Overview of TESS's Various Applications

Countermeasure Development Steps

TTI's primary mission is to provide software simulation products to the international EW community for conducting countermeasure development in National EW Operational Support Centers (EWOSC). The development of proven, effective and robust countermeasures in relation to specific threat weapons is a complex and multi-faceted process. It is a process that includes the following steps:

a) Developing detailed technical knowledge and the subsequent characterization of nationally designated threat weapon systems. This knowledge and characterization must focus not on the weapon's emitter characteristics, but rather on its tracking, guidance and control characteristics. The threat weapon knowledge that is acquired in this step is applied to the national threat characterization database.
b) Developing an understanding of the vulnerabilities of each threat weapon to potential countermeasures. This includes an understanding of the functionality of counter-countermeasure (protective) measures that the threat weapon possesses, some of which may be weapon operator adjustable.
c) Developing optimum countermeasure techniques and tactics in relation to specific threat weapons based on the capabilities of national operational countermeasure equipment and platforms in which the equipment is installed. The process of developing "optimum" countermeasures will depend on the availability and quality of national assets, knowledge, development tools and operator training.

Development Tools

Each of the above three primary steps is itself technically complex, requiring advanced technical training of the analysts who must be supported by appropriate analysis tools. The set of tools required for determining optimum countermeasures may include:

a) Threat weapon modeling tools;
b) Countermeasure dynamic engagement simulation tools;
c) Hardware-In-The-Loop test and evaluation laboratory facilities;
d) Test and training open air range facilities.

Step-by-Step Process

The determination of proven "optimum" countermeasures, suitable for deployment in operational countermeasure systems, requires a step-by-step process that proceeds from:

a) Basic concepts at the idea stage;
b) To execution of engagement simulations that preliminarily demonstrate robustness and effectiveness of countermeasure concepts and narrows the focus to specific techniques;

c) (Robust means relatively independent of attack engagement geometries and relatively insensitive to minor variations in weapon and countermeasure parameters);
d) To verifying that the robustness and effectiveness of the most promising countermeasure techniques (as determined in the dynamic simulation stage) remain robust and effective when tested in hardware-in-the-loop ECM laboratory test facilities;
e) To validating that the techniques remain effective and robust when programmed into operational (or perhaps developmental) countermeasure equipment that is installed on a platform and tested using free space propagation in an open range environment.
f) After each of the above steps is completed to the satisfaction and acceptance of both testing and operational staff, then the programming of this "optimum countermeasure" into the countermeasure equipments in relevant platforms for operational deployment can proceed.

Security

Since the first step of analyzing specific threat weapon systems is almost always classified and often national eyes only, there may be severe restrictions placed on the international release or exchange of this information. Every subsequent step in the determination of optimum countermeasures against that specific threat weapon tends to have similar severe restrictions placed upon it. Generally, the larger more technically advanced nations possess the means to carry out each of the development steps with the necessary assets in a fairly comprehensive manner. They tend to possess the required technical expertise, analysis tools and laboratory and range test facilities. However the smaller nations, in the absence of possessing the full set of such capabilities, face a very substantial challenge in their development of optimum countermeasures. TESS products now provide smaller nations with the capability to overcome this challenge.

TESS products address the security of classified information by offering simulations whose design is based only on open sources and by enabling the user to characterize specific systems using nationally controlled parameters. TTI's clients match the simulated systems to the real-world systems by loading parameters and characteristics that match those of the actual equipment and as obtained from national EW databases. TTI products also assist the client by determining default values for many of the required parameters.

The Application of TESS Products

The application of TTI's TESS products, in their various available formats, can provide enormous assistance in the development of optimum countermeasures including the following elements:

a) Training of analysts;
b) Conducting software simulation-based analyses;
c) Verifying and refining techniques through hardware-in-the-loop testing;
d) Validating the techniques through open air range testing;
e) Developing coordinated tactics;
f) Training operators to respond correctly to each threat weapon.

The way in which TESS products can make very significant contributions in each of the above areas is now addressed briefly.

Threat Weapon Analysis

Developing effective and robust countermeasures against a threat weapon system begins with an analyst understanding and characterizing that threat weapon. This threat weapon analysis is often carried out within a national intelligence organization. Depending on the size, structure and assets of that organization such threat weapon analysis may include exploiting (examining and testing) an actual weapon system or it may simply consist of studying whatever information is available on the system (including perhaps signal intercept data, manufacturer's information and photographs). In the US after the exploitation of select weapon systems the characterization of the systems is carried out using MATLAB®/Simulink® to build software models of each threat weapon. Characterization of threat weapons through Simulink® modeling is also used by TTI in its TESS products. The US program under which this threat software modeling activity occurs is called the Threat Modeling and Analysis Program (TMAPS). Within the DoD organization this program is executed by the Defense Intelligence Agency (DIA) and is supported by various intelligence agencies including the Missile and Space Intelligence Center (MSIC) and the National Air and Space Intelligence Center (NASIC). MSIC also manages the US's current Electronic Warfare Integrated Reprogramming Database (EWIRDB) which is a US national (non-communications) threat database. MSIC is also developing DoD's Next Generation EWIR System (NGES) which is a multi-media system, including not only data, but also photos, audio-video files, MATLAB® script, simulation models and graphs. NGES is planned to replace EWIRDB when it is populated with sufficient data.

TTI's Tactical Engagement Simulation Software may be thought of as an unclassified COTS analogy to TMAP, with the notable difference that TESS products are integrated threat vs platform dynamic engagement simulations. Hence, while TESS products include threat weapon models they also include models of target platforms, countermeasures and signal propagation and the dynamic behavior of these elements. The comparison of TESS products to TMAP and NGEW is re-enforced somewhat through TESS's use of EWIRDB's parameters, units of measure and definitions.

TESS products support the threat analysis process by providing a framework for the analyst to load known threat parameters and characteristics and then, through systematically adjusting other unknown or uncertain parameters, to achieve over-all system performance characteristics, (such as minimum and maximum detection and launch ranges) comparable to those that may be known for the weapon system. The TESS products also support threat analysis by computing a variety of perhaps otherwise unknown parameter values by using optimal control, electromagnetic and aerodynamic equations to compute suggested (default) values for a number of parameters.

ECM Analyst Training

TESS products can be applied to one-on-one or classroom training of students in the effects of countermeasures on sensors and the sensors' associated weapons. For the student analyst if a picture is worth a thousand words then a visual presentation of the dynamic interactions that occur between weapon and countermeasure in a dynamic closed-loop engagement is probably worth a thousand pictures.

COTS TESS products all contain scopes at numerous test points in the weapon system which provide for the student visual output traces of the most important weapon responses (such as weapon mode, power levels, tracking points, line of sight to the target and missile body lateral acceleration) as the engagement unfolds. The student can also add scopes as required to examine in detail the signal processing events that occur within systems or subsystems at any level within the weapon system hierarchy. TESS products are enormously powerful tools for assisting the student ECM analyst in visualizing the complex physics interactions that occur within the weapon system, interactions that may cause the weapon guidance to be disturbed by the countermeasure and lead to the survival of the attacked target. The students' developing such interaction insight is fundamental to his ability to subsequently develop optimum countermeasures.

<u>EW Operational Support and Countermeasure Development</u>

Optimum countermeasure development as carried out in a National EW Operational Support Center, (assuming availability of adequate national assets), may consist of three primary phases:

- Software Simulation
- Hardware-In-The-Loop Testing
- Open Air Range Testing

TESS's contribution to each of these phases is discussed briefly below:

Software Modeling and Simulation

Preliminary Identification of the most promising countermeasures in relation to each nationally identified threat weapon occurs in the software modeling and simulation phase. With virtually an infinite number of possible combinations of engagement geometries, countermeasure techniques and parameter selection, technique sequencing, tactics and timings, the identification of the most robust and effective countermeasures requires the execution of thousands if not tens of thousands of simulation batch runs. Only software simulation is affordable for the collection of such volumes of effectiveness results. Through the execution of such batch runs, statistically significant sets of effectiveness data can be collected to support the preliminary identification of the most effective and robust countermeasures. In this context effectiveness is taken to mean those conditions under which the targeted platform survived the weapon attack. Such survival is determined only by dynamic closed-loop engagement simulations which realistically reflect the characteristics of the weapon system of concern. Since the application of countermeasures against the weapon systems normally causes that system to operate in its regions of non-linear performance it is fundamentally important that the simulations possess the important system non-linear characteristics. Such non-linear characteristics may include electronic ones like saturating amplifiers, "s-shaped" tracking discriminators and sensor mode switching, or mechanical non-linearities like steering surface and antenna gimbal limits.

TESS products have been designed specifically to include the weapon's non-linearities and to also include an integrated batch running capability in which any of the parameters in any of the interacting systems can be varied either randomly or incrementally. Simulation runs can be either deterministic or stochastic. TESS products also include the capability of automatically generating polar plots showing engagement geometry regions of countermeasure effectiveness. Through the collection of thousands of effectiveness plots the most effective and robust of the countermeasure techniques and parameter combinations against a weapon system can be identified. Such batch runs should be executed for each of the nationally identified priority threat weapons. It is noteworthy perhaps that the ECM analyst who has received primary countermeasure effectiveness training using TESS in its training mode will be pre-conditioned to produce effectiveness results quickly and efficiently.

Only after the most promising countermeasure technique and parameter combinations have been identified is it sensible to move forward to the next phase of countermeasure development, that of Hardware-In-The-Loop Testing

<u>**Hardware-In-The-Loop ECM/ECCM Testing**</u>

Having identified the most promising ECM technique and parameter combinations using software simulation it is normally considered an important verification step to then use those combinations in a Hardware-In-The-Loop Test (HWIL) facility. Such a facility may involve an operational jamming system that is interfaced at microwave frequencies, perhaps in an anechoic chamber radiation facility or through direct signal injection, with either an operational or a hardware simulated threat sensor system. The interface would require the use of computer controllable microwave instrumentation (normally using digital rf memory technology) to generate target return signals, propagation (range) delay, Doppler shift, clutter signals and other phenomena like chaff cloud return signals. The cost of running such test facilities is normally several orders of magnitude greater than that of running software simulations. Hence, HWIL testing is normally carried out on only the most promising of the effective, robust countermeasures.

The role of TESS products in such hardware in the loop testing is, at minimum, to control the engagement geometry, the target and chaff signatures and the target maneuvers and to also execute the virtual firing of the weapon (missile or gun). This control and execution would be carried out at microwave frequencies using computer controllable ECM and radar signal DRFM-based instruments. Since the engagement would occur in real time the TESS simulation is made to run in real time by compiling it in its entirety and perhaps distributing the simulation over several computers.

TESS not only dynamically controls the test instrument hardware (programmable radar and target signal generation), executing the virtual weapon firing, but simultaneously runs the same entire closed-loop engagement (including software simulated weapon system, target platform, countermeasure and environment) entirely in software. With this parallel hardware and software closed loop configuration results can be cross checked, test-point by test-point, for consistency, verification and validation purposes.

Open Air Range Testing and Training

Subsequent to successful hardware-in-the-loop testing the most effective and robust countermeasures may be transitioned to testing in an open air range test facility in which those countermeasures are programmed into operational (of perhaps developmental) countermeasure equipment that is installed in service or test aircraft (or other target platform in the land and sea environments). The assets on the open range would include high power radiating threat emitters with appropriately responsive receiving systems, target position measuring equipment (such as air combat maneuvering instrumentation) and a data network which interfaces such range systems into a command and control area which houses TESS simulations. As the target platform executes maneuvers on the range, such maneuvers are replicated in the TESS simulation. Similarly countermeasure occurrences such as the deployment of chaff or the generation of jamming signals are replicated in the TESS simulation. The trial director may from time to time fire virtual weapons in the TESS simulation and the trajectory of the weapon is generated as a result of the closed-loop dynamic interaction between the weapon's guidance and/or homing system, the target, its maneuvers, its countermeasures and the aerodynamic/kinematic responsiveness of the weapon in flight. In this open range test phase, the primary objective of the testing is to validate that the countermeasures identified as the most effective and robust remain so in the open range environment. The demonstration of effectiveness is determined ultimately by the weapon missing its selected target by sufficient distance that the target survives the engagement (or at least most engagements in most engagement geometries).

Clearly open range testing with the greater cost of assets and range personnel is substantially more costly than laboratory hardware-in-the-loop testing which is, in turn, substantially more costly than software simulation testing. Hence at each stage of increasing cost, fewer and fewer tests are feasible and affordable. The greatest amount of knowledge acquisition occurs in the modeling and simulation phase. Subsequent phases provide successive concentration and focus on fewer techniques and are primarily for verification and validation.

The assets that are used for open range testing may be similar to those used for the training of the target platform and countermeasure operators. These training facilities may be somewhat less heavily instrumented and at the end of each training session the operators must be debriefed on the major events that occurred during a training mission. This would require storage of the most relevant data associated with each training mission and the automatic generation of a debriefing report.

The Surface Threat Electronic Warfare System (STEWS) at Canadian Forces Base Cold Lake demonstrates the use of TESS products replicating in simulation the dynamic interaction of threat weapons and target platforms with countermeasures and tactics in an open range training environment. The TESS products in STEWS are run in real time on a distributed computing system. After each training mission a debriefing report is automatically generated. Also, the missions can be replayed in slower time and in freeze frame modes for the detailed debriefing of the operators.

Class Room Operator Training

The proven use of TESS products that are run in real time in distributed simulation systems now makes feasible the use of "physics-based" simulations for operator training. The key element of this use of TESS is that operators can now receive computer-based training that is based on physics interactions between systems rather than previous, sometimes unrealistic, "effects-based" system interactions. The previous synthetic environment simulations used in operator training, in order to run in real time and to also provide realistic "virtual reality" visualization for the operator, did not run a physics based model that included key non-linear elements. Rather they provided a synthetic simplification of interactions based of the simulation's programmer's perception of likely input/output effects. Such previous programming approaches, which were often rules-based, and in which the rules may not be valid for all engagement conditions, may give rise to unrealistic or even incorrect training experiences for the operator.

The TESS-based classroom operator training system is entirely computer based with each training station's display configured to replicate with controls and graphics the system on which the operator is being trained. As with the COTS TESS products the system would be delivered with representative unclassified parameters. The user would enter specific parameters and characteristics to match those of the specific system on which the operator is being trained.

In a multi-station classroom the training could be structured so that an instructor sets up training engagements that may or may not be the same for all students. In this structure the students would be working against pre-scripted scenarios and their reaction to and interaction with those scenarios would be recorded for subsequent playback and debriefing.

In another two student interactive structure, at a more senior training level, a weapon operator may control his weapon's ECCM's, guidance and weapon firing in reaction to a target platform operator who, may be generating countermeasures and executing maneuvers in an effort to nullify the efforts of the weapon operator.

The distributed computer configuration would be somewhat more complex, allowing for "m" weapons to be applied against "n" targets, but the system simulation software would be based on COTS TESS products made to run in real time on a distributed computer system.