Jammer Testing And Chaos

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Background

The developmental and operational testing of the effectiveness of electronic countermeasure equipment against specific weapon systems appears to have a somewhat chaotic history.

In describing the testing of the AN/ALQ-131 jammer, under the heading "Band 3 Ineffective Against Some Threats", GAO Report /NSIAD-1995-47, said: "Developmental testing conducted after the Band 3 entered production has shown that the system has serious performance problems. New, but preliminary, test results compiled after the draft of this report was prepared indicate some improvement in performance; however, significant problems persist."

The test performance of the AN/ALQ-165 (ASPJ) jammer also is not without effectiveness testing problems. The DOT&E FY 1996 Annual Report says: "DOT&E cannot certify that the ASPJ is effective against the original ASPJ requirement." And "Key performance criteria for effectiveness and suitability were not met and the FSD systems were not considered production representative." The report went on to say: "DOT&E assessed the ASPJ as not operationally effective because it did not meet the requirement threshold value for increasing the survivability, in robust multi-threat mission scenarios, of an ASPJ equipped F/A-18 strike force over that of a non-ASPJ baseline F/A-18 strike force."

Since these results were reported (and post-dating the issuing of the DoD Test And Evaluation Process For Electronic Warfare Systems, from the Director, Test, Systems Engineering And Evaluation, of 13 June 1994) a number of initiatives have been taken to develop software tools to assist decision makers to gain insight into the importance of a given EW requirement, and how changing the requirement will impact EW performance and consequently the warfighter's effectiveness.

One such tool, the EW MOE (Measures Of Effectiveness) Tool, developed with SAFAQ/AQPE support, is intended to provide access to data for performing EW system deficiency and requirements analyses. The EW MOE Tool uses data provided by government models, such as ESAMS, and EW contractor engagement models, tied to system specific digital system models and even to test range data. The tool is described as enabling the EW decision maker to gain valuable insight into the importance of a given EW requirement, and how changing the requirement will impact EW performance and consequently the warfighter's effectiveness.

The EW MOE Analysis Workstation is a data-driven effects analysis tool as opposed to a physics-based simulation tool. Effects analysis implies sensitivity and cost/performance types of analyses using various specific sets of input data and assumptions. Such data may be from models,

Measures Of Effectiveness

simulations, hardware-in-the-loop testing and open air testing. Physics-based simulation implies computer models containing mathematical representations of a system whose behavior is based on physics. Such simulations may be the sources for input data used in effects analysis tools.

Simulation, Test and Evaluation

It may be observed that a number of issues and program initiatives, including Developmental and Operational T&E procedures, and Simulation Based Acquisition, each impinge on the primary concern of gaining consistently testable effectiveness results from jamming equipment in development, test and operational use.

In addressing this merging of M&S and T&E issues the Joint Advanced Distributed Simulation (JADS) EW Test Team was mandated to determine if Advanced Distributed Simulation could help the EW community resolve several interrelated testing process issues.

The first issue of concern to the JADS EW Test Team was that of the correlation of test results for ECM systems that are under test across the modeling and simulation, hardware-in-the-loop (HITL), and open-air test regimes. This concern would appear to be related to validating software simulations in relation to hardware performance as measured in HITL and open-air tests. An absence of results correlation may imply, among other factors, that the software model is not valid, that some elements of the HWIL simulation are not valid or that input data and test results in all three test domains were not complete or not sufficiently accurate.

The second issue of concern to the JADS EW Test Team was that of model and simulation fidelity. Adequate fidelity implies that the software simulation is a reasonably good match to the hardware that it is simulating. The absence of an adequate match between hardware and software may give rise to uncorrelatable or widely varying test results, particularly if the software simulation does not model key portions of the hardware in sufficient detail. Such absence of correlatable output results may also result from a mismatch between the parameter values loaded in the simulation. There remains, however, the outstanding issue of identifying the key parameters and subsystems of the hardware that affect over-all system performance and ECM response.

Of fundamental importance to the JADS EW Test design was the statistical correlation of EW measures of performance (MOP) across the test phases. JADS found generally poor correlation between the test results taken in the three domains despite their attempts to limit variance sources. They observed that the primary variance source for most measures was operator action. JADS found wide variances in the test results even when threat operator actions were constrained to a fixed set of allowable actions.

JADS' observed that their "inability to execute a test that sufficiently removed operator variance from the test casts a shadow on the EW community's ability to make statistical analysis a feasible aid for decision makers faced with determining the worth of systems designed to work against human operators." Measures such as jamming-to-signal ratio and tracking error that produce thousands of samples were reported to make the problem worse. The statistics test used was found to produce no useful comparisons for that many samples making the test useless for those two measures.

Countermeasure Success Criteria

The success or failure of deception countermeasures in dynamic engagements with threat tracking radars can be traced primarily to the relative influence of the jamming signal and the target return signal on the radar's tracking when both signals are simultaneously present within one or more of the radar's tracking discriminators. In simple terms the tracking discriminators (in angle, range and/or Doppler) are the components in the radar that continuously adjust the position of the radar's tracking cell (normally under servo control) to keep it positioned over the selected target (which may be a deception signal). This target tracking data is, in turn, used by the threat radar to control or command the missile or gun system.

A primary and fundamental property of discriminators is that they possess very non-linear input-to-output characteristics. Furthermore, when faced with two simultaneous signals a discriminator's characteristic distorts even further.

Tracking discriminators are, in most weapon designs, an integral part of servo controlled tracking loops that are themselves modeled by differential equations. Therefore a simulation that adequately models the interaction between deception countermeasure and threat tracking radar inherently must include a number of non-linear differential equations to provide a reasonably accurate description of the radar.

The simple observation that an adequate simulation of a threat radar should, to attain adequate fidelity, be modeled with non-linear differential equations may have profound consequences on the correlation between software simulation results and hardware test results. One basic property of non-linear differential equations is that they exhibit what has come to be referred to often as "chaotic behavior". One of the properties of non-linear differential equations, particularly for interactions that occur over a period of time is that the outcome can be very strongly dependent on very small changes in initial input parameters or conditions.

Chaotic Behavior A Fundamental Issue

Simply put chaotic systems are potentially unstable, exhibiting a very sensitive dependence on initial conditions. This chaotic behavior of non-linear, time-evolving, dynamic systems was first formally reported by a meteorologist, Edward Lorenz in 1963. While running computer simulations on a set of three nonlinear equations, Lorenz found that, by rounding off initial parameters from four decimal places to two, the time paths of the equations diverged exponentially over time. This finding has given rise to a new mathematical discipline, often referred to as Chaos Theory, that has been studied intensively by mathematicians for about 35 years. Chaotic behavior has been found in a large variety of complex systems from weather systems to human behavior in organizations.

Inherently, because of their systems' non-linearities, chaotic behavior is a property of the dynamic interaction between countermeasures and tracking radars, with or without a human operator in the loop.

Impact of Chaos On ECM Simulation, Test and Evaluation

When the results of the AN/ALQ-131 and AN/ALQ-165 tests and the results found by the JADS EW Test Team are viewed from the perspective of the expected chaotic behavior of the non-linear systems under test, the findings of large variances, non-correlatable results and effectiveness criteria that are not met, are entirely predictable. There are a number of implications of this observation.

If the software simulations do not adequately model various key non-linearities in the radar system, such as those possessed by the tracking discriminators, saturating amplifiers and antenna gimbal limiters, their ability to adequately match the performance of the hardware being simulated is suspect at best. It would appear that incorporation of such non-linear models in simulations is a necessary, but not sufficient condition, for adequate fidelity. Even if such non-linearities are included in the simulations the potential for chaotic behavior implies that, in the execution of related software and hardware tests, increased focus must be placed on the accurate measurement of the input parameters and initial conditions. There must also be a correlation of input conditions before any expectations may be developed regarding correlation of output results from hardware and software tests.

When developmental and operational test and evaluation is carried out involving the dynamic interaction of countermeasure and radar systems and that testing intends to demonstrate that the equipment meets specific performance criteria as defined during requirements development, then those criteria should reflect the potential existence of chaotic behavior. Within the context of the Simulation Based Acquisition process, in which simulation is to be applied across the spectrum of acquisition from requirements to testing, the application of simulations that include appropriate non-linearities at each stage should assist in ameliorating the test problems.

Control Of Chaos

It seems reasonable to ask that, if chaotic and unpredictable behavior is inherent in the countermeasure-radar interaction, does this imply that there are likely be limits to the percentage of times that specific countermeasure may be effective against specific radar and weapon systems? In the absence of a body of research and engineering focused on this question it seems premature to endeavor to provide a definitive answer. However, here are several thoughts. If countermeasures can be structured to avoid the radar’s operation in non-linear regions of its operating regime then perhaps results can be linearly extrapolated and outcomes reasonably predictable.

Finally, in the research community, particularly in the non-linear systems discipline, there are now serious efforts to control chaotic behavior of complex non-linear systems through various schemes of adaptive control. Could such adaptive control be incorporated in the mode selection process in jammers to optimize their effectiveness?

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