiple sensors/platform
Surveillance & targeting Sensors
Intra/Inter Platform Data links
Reference Systems/Errors (PVAFT)
Target geolocation errors
Multiple Combat ID sensors
Warfighter decisions/rules for NCW
Variable time increment (< & > 1Hz)
RF environment visualization
GUI & Scenario Visualization

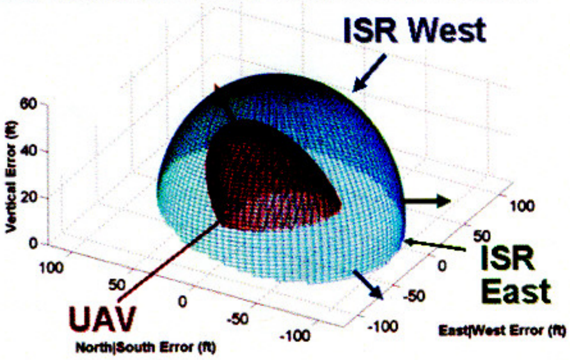
TARGET LOCATION ERROR (TLE)

A unique feature of VECTOR is its capability to dynamically calculate target location error from one or more sensors, from one or more platforms (i.e., locations), with the option to aggregate one or more of these time-stamped measurement sets over discrete multiple looks. As a function of timing, a particular instance of the TLE is utilized in the calculation of target miss distance at weapon impact.

VECTOR calculates two out of three target miss distance components: navigation and TLE; guidance error is a fixed input value. When a TLE is calculated within VECTOR, both the navigation error of the platform, the installation/pointing errors of the sensors, and the sensor's own innate measurement accuracies are combined to produce the 3-D TLE for that particular measurement. An example of a TLE calculated by the VECTOR engine and plotted in STK through our interface is shown in the figure.



In the example below, a user without STK who only has the VECTOR engine can still obtain the same information and plot with his own application such as Matlab, as is shown for a different scenario below.

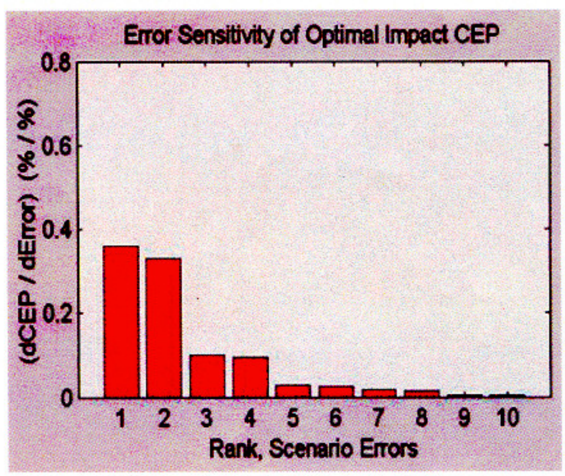


MULTI-LEVEL MEASURES

With the advent of NCW and connected and distributed system-of-systems operations, a new level of operational and performance measures is needed. The standard waterfall chart of engineering characteristics, platform/sensor/weapon performance, and mission/battle measures of effectiveness does not adequately capture the NCW measures. NCW introduces a new category of measures that fits in between platform/sensor/weapon measures of performance and mission or battle effectiveness.

NCW measures include all of the same platform/sensor/weapon performance measures as is appropriate, but instead of measuring individual performance, of which there are many of the same type, NCW is the single aggregate of the individual performance measures. For example, several different ID sensors on the same or different platforms have an individual target classification performance measure. At the NCW level, there is a single system-level classification performance measure. Furthermore, the NCW measure is more than just the fused answer because it also has an associated time component. There are also new measures at the NCW level to include, for example, speed of engaged targets, weapons utilization, platform utilization, rate of targets engaged, and etcetera. This concept of NCW measures is rather new and not yet firmly established within the VECTOR architecture at this time. However, as VECTOR develops, these measures will be included and evolve with research and practice.

One of the new NCW-level measures, provided by the capability brought to VECTOR by TRIMSIM, is the ability to statistically calculate and determine the individual performance parameters that are driving the overall answer. In the case of reference system errors, the chart below ranks the dominant errors within this particular scenario. In this example, this ranking is performed by determining the rate of change of the overall CEP with changes to each of the individual parameters. The highest ranked error parameter is that whose changes would cause the largest rate of change in the overall answer.

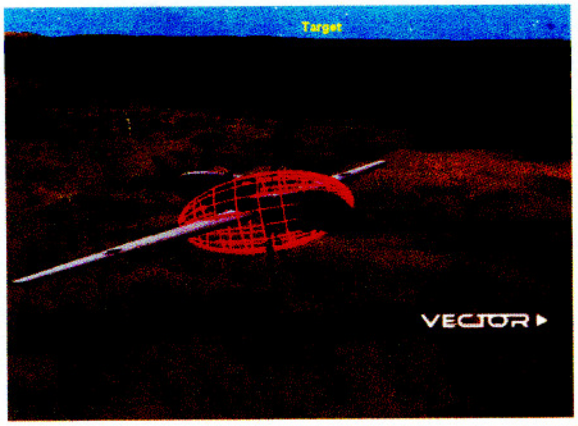


In addition to NCW measures, VECTOR includes a large set of output measures for each of its capabilities. In addition, as VECTOR includes munitions, target Pk and CEP are also one of several effectiveness measures provided.

STK INTERFACE

Application Graphics Incorporated (AGI) has a commercial software product, Satellite Toolkit (STK), which was purchased for interfacing to VECTOR's output. Through a developer version called STKx, AGI provides the ability to embed STK graphics & visualization tools into any mission application.

The development approach for VECTOR was not to *integrate* STK with VECTOR, but rather to *interface* STK and VECTOR. An automated scenario playback interface has been developed that permits the user to visual scenarios previously run with the VECTOR functional simulation engine. It is our intent to maintain this separation of the VECTOR functional engine from STK for many reasons, all of which boil down to user and developer cost, efficiency, and flexibility. As previously mentioned, a GUI was also developed to facilitate the user's control of this interface. A couple of screen shots of this interface in action are depicted in the figures.



APPLICATIONS

Several types of applications have been identified for the fully-implemented VECTOR simulation. Since the development of the original methodology in 2003, VECTOR and its preceding model methodology has been successfully applied to many programs and studies. In general, VECTOR applications include:

- Kill chain analyses for time-sensitive and time-critical targets;
- Conops/Tactics/Planning/ROEs for multi-spectral environs;
- Multi-reference sensor system requirements, deficiency and utility analyses;
- Battlespace access requirements, assessments, and impacts;
- Navwar EA-ES-EP for GPS jammer location and attrition;
- Network centric ISR performance evaluations.

SCHEDULE

A detailed VECTOR development schedule has been created in conjunction with AFRL/SNR based upon programs planned for the years to come along with current funding profiles. These upgrades are chronologically ordered by the need for VECTOR's application in support of these programs, and are bounded by the dependency of new capabilities on existing capabilities. Any upgrades listed below occurring in 2008 or later are subject to change or reordering, but at this time, the current plans through 2013 are summarized below. (The detailed plans can be obtained by one of the authors.) These plans can be modified or accelerated if there is another need within AFRL/SNR or another sponsor.

CY06 ➤	STKx Back-end Playback, Variable Time (Spiral 1)
CY07 ➤	Combat ID functionality & GUI
CY07/12 ➤	Upgrades to include: Data Links/Fusion fidelity, Pilot Decisions, Other SATNAV) & Documentation (GUI & STKx lag updates)
CY08,12 ➤	HITL interfaces
CY08-10,13 ➤	Release versions, documentation, training