Joint Advanced Distributed Simulation (JADS)
Electronic Warfare (EW)
Baseline Testing

22 June 1999

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ABSTRACT (U). This paper describes the methodologies and implementations used by the Joint Advanced Distributed Simulation (JADS) Electronic Warfare (EW) Test team to establish baseline performance data from testing at the open air range (OAR) and a hardware-in-the-loop (HITL) facility, the U.S. Air Force Electronic Warfare Evaluation Simulator (AFEWES). The AFEWES laboratory's real-time, actual-frequency simulations of radio frequency (RF) guided surface-to-air-missiles (SAMs) and anti-aircraft artillery (AAA) projectiles were used to supplement data shortfalls from OAR threat system testing of an aircraft self-protection EW suite. Key points of discussion include 1) gathering/evaluating OAR repeatable baseline data; 2) gathering/evaluating HITL repeatable baseline data; and 3) building JADS EW Test end-to-end scenarios. The Air Force Flight Test Center, Edwards Air Force Base, California, manages both the OAR and AFEWES; the later is located at Air Force Plant Number 4 in Fort Worth, Texas.

1.0 INTRODUCTION (U). The JADS EW Test program is an Office of the Secretary of Defense-sponsored triservice effort designed to determine how well an emerging technology, advanced distributed simulation (ADS), can be used to support EW test and evaluation (T&E). There are three phases for this effort and all phases are complete. However, the focus of this paper is on Phase 1 and how those results impacted our overall test design. The Phase 1 original purpose was to use an OAR flight test to establish the baseline performance, to provide sufficient information to recreate the OAR environment using ADS, and to validate the data from the ADS environment using the OAR data. The baseline performance was characterized using standard measures of performance and measures of effectiveness. These measures will be correlated to measure the enhancement or degradation in performance when using multiple T&E facilities linked together via long-haul telecommunications during the ADS-based test phases. Integral to this approach was understanding the differences between the OAR and at AFEWES facility differences. This paper discusses what the JADS team had to do to isolate ADS differences from facility differences.

2.0 BASELINE COLLECTION (U). The OAR flight test was accomplished in two parts. Both Part 1 (risk reduction) and Part 2 (baseline collection) OAR flights used an F-16 equipped with a self-protection jamming pod flying against ground-based SAM and AAA sites. Risk reduction was a series of six flights designed to ensure success in the baseline collection. Our goal in OAR baseline collection was to collect sufficient data from a single reference test condition to characterize ten different measures of performance (MOP) populations. A statistical comparison of the baseline populations to those produced in the ADS environment was expected to demonstrate the extent that the ADS environment changed the OAR results. A number of approaches were tested and refined in the risk reduction flights allowing JADS to minimize trial-to-trial variance and to characterize the instrumentation available on the range. Ultimately, a wing-level, fixed-altitude flight profile with fixed end points was selected to reduce pilot induced variation. The jammer pod software load was created to minimize false alarms and to provide a single response technique per threat. The threat operator rules of engagement were established to reduce operator induced variance and to ensure the engagements could be recreated in the distributed environment. A single pod, a single aircraft and a standard aircraft load were selected. Instrumentation was characterized and JADS elected to add an additional HITL test to the baseline data collection.

(U) The OAR risk reduction flights proved the available instrumentation was not sufficient to collect all the measures, and it was insufficient to allow several known variance sources to be separated from ADS errors in the later ADS-based phases of the test. The instrumentation available for measuring the time the pod needed to correctly identify the threat and to respond could not be synchronized to any clock source making it impossible to measure reliably. Ground instrumentation could not be used to overcome this problem. In addition, the range instrumentation was not sufficient to completely monitor and characterize unintended RF emissions. The range receivers were manually tuned making it difficult to observe and quickly capture transient signals in the range environment. The pod was programmed to ignore most of these signals to help compensate for this shortfall. While this helped overcome some variance sources other variance sources remained. These are listed in the figure below.

Test Component
F-16 radar cross section (RCS)
ALQ-131 antenna patterns
Threat representation
Electronic countermeasures (ECM) technique
Missile flyout
Time-space-position information (TSPI)/attitude
RF environment

3.0 HITL TEST APPROACH (U). The JADS EW Test integrated product team (IPT) met in early March 1998 and determined the best approach to meeting the data shortfall. The IPT considered several alternatives to collect the missing data; however, the winning approach was to conduct a hardware-in-the-loop test at AFEWES. This alternative provided a natural bridge for aggregating the known non-ADS variance sources and looking at their impact in a single test event. The approach was to execute the test and use the same correlation process to determine the impact of the variances on the ten MOPs. In order for this "unscheduled" event to occur, multiple challenges were immediate: 1) EW hardware and maintenance personnel from the Air National Guard Air Force Reserve Test Center (AATC) in Tucson, Arizona, would need to be moved from AATC to AFEWES in Fort Worth, Texas; and 2) Funds would need to be identified and put on contract in time for a July HITL test. These challenges were met and the test was executed on schedule. The following paragraphs discuss the test assets and execution of the HITL test.

3.1 General AFEWES Overview (U). The AFEWES laboratory contains simulations of a number of threat weapon systems along with the instrumentation and monitoring resources necessary to allow realistic, relative effectiveness evaluation of electronic combat equipment. The weapon system simulations employ electronic circuitry and components modeled after those employed in actual systems to provide a real-time RF interface with the electronic combat equipment. Display interfaces are simulated to provide authentic man-in-the-loop responses. Free-space signal propagation effects, antenna systems, aircraft characteristics, and weapons parameters are modeled within digital computer programs. These computers and models are interfaced with the RF hardware to produce the complete simulation environment.

3.2 Threats (U). The closed-loop threats for this effort included the Simulated Air Defense System (SADS) III, SADS VIM, AAA and SADS VIII. Antenna patterns for threat radars, as well as for the system under test (SUT) were loaded into computer look-up tables. A brief overview of the four AFEWES threat simulators is provided in the following paragraphs.

3.2.1 AFEWES SADS III (U). The SADS III simulation was three different simulations running in real time during dynamic testing. The first simulation was the threat target-tracking radar with scope displays and man-in-the-loop interfaces. The second simulation was that of the missile associated with the SADS III. The third simulation component was the penetrating aircraft. The threat target-tracking radar simulation was interfaced with the SUT at RF. The missile simulation, which is primarily a computer simulation, was interfaced with the SUT by sending a RF up-link signal.

3.2.2 AFEWES SADS VIII (U). The SADS VIII simulation was four different simulations running in real time during dynamic testing. The first simulation was the threat target-acquisition radar with displays and man-in-the-loop interfaces. The second simulation was the threat target-tracking radar; it too had a radar scope display and man-in-the-loop interfaces. The third simulation was the missile associated with the SADS VIII. The fourth simulation component was the penetrating aircraft. The threat target-acquisition radar and target-tracking radar simulations were interfaced with the SUT at RF. The missile simulation, which is primarily a computer simulation, was interfaced with the SUT by sending a RF up-link signal.

3.2.3 AFEWES SADS VIM (U). The SADS VI RF missile simulator provided a high fidelity target generation through signal injection immediately behind the antenna feed assembly at actual RF wavelength and at the correct real-time amplitude and phase. The target generation system provided a highly accurate signal fidelity including the effects of

- Target (victim aircraft) cross section
- Range attenuation
- Antenna patterns
  - Illuminator transmitter antenna
  - ECM receiver antenna(s)
  - ECM transmitter antenna(s)
  - Missile receiver antenna patterns (including sum, pitch, yaw and rear reference)
- Transmitter power levels
- Insertion losses
- Doppler frequencies
  - Target-tracking radar (TTR)-to-target
  - Target-to-missile
  - TTR-to-missile
- Time of arrival

(U) In multiple target test environments each target is generated independently for each of the RF paths (i.e., TTR-to-target, target-to-missile, and TTR-to-missile) and the signals are combined in passive RF combiners prior to injection into the appropriate antenna port. This is the same method of signal combination that occurs at the antenna in a free-space environment. All RF modulation is calculated in real time at the simulation interval, and the levels and frequencies are derived from the instantaneous solution of the appropriate radar range equation.

(U) The position and velocities of the target and the missile are monitored and recorded in real time and vector miss distance is determined for each target when the point of closest approach is reached for that target.

3.2.4 AFEWES Anti-Aircraft Artillery (AAA) (U). The AAA simulation was four different simulations running in real time during dynamic testing. The first simulation was the threat target-acquisition radar with displays and man-in-the-loop interfaces. The second simulation was the threat target-tracking radar; it too had a radar scope display and man-in-the-loop interfaces. The third simulation was the AAA projectiles. The fourth simulation component was the penetrating aircraft. The threat target-acquisition radar and target-tracking radar simulations were interfaced with the SUT at RF. The projectile simulation was a computer simulation. The penetrating aircraft was also computer generated.

3.3 Penetrating Aircraft (Closed Loop) (U). The AFEWES is capable of providing RF simulations of as many as four penetrating aircraft for most threat simulations. Only a single aircraft formation was used during this test program. In all cases, the penetrator was an F-16C aircraft carrying a self-protection jamming pod. The radar cross section

(RCS) simulated for the penetrating aircraft used modeled F-16C data. The RCS was obtained for each radar from data matrices based on the individual azimuth and elevation aspect angles. Generally, a special tape is created for each aircraft flight path represented in the test. AFEWES elected to demonstrate technology that would be used in the later ADS-based test phases. AFEWES used their newly developed high level architecture (HLA) interface to provide the AFEWES facility with aircraft position and attitude based on OAR TSPI data.

3.4 JammEr Technique Simulator (U). The JammEr Technique Simulator (JETS) is an open-loop simulation which can be used as a surrogate jammer, a cooperative jammer, or as a background emitter simulating a terminal threat. AFEWES lacked sufficient trained operators to man all four threats at the same time. Therefore, threats were manned in pairs. JADS elected to use the JETS to simulate unmanned terminals to recreate the OAR RF environment. This allowed JADS to approximate the RF load on the jammer pod processors seen in the OAR to better recreate threat identification and response times.

3.5 AFEWES Closed-Loop Simulator Instrumentation (U). Instrumentation of the AFEWES closed-loop simulations was provided by the AFEWES Test Director System (TDS). The TDS consists of multiple test management centers (TMCs). The TMCs provide instrumentation and control of the individual AFEWES simulations on a one-to-one basis by the following:

- optical disks for mass storage of raw simulator data
- digital strip chart recorders
- digital data display
- an online printer for test monitoring
- a data reduction computer for processing miss distance data
- video tape recordings of the simulator displays

(U) AFEWES again elected to augment the standard data collection by using their HLA interface to "publish" the data elements that would be published in the later ADS-based phases. This allowed JADS to avoid the cost of changing the data analysis tool to accept the HITL data.

4.0 CORRELATION METHODOLOGY (U). The JADS test design intended to use a rigorous statistical comparison of results from different test environments to determine the impact of using ADS in testing EW systems. The statistical comparison chosen was called correlation. As JADS test design progressed, the term correlation came to mean a process using a combination of analysis and statistics to compare two sets of data. The basic methodology for accomplishing correlation was developed from a CROSSBOW-funded EW test results correlation study conducted by Georgia Technical Research Institute. JADS first articulated the methodology in their May 1996 analysis plan for assessment. The method centered on using the Smirnov test for comparing the distributions of the data. The key to meaningful correlation is not the test, but in making sure that the test used will provide meaningful insight into the data for decision makers.

As our methodology matured, several tests were considered including Kolmogorov-Smirnov (K-S), Anderson-Darling, Student T-Test, F-Test, and Chi-Squared Test. We selected the K-S for comparison of differences in distributions, the Student T-Test for comparison of differences in means, and the F-Test for comparison of differences in variances. The drawback for the Student T-Test and F-Test is the assumptions they make about the underlying population. The K-S test is nonparametric and makes no assumptions about the underlying population. These tests gave us a slightly broader view of the methodology than strictly applying the K-S test.

(U) The process used was straight forward. The steps are listed below.

Step 1 - Assemble the test data from the first environment.
Step 2 - Assemble the test data from the second environment.
Step 3 - Perform qualitative correlation analysis.

- Graph all numbers from each environment as a function of run number to check for learning or other future "residuals."
- Graph the raw data from each environment as a relative frequency histogram and experiment with different interval sizes and end points to find the most meaningful representation. Make an initial determination about the type and distribution of the data.
- Qualitatively compare the relative frequency histograms between environments.
- Use SUT and facility knowledge to determine if additional factors are present that need to be accounted for or adjusted. These may be most evident in the outliers. Carefully document the reasons for any dropped data.
- Establish the new baseline data from each environment by removing or adjusting all data affected by the additional factors.

Step 4 - Perform quantitative correlation analysis and express results in P-factors.
Step 5 - Interpret results.
Step 6 - Document results.

(U) JADS intended to simply publish the P-factors and allow the community to draw its own conclusions. We did not expect perfect correlation. However, examination of the data, especially in light of the concerted effort to collect repeatable data, caused us to question the viability of statistical correlation for system measures of performance that are highly affected by operator actions. These questions apply to EW systems that are required to work against human operators. Other classes of systems that do not work against human operators deserve more investigation before any conclusions can be reached.

5.0 RESULTS (U). More than 267 runs were collected in two weeks of testing at AFEWES. However, all objectives were not met. Although internal timing measures were collected, we discovered post test that all of the instrumentation was not time synchronized and these measures could not be used for analysis. An additional test in a system integration laboratory was conducted later to capture these timing measures. Data analysis on the HITL data was completed and several conclusions were reached.

- The data were sufficient to allow JADS to create one ADS-based test environment and execute two ADS-based tests.
- The data collected were generally sufficient for the JADS purpose of collecting a significant sample of data for characterizing the populations of the ten MOPs. More data would have increased our confidence that we had a good characterization; however, more data would have made the statistical tests more sensitive.
- The data collected between the OAR and HITL, while generally comparable, exhibited very weak statistical correlation. While several factors, including threat simulator variations, contributed to this, operator actions were by far the largest source of variation.
- The data collected were not sufficient for verifying and validating (V&V) the ADS-based test architecture. The OAR and HITL data were useful only for making general comparisons. Again, statistical correlation between the ADS and baseline tests was very weak and could not support V&V. As expected, the operators were a significant source of variation. However, we found evidence to suggest that the samples may not fully capture the real variation possible within the population. One of the threats had no operator variance and yet displayed high variation in the dry miss distances produced. (Engineering analysis is not yet complete; however, the preliminary indication is that slight variations in the flight path are the only identifiable difference.) JADS had to rely on subject matter experts to V&V the architecture.

6.0 IMPLICATIONS FOR THE EW COMMUNITY (U). The JADS EW Test was focused on testing a RF self-protection jammer against threat systems employing human operators. Considering this narrow problem, the following are our observations for the EW community.

- We found no evidence to suggest that statistical correlation is practical for measures of performance that rely on <u>human operator actions</u>. Certainly there may be statistical tests that could be performed that may be less sensitive to high variance and outlying data points that human operators produced in our test. This may merit further investigation. However, the statistical tests we performed have minimal utility for EW decision makers given the current infrastructure and affordable sample sizes.
- For similar reasons, we found no evidence to suggest that statistical correlation between ADS environments and OAR test data for V&V of the environments is practical. Subject matter experts are a better source for V&V of ADS environments.
- We are not surprised that the EW community has difficulty understanding and articulating military utility of EW systems to decision makers. Obtaining repeatable results in a simplistic environment proved to be extremely difficult in a laboratory environment such as AFEWES. This was even more difficult on the range. We do

not believe it is possible to understand OAR results without sufficient laboratory testing to characterize the normal operation of the system under test.