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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO AGARDograph 300

Flight Test Techniques Series – Volume 17

Electronic Warfare Test and Evaluation

(les Essais et l'évaluation du matériel de guerre électronique)

This AGARDograph has been sponsored by the SCI-055 Task Group, the Flight Test Technology Team of the Systems Concepts and Integration Panel (SCI) of RTO.

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edited by

H. Banks
R. McQuillan

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Electronic Warfare Test and Evaluation

(RTO AG-300 Volume 17)

Executive Summary

Control and exploitation of the electromagnetic spectrum has become as much a part of modern warfare as air superiority or dominance of the sea lanes. Electronic Warfare (EW) is the mission area responsible for establishing and maintaining a favorable position in the electromagnetic domain. Test and evaluation (T&E) of those devices used on modern military aircraft to prosecute this critical mission area requires the use of a wide range of test techniques and analytical methods to assure users of the readiness of EW systems to meet the challenges of the combat environment. Actual in-flight testing comprises a relatively small portion of the EW T&E process. As a result, the reader will find that the concentration in this document is far broader than "flight test" - ranging from laboratory efforts to establish the system performance baseline through complex ground-based simulations and finally the limited verification accomplished in the open-air range environment.

This document is intended as an introductory text dedicated to EW systems test and evaluation. While other volumes in the Flight Test Techniques Series have provided limited coverage of EW system testing, they have been generally aimed at a broad view of T&E and have not resulted in a singular focused handbook on EW test techniques.

While the primary goal of this document is to introduce the novice to a disciplined approach to EW testing, it will also serve more experienced testers and program managers as a concise reference for the EW test process and test resources. It begins with an overview of the test process in the context of the roles and missions expected of EW systems. Subsequent chapters provide examples of test requirements for major categories of EW systems. The final chapters focus on descriptions of specific types of test resources and how they can be linked to simulate predicted operational conditions. A catalog of some useful EW Test Facilities is included in an annex to this document.

Les essais et l'évaluation du matériel de guerre électronique

(RTO AG-300 Volume 17)

Synthèse

Le contrôle et l'exploitation du spectre électromagnétique font partie intégrante de la guerre moderne au même titre que la supériorité aérienne ou la domination des voies maritimes. La guerre électronique (EW) est la fonction opérationnelle destinée à établir et à maintenir une position favorable dans le domaine électromagnétique. Les essais et les évaluations (T&E) des dispositifs permettant aux aéronefs militaires modernes de réaliser cette mission essentielle font appel à une large gamme de techniques d'essais et de méthodes analytiques pour assurer aux utilisateurs la disponibilité des systèmes EW malgré les difficultés posées par l'environnement de combat. Aujourd'hui, les essais en vol ne représentent qu'une proportion relativement faible du processus EW des essais et évaluations. Par conséquent, le lecteur trouvera dans ce recueil des documents dont le champ d'intérêt dépasse celui des « essais en vol », allant des travaux effectués en laboratoire pour établir une base de référence pour l'évaluation des performances des systèmes, aux simulations au sol complexes et, enfin, aux vérifications limitées effectuées à l'extérieur, sur les zones d'essai.

Ce document est un texte préliminaire consacré aux essais et aux évaluations des systèmes EW. Bien que d'autres volumes dans la série sur les techniques des essais en vol aient proposé un traitement limité des essais des systèmes EW, ils ont, le plus souvent, donné une description assez générale du T&E, sans aboutir à un manuel consacré aux techniques d'essai du matériel EW.

Si ce document a pour objectif principal de présenter au débutant une introduction à une approche rigoureuse des essais EW, il servira également d'ouvrage de référence succinct pour les responsables de programme et les ingénieurs d'essais plus expérimentés. L'ouvrage commence par un aperçu du processus d'essai dans le cadre des missions et des rôles prévus pour les systèmes EW. Les chapitres qui suivent fournissent des exemples de spécifications d'essai pour les grandes catégories de systèmes EW. Les derniers chapitres sont axés sur des descriptions de moyens d'essai spécifiques et les possibilités d'association afin de simuler les conditions opérationnelles prévues. Un catalogue d'installations d'essais EW intéressantes est inclu en annexe à ce document.

Click inside the blue boxes to view the corresponding section

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Preface

Most students of Electronic Warfare (EW) would declare its beginning to be about 1936. Many would say that the golden years of EW were in this early period leading up to and continuing through World War II. Little was spoken of EW's contribution in those early days, and frequently clear evidence of the EW systems effectiveness was lacking. Today, EW is a recognized requirement for nearly every weapon system. But clear judgements of its effectiveness remain elusive. This is the burden left to the tester. Test and Evaluation processes must be devised to rigorously establish the effectiveness and military worth of the EW system. These processes must be able to predict and then create the complex electromagnetic environment expected to occur in actual warfare.

The past decade has seen an enormous increase in the use and importance of the "electronic battlefield." The cat and mouse game of detection and evasion through the use of the electromagnetic spectrum has become the dominant feature of modern air warfare. A basic grounding in test methods and processes is essential to today's test pilots and flight test engineers.

Today's tester makes judicious use of a plethora of models, simulations, and hardware-in-the-loop test facilities prior to and during the more realistic open-air range and installed system test facility events. Analysis of data derived from each of these test opportunities leads to the overall evaluation of the EW system. This volume will introduce the concept of the EW Test Process and subsequently show how it is applied in each class of test facility and to each major division of EW systems.

Foreword

While other volumes in the Flight Test Techniques Series have provided limited coverage of Electronic Warfare (EW) system testing, they have been generally aimed at a broad view of test and evaluation (T&E) and have not resulted in a singular, focused handbook on EW test techniques. This volume has as its sole focus the processes, techniques, facilities, and goals of T&E of modern EW systems. Much of the world of EW remains shrouded in secrecy, and detailed descriptions of some test resources, test results, and EW techniques cannot be presented herein. However, this volume can fulfill its desired goal of serving as a comprehensive introduction to the practice of EW test.

The first section provides a historical perspective of EW system development, an overview of EW systems, and basic motivations for T&E. The reader will quickly realize that the development and eventual qualification of EW systems is heavily reliant on the use of ground-based test and evaluation resources. Since EW system performance is substantially scenario dependent, much of the testing must be accomplished in a combat representative electromagnetic environment. These high density and wildly dynamic conditions can only be offered to the tester through the application of complex models, simulations, and analytical processes.

Sections 2, 3, and 4 of this document examine the motivation for testing each of the three primary classes of EW systems; Electronic Support Systems, Electronic Attack Systems, and Electronic Protect Systems. Examples of test objectives, measures of effectiveness and performance, and test resource utilization are discussed. Section 5 introduces architectural considerations for EW Systems and discusses how various architectures may affect the test approach.

The EW Test Process, defined in Section 1, is based on an organized application of test resources including measurement facilities, models, simulations, hardware-in-the-loop facilities, installed system test facilities, and open-air ranges. Sections 6, 7, and 8 provide a discussion of how and when each of these test resource categories should be considered for inclusion in the test program. A catalog of some useful EW Test Facilities is included in the annex of this document.

Finally, some lessons learned in the T&E of EW systems have been collected in Section 9. While the specific issues depicted by these anecdotes may not be present in some future test program, the general nature of the lessons may be useful in avoiding costly mistakes.

Overall, this document will help the novice EW tester become familiar with the major elements of EW developmental and operational testing. More experienced testers will find the document to be a helpful reference source with a concise description of both test processes and test resources throughout the US and Europe. For those individuals with broader responsibilities in the acquisition, operations, or sustainment of EW systems, this volume will be a useful introduction to the potential for gaining in-depth understanding of EW system functionality and performance through the disciplined application of the EW test process.

Acknowledgements

The complexity and breath of application of modern EW Systems is such that any comprehensive overview requires the knowledge and insight of a great many individuals. The authors wish to recognize the efforts of several of those who contributed either directly or indirectly to the information presented in this volume. Mrs. Stassi Cramm and Mr. Dave Carroll of the U.S. Air Force Electronic Warfare Test Directorate at Edwards Air Force Base are recognized experts in the field of Modeling and Simulation and were solely responsible for the preparation of Section 6. Mr. Bill Flothmeier, Mr. Scott Hanssen, Mr. Doug Johnson, Mr. Lance Stevenson, and Mr. Gus Pignataro of the Naval Air Warfare Center, Weapons Division at Pt Mugu, California, shared their expertise in various areas in the formulation of Sections 2 and 3. Mr. Harry Franz was instrumental in collating the lessons learned in Section 9. Mr. Roland Graves was very helpful in detailing the EW capabilities at the NATO Consultation, Command, and Control Agency in The Hague, The Netherlands. Madame Francoise-Elisabeth Etling, chef du bureau information économique, of DGA was instrumental in informing the authors of the extensive EW Test and Evaluation resources available in France. Electronic Warfare test facilities within the United Kingdom form an important resource for NATO. Mr. Dave Burleigh and his cohorts at DERA, Farnborough, UK, were most cooperative in providing information on their facilities and processes for inclusion in this document. Herr Galleithner of Deutsches Zentrum fur Luft und Raumfahrt (DLR), Herr Dr. Hetzner and Herr Walsch of Daimler-Benz Aerospace (DASA), and Herr Dr. Schober and Herr Elvermann of WTD-81 provided the authors with an in-depth understanding of EW test resources in Germany.

List of Figures

Acronyms, Symbols and Abbreviations

AI	Airborne Intercept
AOA	Analysis of Alternatives
AAA	Anti-Aircraft Artillery
ARMs	Anti-Radiation Missiles
DECM	Defensive Electronic Countermeasures System
DT&E	Development Test and Evaluation
DSM	Digital System Model
DOA	Direction of Arrival
ERP	Effective Radiated Power
EMI	Electromagnetic Interference
EMI/EMC	Electromagnetic Interference and Electromagnetic Compatibility
EA	Electronic Attack
ECCM	Electronic Counter Counter Measures
EP	Electronic Protection
ES	Electronic Support
EW	Electronic Warfare
FCR	Fire Control Radar
HITLs	Hardware-in-the-Loop facilities
HPM	High Power Microwave
IR	Infrared
ISTFs	Installed System Test Facilities
IC	Integrated Circuit
LPF	Low Pass Filter
LWS	Laser Warning System
MFs	Measurement Facilities
MMI	Man-Machine Interface
MOE	Measures of Effectiveness
MOP	Measures of Performance
MDS	Minimum Detectable Signal
MWS	Missile Warning Set
MDF	Missile Data File
M&S	Modeling and Simulation
OFP	Operational Flight Program
OAR	Open Air Ranges
OT&E	Operational Test and Evaluation
PTC	Planned Test Conditions
PRI	Pulse Repetition Interval
PRF	Pulse Repetition Frequency
RCS	Radar Cross Section
RIL	Reduction in Lethality
RIS	Reduction in Shots
RTC	Reference Test Condition
RWR	Radar Warning Receiver
SOJ	Stand-Off Jammers
SMA	Sub Miniature A
SAMs	Surface-to-Air-Missiles
SILs	Systems Integration Laboratories
SUT	System Under Test
T&E	Test and Evaluation
TSPI	Time Space Positioning Instrumentation
UV	Ultraviolet
UDF	Users Data File
VV&A	Validation, Verification & Accreditation

1.0 INTRODUCTION TO ELECTRONIC WARFARE TESTING

1.1 Purpose

Test and Evaluation (T&E) of Electronic Warfare (EW) systems requires a disciplined application of the scientific method, modern measurement systems, and rigorous analysis of resulting data products. The need for a rigorous T&E process for EW is accented by concerns over the capability to acquire and field effective EW systems. As a result, an improved T&E process has evolved that is characterized by a Test-Evaluate-Compare strategy rather than the previously practiced Fly-Fix-Fly approach. This AGARDograph serves as a primary reference to introduce this improved T&E methodology, discuss its application to the evaluation of specific EW systems, provide a useful directory of key EW T&E resources available to NATO members, and list lessons of the past which will improve the productivity of future testing. While much of the content is aimed at personnel with relatively little experience in the field of EW T&E, it is hoped that this volume can also serve as a basic "checklist" of issues to be covered in planning, conducting, and evaluating EW tests. In order to gain an appreciation for current practices in EW T&E, some discussion of the history of EW system development, EW system application in modern warfare, and generic elements of disciplined testing are presented in this introduction.

With the rapid evolution of military electronics and computer science, the range, complexity, and sophistication of EW systems has grown significantly. It would, therefore, be impractical to cover all aspects of EW system testing in a single volume. It is, however, desirable to cover the core T&E concepts, procedures, and techniques that apply generically to most EW systems. The subject matter is focused on testing avionics systems for military aircraft whose purpose is primarily for electronic countermeasures and counter-countermeasures. This testing has much in common with the testing of any avionics system, especially in those areas that relate to the "-ilities", i.e., availability, operability, supportability, and reliability.

1.2 Definitions

While a complete glossary is included in this document, some understanding of terminology commonly used in the descriptions of EW systems and the attendant test procedures is thought useful at this point. Throughout the past decade the terms "Electronic Warfare" and "Electronic Combat" have been used somewhat interchangeably. As of this writing, the term Electronic Warfare seems to be the standard in the U.S. military lexicon and will be utilized throughout this AGARDograph. Electronic Warfare is defined as military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy. It is interesting to note that the definition of EW does not make any reference to the equipment used, but rather is confined to a description of the task or mission.

For the most part, the equipment used specifically in the accomplishment of EW is avionics. Avionics is defined as the science and technology of electronics applied to aeronautics and astronautics. This relationship between EW and avionics establishes the domain of EW T&E in the aerospace environment. Testing and evaluating EW systems requires the application of the skills and insights requisite of testing avionics equipment in general, tempered with a view of the military actions to be accomplished using these devices. The functionality and military worth of EW systems are highly scenario dependent.

For the purposes of this document, Electronic Warfare has been sub-divided into three major categories: Electronic Attack (EA), Electronic Protection (EP), and Electronic Support (ES). EA uses electromagnetic or directed energy to attack an enemy's combat capability. EP constitutes protection of friendly combat capability against undesirable effects of friendly or enemy employment of EW. Included under ES is surveillance of the electromagnetic spectrum for immediate threat recognition in support of operations and other tactical actions such as threat avoidance, homing, and targeting. Figure 1-1 shows the relationship of the various elements of electronic warfare.

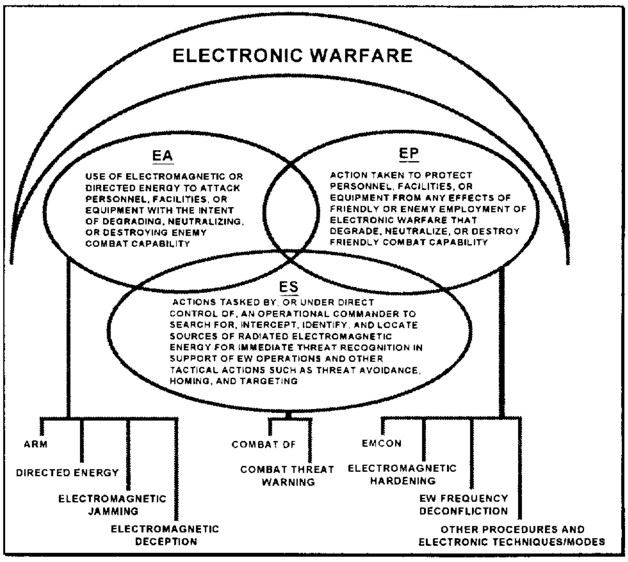

Figure 1-1 Electronic Warfare Elements [1]

1.3 Test Resource Categories

Testing of EW systems spans an enormous range starting with inspection of components and materials to be used in the manufacture of systems and culminating with inservice troubleshooting and failure diagnosis. This AGARDograph concentrates on that testing used to assess the capability of an EW system to comply with system level specifications, perform its intended military role, and its potential to be serviceable and supportable in the field. These qualities are generally assessed using a combination of flight and ground-based tests and employing a wide range of test resources. Test resource categories applicable to EW testing include Measurement Facilities (MFs), System Integration

Laboratories (SILs), Hardware-in-the-Loop (HITL) facilities, Installed System Test Facilities (ISTFs), and Open-Air Ranges (OARs). A sixth resource category of growing importance is Modeling and Simulation (M&S).

It is tempting to equate "types of tests" with specific test facilities. For instance OARs provide an environment where aircraft can be operated in their intended flight regimes, but can also often support testing of systems installed in the aircraft while the vehicle is on the ground. In this scenario, we would be conducting an "installed system" test type using an OAR resource category. Large anechoic chambers, capable of holding an actual aircraft, are frequently classed as "Installed System Test Facilities." While this categorization is applicable, it does not convey the full range of applications for which an ISTF may be suitable. Frequently, ISTFs are used to support HITL tests, integration activities, and simulations. As a result, we may arrive at inaccurate or incomplete understandings of the T&E value of many test resources if we allow the resource category description to define the test types that the resource can support. This AGARDograph will use the terminology **Test Resource Category** to identify the primary role of a specific test facility and will use **Test Type** to reference the various levels of testing and system integration that may be accommodated at a given facility.

1.4 Types of Tests

Generally speaking, there is a hierarchy of test types which must take place in order to quantify the overall performance of the system under test (SUT). This sequence of T&E events tends to mirror the overall maturing of the SUT as it progresses through the development process. Figure 1-2 depicts this process and helps to characterize an important attribute of the test process; it is a purposefully recursive process that continually refines the estimated performance of the SUT as it reaches higher levels of integration and maturity. Throughout this process, the predict, test compare concept is employed.

Of course such a deliberate process may be difficult or even impossible to achieve due to fiscal, schedule, or test facility constraints. Each of the desired test events represent an opportunity to, in some manner, reduce risk in developing the EW system. Here is where the tester's experience must be applied to make wise choices in identifying test events to reduce in scope or totally eliminate in order to fit the test program into the available budget, schedule, and test facilities.

Some of the choices may be less than obvious. For instance, flight testing is generally considered to be a more complete test than those events accomplished in a HITL or ISTF. The experienced tester, however, may determine that due to limitations of threat simulators available on the OAR, he can actually create a more realistic test scenario in an ISTF. This particular type of choice is frequently encountered when testing the effects of high threat or signal density. Most OARs are very limited in the quantity of threat simulators they can provide. On the other hand, HITLs and ISTFs can most often simulate very large numbers of threat signals.

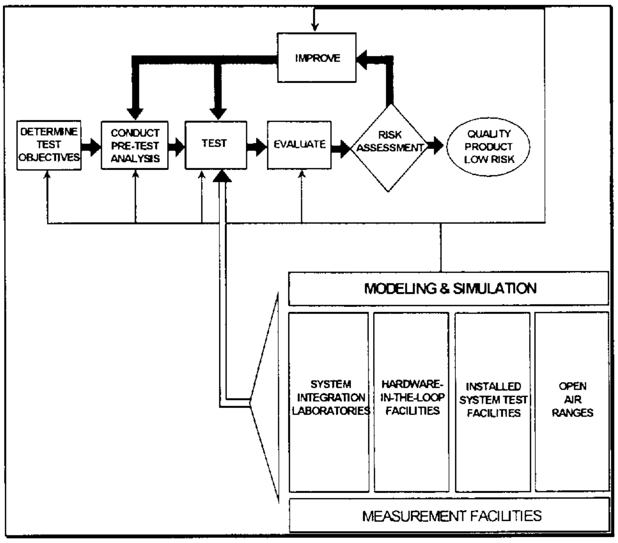

Figure 1-2 T&E Process [1]

1.5 History of EW

Many would argue that EW dates back to the American Civil War and the advent of telegraph as an important form of military communications. Early EW techniques included interruption of the enemy's communications by cutting the telegraph lines, and spoofing by sending misleading messages. These processes are similar to our current concept of EA. Listening in on the enemy's transmissions by tapping the telegraph lines may be the earliest form of ES. In any case, while no radiated electromagnetic energy was involved at this point, the rudimentary concepts of attacking, protecting, and exploiting electronic communications had begun.

The pursuit of EW in military aviation first started in earnest during World War II. Radio beams were used to guide bombers to their targets, radar was used to detect and locate enemy aircraft, and radio communication were becoming the primary means of establishing command and control. As each new electronic measure was employed, the adversary would develop a countermeasure or EA capability. In many instances, in order to preserve the advantage of the initial electronic measure in the face of countermeasures, counter-countermeasures or EPs were developed.

Although the emergence of aircraft electronic self-protection systems can be dated much earlier, particularly for strategic bomber and reconnaissance aircraft, the Vietnam conflict provided the overwhelming urgency for the large scale introduction of means to counter Surface-to-Air Missiles (SAMs) and radar-directed Anti-Aircraft Artillery (AAA). During the period of combat air operations over Vietnam, tactical aircraft progressed from virtually no EA capability to a status where EA capable systems were a requirement for every exposure to a threat envelope. This era marked the beginning of modern requirements for survival in the presence of electronically directed enemy fire control.

1.6 EW System Application In Warfare

As discussed earlier in this chapter, EW can be broken down into three primary divisions; EA, EP, and ES. In order to better understand the test requirements, a brief overview of each of these primary divisions is given below. It is not the intent of this publication to fully describe the role of EW in military actions or to provide a detailed analysis of specific EW techniques.

1.6.1 Overview of EA

EA is the use of electromagnetic or directed energy to attack personnel, facilities, or equipment. There are four basic sub-divisions of EA; jamming, deception, anti-radiation missiles (ARMs), and directed energy weapons. Jamming is generally defined as deliberate radiation, re-radiation, or reflection of energy for the purpose of preventing or reducing an enemy's effective use of the electromagnetic spectrum. With recent advances in technology and more frequent use of spectra outside the electromagnetic range, this definition can be extended to cover similar action against infrared (IR), ultraviolet (UV), and electro-optical systems.

Jamming is the most prevalent form of EA and has three major sub-divisions; self-protection, escort, and stand-off. In self-protection jamming, the same vehicle being targeted by the enemy radar or sensor system carries the EA system. Usually, this form of jamming has the disadvantage of being limited in the amount of effective radiated power (ERP), but has the advantage of being able to inject EA in the main lobe of the enemy system. In escort jamming, the escort vehicle (the vehicle carrying the EA system) is often dedicated solely to EA, thus providing for more available ERP and having the advantage of injecting interference in the main lobe of the enemy system as well as the sidelobes. In stand-off jamming, the EA platform is at a long range from the enemy defenses and is usually in the sidelobe of the enemy radar, but it too can provide more ERP by being dedicated to EA.

There are basically two types of enemy radar that must be jammed by EA. The first is surveillance, or search radar, used to locate the position of a target within a large coverage volume. A specific type of surveillance radar of interest to the EA designer is the acquisition radar used to locate targets for fire control systems. The second type of radar to be jammed is the tracking radar that is usually given high priority in the hierarchy of EA threats because it is associated with the terminal phases of a weapon guidance system. EA techniques are used to disrupt or break the threat's range, velocity, or angle tracking capability and force the acquisition radar to relocate the target and re-aim the weapon - a process which could provide the target the time to pass harmlessly through the threat's engagement envelope.

Passive techniques are also used to avoid, degrade, or deceive an adversary's sensor systems. Chaff, passive decoys, and signature reduction are all elements of EA.

Several jamming techniques are often used in conjunction to confuse the enemy radar system. For example, it may not be enough to break range or velocity lock in a tracking radar. If the acquisition radar still has valid angle information to provide to the weapon, the target can be quickly re-acquired. Several EA techniques can be used in concert to completely mislead the acquisition system, thus preventing the target from being relocated in time to re-aim the weapon.

1.6.2 Overview of EP

EP is that action taken to negate the effects of either enemy or friendly EA that would degrade, neutralize, or destroy friendly combat capability. EP techniques tend to be the result of developments of EA capabilities. Most EP techniques are defined in relation to how they counter a specific EA threat. Usually, the EP technique is some improvement in the sensor design that counteracts the effect of a specific EA technique; therefore, it is difficult to understand the purpose of a specific EP technique without knowing the EA technique that it is designed to counteract.

Usually, the design requirements of a system that operates in a jamming environment will exceed the requirements of a similar system designed to operate only in a friendly environment. For example, a radar receiver designed for use in a friendly environment can tolerate relatively wide band frequency response with only minimal degradation in performance. A similar receiver designed for use in a jamming environment would require narrow band frequency response to prevent skirt jamming.

The EP designer may utilize sophisticated transmitted waveforms and receiver processing that will make deception jamming difficult. This forces the enemy to use high-power, brute-force noise jamming. The EP designer can then use frequency hopping or multiple simultaneously transmitted frequencies so that the enemy must broaden the bandwidth of his jamming. This causes the enemy jammer to diffuse its energy over a wide bandwidth, thus reducing the effectiveness of the EA. A true cat and mouse game between EA and EP designers results.

1.6.3 Overview of ES

ES is that division of EW concerned with the ability to search for, intercept, identify, and locate sources of radiated electromagnetic energy. ES is used in support of tactical operations for situational awareness, threat avoidance, homing, and targeting. Onboard radar warning and missile warning receivers, as well as many off-board surveillance systems, are considered elements of ES.

1.7 EW Test and Evaluation Process

An overall plan or process is required to conduct efficient, cost effective T&E. The EW T&E process presented here is intended to be universal, for use by all participants involved in weapons acquisition and development. Its use implements a predict-test-compare philosophy and stresses adequate ground testing before implementing a flight testing methodology. This process is applicable in developmental, operational, and other phases of military systems testing. If you are starting to plan, manage, or conduct an EW T&E effort, this process will help you do it in a disciplined, scientific, and cost-effective manner. As depicted in Figure 1-3, the methodology recommended in this document is based on a solid foundation of cost effective ground-based tests leading to a focused evaluation in the proposed operational environment.

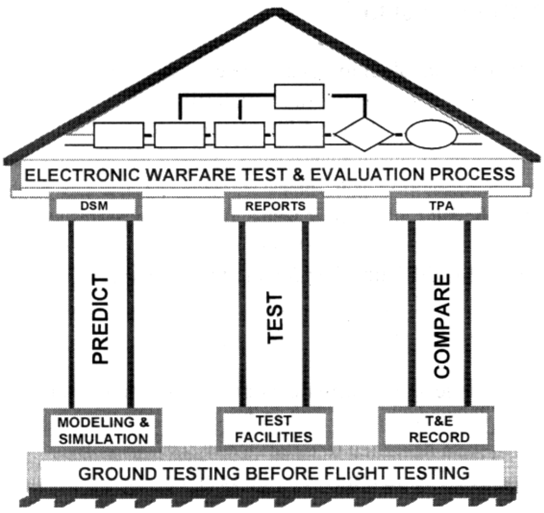

Figure 1-3 Predict-Test-Compare [1]

1.7.1 Objectives of the EW T&E Process

The three primary objectives of the EW T&E Process are: 1) to reduce the risk of hidden flaws in the product that will be very costly to fix later; 2) to demonstrate system performance that proves new and modified systems are being properly developed/improved and will meet the needs of the user; and 3) to contribute timely, accurate, and affordable information for life cycle acquisition and support decisions.

The need for such a well defined process, as shown in Figure 1-4, has been demonstrated many times by the troubled histories of EW programs that came on line too late, were over budget, or unable to meet user needs. Past EW programs have displayed a pattern of latent deficiencies manifesting themselves in operational test and evaluation, necessitating expensive fixes and re-testing.

Efficient use of limited and costly resources that exist to support EW T&E is of growing importance during periods of consolidation, down-sizing, and reorganization. This means using test concepts that take advantage of current and emerging Modeling and Simulation (M&S) and ground test technologies to streamline Developmental Test and Evaluation (DT&E) and Operational Test and Evaluation (OT&E). Test concepts that promote a **fly-fix-fly** methodology or emphasize open-air range testing as the primary test method may not be cost effective approaches to testing.

The process suggested here is aimed at improved risk assessment and risk management. Risk as used here means the probability that the product will have latent deficiencies that will not show up until later testing or when fielded. This risk will likely cause significant: 1) disruption of schedule; 2) increase in cost; and/or 3) degradation of performance. Risks are always a future consideration. Once a risk event happens, it is no longer a risk; it is a problem.

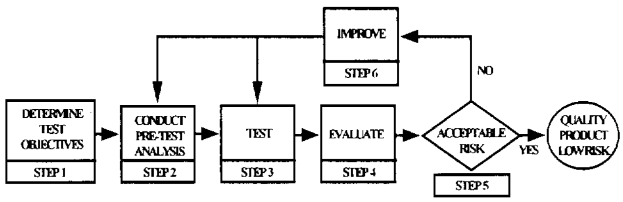

Figure 1-4 EW T&E Process

Using this process involves taking actions and making decisions that answer the questions presented in the following six steps.

Step 1) **Determine Test Objectives**—This is an action step. What are the technical and operational issues that must be proved? What are the risk areas? What T&E information is needed by decision makers? Are the test objectives based upon mission, task, and performance requirements? What are the underlying assumptions supporting these objectives, and are they likely to change?

Step 2) **Conduct Pre-Test Analysis**—This is an action step. What is the test concept? What are the test points? What are the predicted outcomes? What analytical tools must be developed? What types and quantities of data are needed?

Step 3) **Test**—This is an action step. Are the appropriate T&E resources being used to conduct the tests? Will they accomplish the major test objectives? Will the tests show if risk mitigation measures work? Is the required data being collected and analyzed? Are results being reported?

Step 4) **Evaluate**—This is an action step. Have conclusions been reached and recommendations made? How do results compare with predictions? Did post-test analysis compare predicted outcomes to test measured outcomes? Has analysis identified the root cause of discrepancies? Have technical and operational judgments been applied to the results? Has the information been reported to decision makers?

Step 5) **Acceptable Risk?** —This is a decision step, a judgment call by a decision maker. Was the test outcome satisfactory? Have technical and operational risks been reduced to acceptable levels? Will the needs of the user be met? If yes, proceed forward. If no, go to the sixth step of the process.

Step 6) **Improve**—This is an action step. What must be changed or refined? Who must take corrective action? These are actions to improve the EW system design, correct a flawed test method, find and fix errors in models and simulations, or improve the test process.

1.7.2 Integrated Processes

The EW T&E Process supports and must be integrated with the more complex Acquisition Process. The EW T&E Process interfaces with the system acquisition process as shown in Figure 1-5. The user defines system requirements and deploys the system after development. The program manager controls program specifications, design, and production. The Test Organization is responsible for detailed test planning, conduct, evaluation, and reporting. Information must be developed and shared between user, tester, and acquisition communities. EW testing requires an integrated effort (teamwork) to get a quality product with low risk that meets user needs.

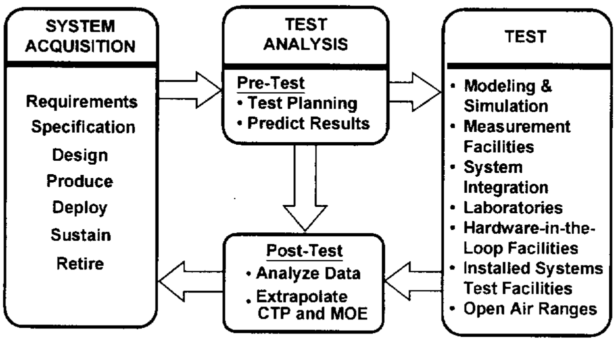

Figure 1-5 Integrated Effort [1]

1.7.3 More Productive Flight Testing

The EW T&E Process replaces the **fly-fix-fly** test philosophy with the more scientific **predict-test-compare** philosophy. Rigorous ground testing is done before and during flight testing to permit a high confidence flight test. Simulations are used to predict ground and flight test results at specific points in the performance envelope. Ground tests are then conducted, differences analyzed, and if appropriate, deficiencies corrected. Once ground testing demonstrates that performance is as predicted, flight testing can begin, using the predict-test-compare philosophy with deficiencies investigated on the ground and necessary model updates accomplished. Verification of the ground test data at the proper envelope points means flight testing will not have to be done throughout the entire performance envelope. This approach amounts to flight testing **smarter, not harder**.

1.7.4 Data Reduction

The test itself only provides data, observations, and information to be subsequently evaluated. The bridge between testing and evaluation is "data reduction." Often this step is thought to be a simple act of feeding data to the computers and waiting for the output to appear on the engineer's desk. Experienced testers know differently; they are fully aware that factors such as selection of data, editing of "wild points," and determination of statistical processes to be applied to the data can have a major effect on the outcome of the evaluation. A thorough understanding of experimental statistics is a prerequisite for the successful evaluation of any EW system.

1.7.5 Examples

Figure 1-6 contains examples of how the six resource categories support the different kinds of EW testing required. The annex of this document provides summary information on specific facilities representative of those typically used.

1.8 EW T&E Resource Utilization

Recognizing that threat system availability, threat density, and closed-loop effectiveness may dictate resources used, the following considerations apply.

1.8.1 Relative Cost

In general, the cost per test becomes more expensive as the testing moves to the right as shown notionally in Figure 1-7. The use of models, simulations, and ground testing can reduce overall test costs since open-air flight tests are the most costly. In general, the cost per test becomes more expensive as the testing moves to the right, as shown notionally in Figure 1-7. The use of models, simulations, and ground testing can reduce overall test costs since open-air flight tests are the most costly.

1.8.2 Relative Use

Due to the complexity of EW systems and threat interactions, modeling and simulation can be used in a wide range of progressively more rigorous ground and flight test activities. Figure 1-8, also notional, shows that modeling and simulation and measurement facilities are used throughout the test spectrum. It also shows how the number of trials/tests should decrease as the testing proceeds to the right through the categories.

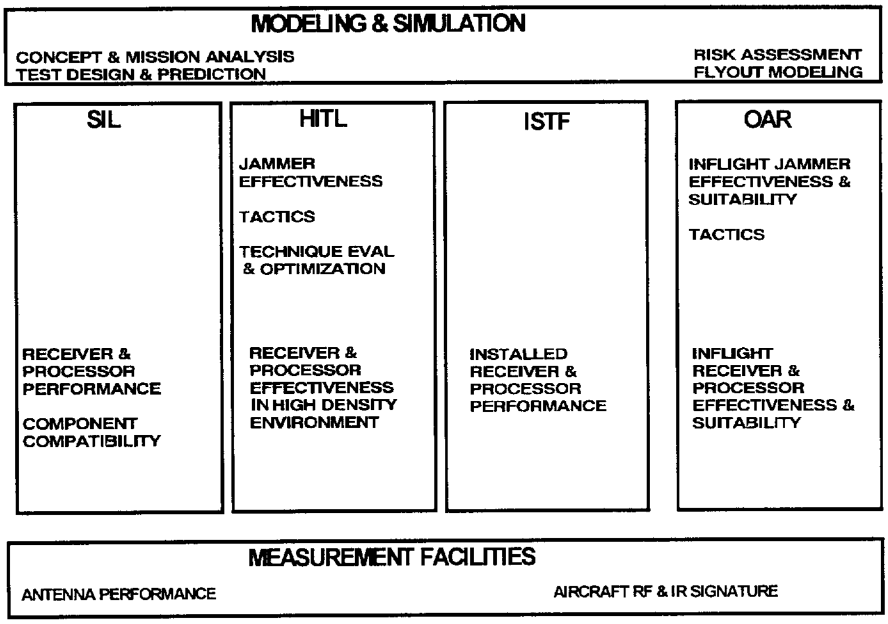

Figure 1-6 EW T&E Resource Category Examples

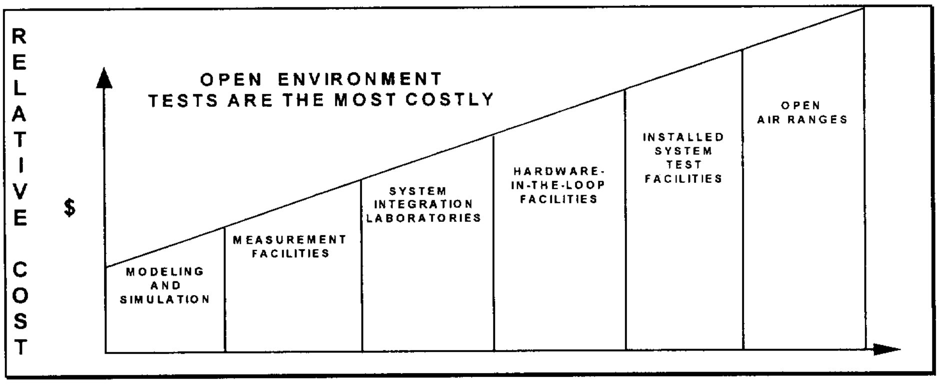

Figure 1-7 Relative Cost--T&E Resource Utilization [1]

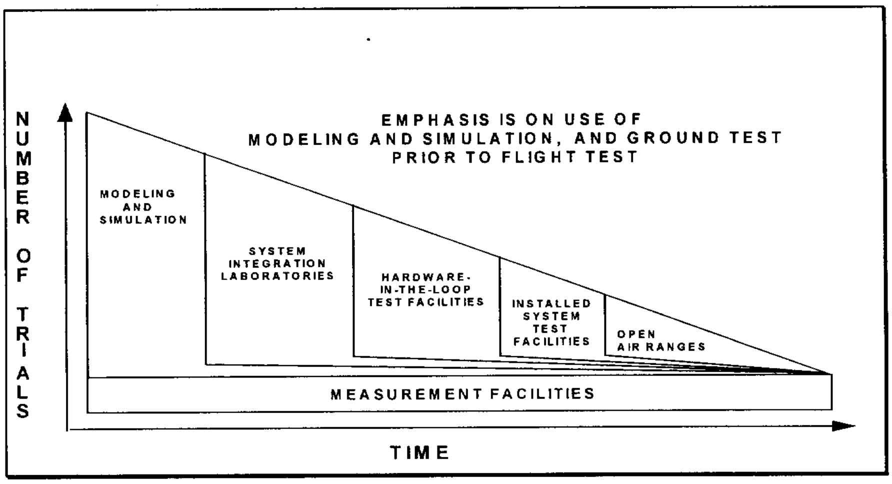

Figure 1-8 Relative Use--T&E Resource [1]

1.9 Safety Considerations

No introduction to EW test and evaluation would be complete without some mention of safety. Specific safety procedures must be developed and observed for each type of test in each type of facility. Some basic considerations should be obvious, but are all too often overlooked.

1.9.1 Electrical Shock Hazard

Many EW systems utilize high power transmitters requiring high voltage excitation for the final output stages. In addition, nearly all EW systems make use of either 115VAC or 28 VDC electrical power for operation. While these power sources are generally well protected when the system is installed in its operational configuration, they may be exposed and easily contacted during test activities. This is particularly true in the HITL and SIL environment.

1.9.2 Radiation Hazard

As metioned in the previous paragraph, it is common to find high power RF transmitters in Electronic Attack systems. Effects of human exposure to high intensity RF fields can very from minor reddening of the skin to severe and permanent damage to internal organs. High power radiation can also cause equipment damage. The most common opportunity for such damage is in anechoic chambers. The radar absorbent material (RAM) used in these chambers will absorb rather than reflect the RF energy from the systems in operation. The absorption of energy causes heating of the RAM. As a result, power levels must be carefully monitored and constrained to levels below that at which the heating of the RAM will result in a fire. Radiation hazards can exist in all test environments but are most frequently encountered in the ISTF and OAR testing phases.

1.9.3 Pyrotechnic Hazards

EW expendables such as chaff and flares rely on pyrotechnic (explosive) devices for ejection. One can easily imagine the results of an inadvertent firing of these devices during ground maintenance or test operations. Also, EW pods carried on centerline or wing stations of aircraft are frequently jettisonable. Unintended firing of the explosive charges that initiate the jettison sequence may result in both personnel injury and equipment damage. These pyrotechnic hazards are most likely to occur during ground test or preparation for flight test in the OAR testing phase.

1.10 The Test Plan

All test activities require careful planning to be successful. While test planning is not unique to EW, a mention of this element is made here for completeness.

Test plans come in a multitude of forms and formats; each created to ensure a specific requirement or group of requirements are satisfied in the most complete and efficient manner possible. Clearly, a complete description of the many forms of test plans is well beyond the scope of this document; however, we will discuss some of the key attributes and motivations for good test planning.

1.10.1 Cost and Test Budget

Few, if any, test programs have unlimited funding and so budgeting for each test event is critical. It is difficult to accurately predict the cost of an unplanned or poorly planned activity. Early in the program when test events are not clearly specified, the budgeted cost for testing will likewise be only a rough estimate. The sooner more complete test planning is accomplished, the sooner the test budget can be accurately determined. Generally, as the program progresses, the potential for acquiring additional funding is reduced. Poor budgeting at the beginning of the program will nearly always result in severe constraints on test execution and failure of the test effort to deliver the information required.

1.10.2 Schedule

As with the budget, the schedule for testing is affirmed through the development of detailed test plans. Test facilities needed to accomplish the desired testing may have very full schedules. Your chances of having access to the facilities you need, when you need them, is greatly increased if detailed test planning is accomplished early. The schedule tends to be a major driver for the budget. Inaccurate schedule projections will generally lead to budget discontinuities and, in the end, failure of the test program to deliver the required information.

1.10.3 Test Efficiency

Accomplishment of test events in the correct sequence can substantially reduce the amount of retest or regression testing required. Again, test planning is your primary tool to understand and analyze the best sequence of events. It is also the process where experienced testers accomplish the trade studies to assess how programmatic risk will be effected by elimination or insertion of test events.

1.10.4 The Bottom Line

It is the test planning process that permits a logical sequence of test activities with reasonable expectations at each stage. Data reduction and analysis, safety, and certainly a meaningful evaluation are all virtually useless (and probably impossible) without a carefully developed test plan.

2.0 TEST AND EVALUATION OF ELECTRONIC SUPPORT SYSTEMS

2.1 General Considerations

Electronic Support (ES) is that division of Electronic Warfare (EW) concerned with the ability to search for, intercept, identify, and locate sources of radiated electromagnetic energy. ES is used in tactical operations for situational awareness, threat avoidance, homing, and targeting. On-board radar warning, laser warning, and missile warning receivers, as well as many off-board surveillance systems, are considered elements of ES.

2.2 Radar Warning Receivers (RWRs)

Radar warning receivers have three basic components: some type of sensor (usually a set of antennas to capture the RF signals of interest), a receiver/processor to measure and analyze the RF signals of interest, and a display to make the information available to the pilot. There are numerous combinations of these components depending on the particular mission and configuration of the platform in which they are installed.

A typical RWR system, as shown symbolically in Figure 2-1, consists of an antenna array, an RF signal processor, and a control panel and display. For this example, four antennas, each with an azimuth beam-width of approximately 90 degrees, are used. The antennas are mounted on the aircraft 90 degrees apart in azimuth such that the entire perimeter of the aircraft can be monitored. On tactical aircraft the locations are usually 45, 135, 225, and 315 degrees with respect to the nose of the aircraft. Elevation coverage varies (usually around 30 degrees) and the pattern is biased 10 degrees or so below the horizon.

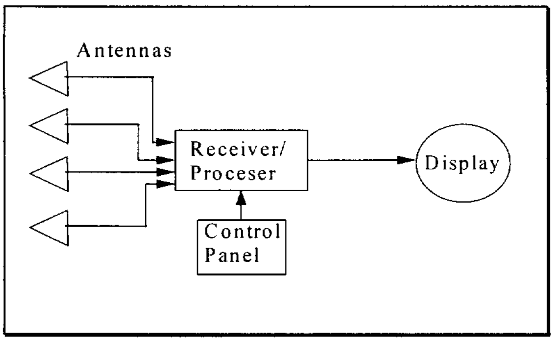

Figure 2-1 Simplified RWR Block Diagram

2.2.1 Receiver/Processor

The receiver/processor measures the magnitude of the RF energy at the four antennas and performs an amplitude comparison to see from which direction the RF energy is being radiated. The receiver/processor measures several other parameters of the RF signal. The time of arrival of each pulse referenced to an internal clock is determined. If the signal is Continuous Wave (CW), then the band the RF energy is in, or in some cases the actual RF frequency, is measured. The pulse width may also be recorded. Amplitude change over time may also be measured such that radar scan information can be derived. The amplitude of the signal can also be used to estimate the radar's range from the aircraft.

Through an iterative process of sorting the received signals in frequency or at least frequency band, and then subtracting the time of arrival of one pulse from the next, the time between pulses can be found. This is termed the pulse repetition interval or PRI. A CW signal will not have a PRI but is simply sorted as a CW. When data consisting of frequency, pulse width, PRI or CW, and scan are collated about one received RF signal, it is compared to a list of the parameters of known threat radars called a user data file (UDF). If the measured parameters match an entry in the UDF, the received signal is declared a threat and is displayed to the pilot.

2.2.2 Displays

The information provided to the pilot indicates the type of radar that is directing energy toward the aircraft and possibly its mode of operation, the direction it is radiating from, and an estimate of its range indicating its lethality. Many systems utilize a 3" (7.5cm) diameter CRT to present this information to the pilot. In newer systems the information may be presented on a page of a multi-function display. The displays are oriented such that the top of the display represents the nose of the aircraft and the bottom of the display the aft of the aircraft. There may be several concentric rings on the display that are used to separate the threats by lethality.

2.3 RWR Testing

When testing an RWR there are many factors to measure/consider. The high level requirements are easy to define. The system must be able to identify specific radars and place a unique symbol on the display at the correct angle, distance from the center of the display, in a specified amount of time. These requirements seem easily quantifiable. Specifications will detail the signals to be identified and which threat radar modes system will identify. The specification will also detail the required reaction time as well as how many signals the system can handle simultaneously. Several key subsystems or characteristics that must be tested and well understood will be discussed in greater detail in following sections. They are antenna performance, receiver performance, threat recognition capability, multiple signal environment operation, display quality, and interfaces.

2.3.1 Antenna Performance

Physical size and electrical performance in terms of gain versus frequency and gain versus angle of arrival of the signal characterize antennas. Ideally, RWR antennas would be small in physical size, and have a positive constant gain over all frequencies and all angles. For RWRs utilized on tactical aircraft it is possible to cover the 2-18 GHz band with 3dB beam-widths of approximately 90 degrees. Where an antenna is located on the aircraft can greatly influence the operation of the entire RWR. However, in most cases, the characteristics of the antenna are chosen to minimize the change in RCS on the host platform. Computer modeling is used to design antennas and antenna placement. Actual antenna performance is first determined at a measurement facility (MF) or antenna range designed specifically for the purpose of measuring antenna performance. Installed antenna performance is then characterized at an Installed System Test Facility (ISTF) or MF.

2.3.2 Receiver Performance

Receiver performance is critical to the overall performance of the RWR system because the quality of the receiver output determines what data the processor has to work with. It is difficult to talk generically about receivers because almost every receiver is unique to meet the specific needs of the system it was designed for. There are, however, a few common measurements that need to be understood. Receiver sensitivity is a key parameter because it gives a good idea about how well low power signals are measured. The most common measurement of receiver sensitivity is minimum detectable signal (MDS). MDS is the smallest power level value of an input signal that the receiver can detect. It must be made clear that the receiver is able to process the signal and not merely detect it. The operating range of the receiver is the frequencies where the receiver meets its MDS specification value. How well a receiver can resolve two signals close together in frequency (selectivity) is also very important. If the receiver is able to provide the processor more accurate frequency values, it will make it easier to distinguish between radars that are operating at nearly the same frequency. Different types of receivers operate differently in high signal densities and with simultaneous signals. The better the receiver operates in a high-density environment, the easier it is for the processor to properly identify and classify received signals.

2.3.3 Threat Recognition Capability

Probably one of the most visible measures of merit is how well an RWR can uniquely identify the radars it is programmed to display. Two features that greatly effect how well an RWR can do this are the detail in the user data file (UDF) and the measurement capabilities of the receiver. The UDF contains parameters to characterize the threats that are to be displayed or intentionally not displayed. Mission data file (MDF) is another name for these data. The parameters usually found in the UDF are: radar frequency operating range, pulse or CW operation, pulse width range, pulse repetition interval (PRI) range, scan type, and scan frequency range. These are just the basic parameters. Each system will have unique parameters to optimize identification accuracy and response time. The RWR must be able to identify the threat over its entire operating range of the modes it has been programmed to respond to. RWRs are usually only programmed to display the target tracking modes of threat radars but may have other modes of the radars in their UDFs to make sorting easier. The target track modes are the only ones displayed because they are the only ones that can lead to the launching of a missile or direct gun fire toward the aircraft. Threat recognition is tested by stimulating the system under test with the radar signatures it is designed to detect and viewing the response on the display. During these tests the display is monitored to verify key characteristics. The time required to process and display threat warnings, correct symbology, and proper location of symbology can be observed. Generations of unwarranted symbols (false alarms) and missed detections are also observed. The entire UDF needs to be verified by testing at the extremes of all the parameters. Initially, testing is conducted using only one signal at a time. Testing continues to increase in complexity when a multiple signal environment is used.

2.3.4 Multiple Signal Environment Operation

RWR performance in a dynamic, multiple radar environment is the only way to determine just how well the system will perform in its intended environment. However, when a multiple signal environment is encountered there are factors that can only be measured qualitatively. Dense signal environments are frequently generated using open-loop radar simulators when testing is performed on the ground and by pointing multiple radars toward the aircraft during flight test. The quality of the simulators can greatly affect the types of tests that can be performed on the RWR.

2.3.5 Display Quality

How "smoothly" a display changes when threats appear or change angle is very important to a pilot's ability to interpret the data being presented. How quickly the RWR will update the display to show relative position and priority changes can also be critical to the pilot's situational awareness. These features are difficult to analyze and usually not detailed in a specification. Operational testing frequently reveals the overall suitability of the display.

2.3.6 Interfaces

The RWR may be integrated with other on-board avionics. It may share information with the aircraft's radar, the jamming system to help each system resolve ambiguities, and be used in the decision criteria on whether or not an expendable will be utilized. Blanking schemes from the jammer, the aircraft's radar, or the radar altimeter may degrade the performance of the RWR. All these interfaces must be tested singularly and then in combination.

2.3.7 Ground Testing

There are many different ground tests during the development of an RWR system. Actual antenna performance should be obtained at a measurement facility built to perform that type of testing. An accurate way of positioning the antenna and measuring the resulting angle between source and antenna is important as well as spectrum analysis capabilities and computer processing capability to compute gain values and present data. Parametric testing, as discussed in Section 2.3.2, to determine the receiver performance should be accomplished during ground testing for two reasons. First, it is easier to access the hardware to conduct the tests, and second, it avoids waste expensive flight time with an immature receiver. Hardware-in-the-Loop (HITL) testing is a large part of ground testing and may be the first time the RWR system has seen a dense threat environment due to limited simulation ability at the contractor facility. In the HITL, threat recognition, display quality, and multiple signal environment capabilities are tested. Testing begins by stimulating the RWR system with a single threat emitter to determine the one-on-one receiver operation. After confidence is gained that the system is performing well one on one, multiple signal environments are tested. An ISTF is where the RWR system is first tested in the actual platform it will be used. This is the best place to perform interface testing because all the various avionics boxes are functioning together for the first time.

2.3.8 Flight Testing

Flight testing is the final step in the testing process. The RWR is installed in an operational configuration and flown against actual radars. Initial flights may consist of only one radar being turned on at a time to get a baseline capability and to verify the system is operating as it was during ground testing. More and more radars are turned on as confidence is gained that the system is performing as it should until all available radars of the test range are radiating against the RWR to provide as dense an environment as possible.

Of particular interest during flight testing will be the evaluation of false alarms. From an operational point of view false alarms erode aircrew confidence. False alarms are said to occur when the RWR indicates the presence of a radar known not to be in the environment at the time of the indication. Frequently testers attempt to characterize this phenomenon as "false alarm rate." This is an appropriate measure of performance (MOP) for a radar, but not for an RWR. The word "rate" implies that performance is characterized as a function of time alone. Certainly if a false alarm occurs once every minute, this would seem to be more problematic than if false alarms occurred only once an hour. However, what is more important is determining what fractions of all alarms presented are false. This approach leads to the appropriate MOP: False Alarm Ratio. This MOP should be extensively evaluated during SIL, HITL, and ISTF tests to bound the expected level of false alarms. Once this has been determined, flight tests can be planned to collect sufficient data to support calculation of the actual ratio for in-flight operation. As with all EW receiver performance tests, the types and quantities of threat simulators available at the OAR will be the primary constraint on the validity of the testing. Confirmation of the source of the false alarm is important and frequently difficult. In the OAR environment, for instance, it is possible that unintended signals may be observed from adjacent range activities. Knowing exactly what sources of RF emissions are visible to the test aircraft may be impossible. The only viable solution may be to repeat the test at different altitudes or time of day. In the final analysis, the tester must question if the RWR is generating false warnings, or is there an unintentional emission in the environment that actually represents the threat signal of interest.

2.4 Missile Warning Systems

Passively guided surface-to-air missiles are a significant threat to low-slow flying aircraft. These threats have accounted for the majority of aircraft losses in combat over the last 20 years. Passive threat warning systems, usually referred to as Missile Warning Sets (MWSs), are now operational on helicopters and transport aircraft.

Passive threat warning systems are designed to detect the electromagnetic radiation from the rocket motor of the threat missile. Detection can occur due to the rocket motor ignition (launch detection) or by detection of the burning motor during fly-out (in-flight detection). Most modern systems employ sensors that use a combination of the two types of detection. The problem to the passive warning system is to differentiate between the signature of the threat rocket motor and the various background sources that are always present. The inability to completely separate the background from the threat gives rise to system false alarms. This is probably the most important shortcoming of the passive warning systems. Since they operate in a totally passive mode, they must possess very sophisticated algorithms in the processor to detect and warn of threat missile approach in a very cluttered background. Figure 2-2 shows a simplified block diagram of a missile warning system.

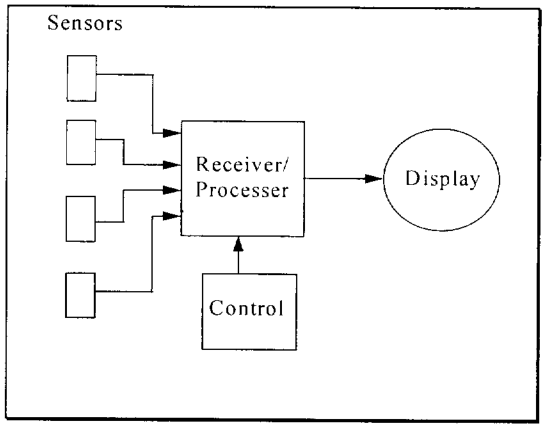

Figure 2-2 Simplified MWR Block Diagram

2.4.1 Sensor

From a sensor point of view, passive MWSs fall into two broad categories. Infrared (IR) passive warning systems were the first to be developed over 30 years ago. Present day systems can be either scanning or staring sensors. These systems normally operate in the mid-IR band (4 - 5 micrometers wavelength). Scanning systems provide high-resolution direction of arrival information that is often useful for effective countermeasures deployment. However, they generally give up some capability in the processing area because the time required to scan can prevent the MWS from detecting signature characteristics needed to identify the threat. Staring systems cover large fields of view (up to 90 degrees) continuously. The cost of this capability is often lower sensitivity because the system is looking over a larger area.

The second type of passive MWS sensor operates in the ultraviolet (UV) region. This portion of the electromagnetic spectrum features lower background noise than the IR region with good signatures from missile rocket motors. These sensors are typically low-cost, simple photo-multiplier devices that are very rugged. They are typically staring, wide field of view (90 degrees or more) sensors.

2.4.2 Processor

Threat detection algorithms are usually based upon a number of criteria. Signal-to-noise ratio is a fundamental parameter. The MWS looks for a signal that exceeds the background signal level from the environment. It looks for signal stability and possibly a particular signal amplitude growth which is characteristic of an approaching threat. It may also look for other time depend characteristics such as an ignition pulse followed by a short time delay before main motor ignition, a condition typical of shoulder-launched surface-to-air missiles.

The MWS algorithms must differentiate between a complex battlefield electronic environment or background from an approaching threat missile. This means that the processing software must distinguish between a ground source of radiation that the aircraft is flying toward (so its signature is increasing) from an approaching missile. The system must also differentiate from a missile that is approaching but not directly at the carrying aircraft such as a missile launched at another aircraft in the formation. These are very subtle situations for a passive warning system's detection and warning logic.

2.4.3 Display

A stand-alone MWS will have a very simple display providing aural and visual information. The aural information consists of tones to alert the pilot to a new threat and the visual information will be some estimate of the direction of arrival (DOA) of the approaching threat, usually only with quadrant resolution. An integrated MWS will most commonly use the display of the RWR to provide the pilot with missile warning information. However, the displayed information may not be any more sophisticated than a few simple tones and quadrant DOA information.

2.5 Missile Warning System Testing

While a multitude of parameters characterizes the operation of the MWS, two primary categories exist: effectiveness and suitability. Key effectiveness parameters that must be tested are probability of a threat declaration, warning time, false alarm rate, and flare dud detection. Suitability characteristics that must be evaluated are mission reliability, maintainability, processor re-programmability, as well as aircraft integration.

2.5.1 Effectiveness

The calculation of probability of threat declaration is not simply the number of missiles detected divided by the number of missiles fired. The system needs to be able to determine if the missile is really coming toward the aircraft of interest within a 10 to 15 degree window. It must be able to detect and warn of threat missiles at all ranges of the weapon with enough warning time to allow the system to respond with a countermeasure. A large number of false alarms or missed detections will rapidly erode aircrew confidence in the MWS. False alarm ratio is difficult to define and determine. It is necessary for the MWS development team to arrive at clear definitions and means of calculating probability of detection and false alarm ratio prior to the start of testing. Flare dud detection is the ability of the warning system to determine that the dispenser system that is associated with the warning system launched a flare that did not ignite and signal the dispenser that it needs to launch another flare.

2.5.2 Suitability

Key drivers in the suitability evaluation will include reliability, maintainability, re-programmability, and aircraft integration issues. Reliability and maintainability are determined as in other devices using statistical data acquired over time. Re-programmability characterizes the process of changing parameters or algorithms in the system to meet new threat scenarios. Aircraft integration is how well the MWS interacts with the dispenser system and other aircraft sub-systems.

2.5.3 Ground Tests

Ground tests are broken down into three areas: qualification testing, hardware-in-the-loop testing, and integration testing. Qualification testing is usually performed at the developing contractor's site. This testing is a first look at the capability of the developing system. Parameters such as sensor field of view and sensitivity are measured. In hardware-in-the-loop testing, the processor algorithm optimization process begins. Sensor output data, usually in a digital format, from actual flight testing are recorded and played into the processor. This allows for repeated tests without actually flying the system. During integration testing, various components of the system are tested together as well as with any other avionics that they may have to interface with.

2.5.4 Flight Tests

Flight tests can be broken down into two areas: background testing and live fire testing. Background testing involves the system flying on an actual aircraft even though it may not be the platform the system is being designed for The purpose of the test is to collect actual "Background" environment data with the sensor. If false alarms occur, the sources are determined and as much data are collected as possible to be used for analysis to again modify the algorithms to eliminate or at least minimize the number of false alarms. A database of responses is maintained for future analysis. Live fire testing, where remotely piloted vehicles or other unmanned platforms are used to carry the MWS, tests the system in as close to a tactical environment as possible. Real missiles are fired at the platform containing the system to evaluate its combat effectiveness.

2.6 Laser Warning Systems

Airborne laser warning is currently provided mainly for low and slow aircraft. Priority was given to this class of aircraft because it has been the most vulnerable to past laser threats. Primarily, these threats include rangefinders for anti-aircraft artillery (AAA) and surface-to-air laser beamrider missiles. However, the development of higher-performance beamrider missiles and designated missiles is increasing the laser threat to high-performance, tactical aircraft. Also, the use of a laser rangefinder in conjunction with AAA poses a threat to tactical aircraft. For these reasons, there have been efforts to develop laser warning for tactical aircraft.

There really isn't a "typical" laser warning system (LWS). However, the modules required are essentially the same as in a missile-warning receiver as shown in Figure 2-2. In general, these systems consist of sensors to detect the laser signal, a processor to analyze the sensors data, and a mechanism to warn the pilot.

2.6.1 Sensor

The minimum angular resolution for laser warning is quadrant, and this resolution is provided by currently deployed systems. However, for certain countermeasure applications, a much more accurate angular determination of the threat location will be required. As with most sensor technologies, angle-of-arrival determination for laser warning systems continues to improve. These improvements drive test facility and instrumentation requirements to accurately measure system performance.

2.6.2 Processor

The primary requirement for a laser warning system is to provide detection of a laser range finder. This threat is common, occurring in large numbers in many countries. Generally, LWSs have provided detection but not measurement of the actual wavelength of the threat. Precise knowledge of the laser wavelength could be important if countermeasures are to be employed. Systems capable of wavelength measurement have been developed, but not deployed.

An additional wavelength requirement for laser warning systems is in the mid-infrared spectral region. This capability has generally been provided in systems that have been developed, but has not been considered to have much importance. However, this attitude is changing as new, eye-safe threats are coming on line. Eye-safe lasers (operating above a wavelength of 1.54 micrometers) are increasingly being used as military units seek systems that can be used safely in training and that will eliminate accidental exposures.

Any viable laser warning system must provide the capability to detect the laser beamrider. This is a serious threat, especially to low and slow aircraft. The detection problem is difficult because the beamrider laser puts an extremely low energy density on the target.

2.6.3 Display

To reduce weight and space requirements, the approach for laser warning has been to integrate the display with the display of some other system aboard the aircraft. Until now, this other system has always been the radar-warning receiver. Recently, with the deployment of reliable missile launch detection systems, the thinking has been to integrate laser warning with the missile warning system. This approach does make more sense, since often, as in the case of a laser beamrider missile, threat verification can be enhanced by the simultaneous detection of a laser threat and a missile launch.

2.7 Laser Warning System Testing

To completely evaluate a laser-warning receiver, several important parameters need to be measured both on the ground and in airborne tests. The same parameters can be measured in both ground and airborne tests, but generally, more detailed and accurate results are obtained in ground tests because the scenario is more easily controlled. Flight tests must be conducted to verify that neither installation nor integration with other avionics has significantly altered system performance. Usually a smaller sample size is obtained during flight test. The data are then compared with ground test data to show correlation. The important parameters to measure are described below.

Sensitivity: This parameter determines the maximum range at which a receiver can detect a threat. Also, it determines the off-axis detection capability of the system. Off-axis capability is important because often the receiver aperture will not be located in the main threat laser beam. The receiver must be sensitive enough to detect the laser in the outer regions of the beam cross-section. This is especially true for large aircraft.

Field of View and Angle of Arrival: Some laser receivers are capable of determining the threat location to within a few degrees. Others provide only quadrant information. Usually, sensitivity falls off at the edges of the field of view. The field-of-view response must be characterized to determine if there are any holes in the coverage.

False Alarm Rate, Ratio, and Susceptibility: False alarm rate is how often a non-threat source is declared a threat. This is a time dependent measurement and does not inherently consider the electromagnetic environment. False alarm ratio characterizes the false alarm problem in terms of the signal environment. Both measures should be considered. Each LWS needs to be evaluated to see how susceptible it is to common false alarm sources.

Dynamic Range: The range of irradiance levels that the LWS can measure and correctly operate over is called the system's dynamic range. The irradiance produced by a laser threat at the target can vary greatly, depending on whether the receiver is in the main beam or only in the scattered radiation at the edge of the beam. Type of laser and distance can also effect the irradiance received. Receiver performance is often found to be degraded at both the high and low ends of the dynamic range.

Wavelength Determination: Most laser receivers determine the wavelength of the threat, some only in broad wavelength bins, others quite accurately. Knowing the threat wavelength can be useful in determining the type of threat and any potential countermeasure action. For both ground and flight tests, lasers with as many different wavelengths as possible should be available. Of primary importance are the wavelengths 0.905, 1.06, and 1.54 micrometers.

Beamrider Detection: The laser beamrider missile is an increasing threat to aircraft. It presents a special detection problem because of the extremely low irradiance levels involved. A beamrider simulator should be provided for ground and airborne tests that can produce not only the proper wavelength, but also the proper pulse coding because detection algorithms used to get good sensitivity can be effected by the pulse code format.

2.7.1 Ground Tests

Laboratory tests are used to put numbers on most of the performance characteristics of a laser warning receiver. Tests on the flight line are always performed before flight tests to ensure that the system will function properly in an outdoor environment. For example, bright sunlight and atmospheric visibility can effect receiver performance. Initial sensitivity measurements are made in the laboratory to determine the minimum detectable signal (usually measured in watts per square centimeter). This value is determined for several positions in the receiver field of view by placing the system on a rotary turntable. Since receiver sensitivity is degraded when operated in bright sunlight, sensitivity is also measured in outdoor tests. However, the numbers obtained in this case are not as accurate as laboratory measurements because atmospheric scintillation causes fluctuations in the received power density. Off-axis detection capability is also measured in outdoor tests. Field-of-view and angle-of-arrival measurements are best accomplished in the laboratory, but are usually repeated in both outdoor ground tests and airborne tests. In laboratory and outdoor tests, several false alarm sources (strobe lights, firearms, sun glint) are used in the field of view of the receiver to determine susceptibility to optical false alarms. If possible, electromagnetic interference and compatibility (EMI/EMC) testing should be conducted. Dynamic range is best measured in the laboratory.

2.7.2 Flight Tests

Flight tests are conducted to determine if there are problems unique to the flight environment. These problems can include compatibility with other aircraft systems, electromagnetic interference, field-of-view restrictions, scattering of laser radiation from aircraft surfaces, and aircrew operational interface. Airborne tests are also conducted to ensure that the receiver can perform in an aircraft environment (vibration, temperature, pressure and EMI/EMC). In addition, flight tests are useful in evaluating maximum detection range and false alarm rate in an operational environment. Maximum detection range is determined in airborne tests by flying the aircraft inbound and outbound to the threat and noting at which point detection is obtained or lost. The maximum range also needs to be measured for various locations in the receiver field of view. This is accomplished by flying racetrack patterns at various ranges from the threat. In the case of helicopters, a series of hover-turns are performed at various ranges. False alarm rate is best determined by obtaining several flight hours over various types of terrain, including primarily water and urban locations. Atmospheric scintillation can effect the angle-of-arrival accuracy, and aircraft parts can effect the field of view. Even for quadrant detection systems, it is important to determine how the receiver handles the transition region between quadrants.

3.0 TEST AND EVALUATION OF ELECTRONIC ATTACK SYSTEM

3.1 General Considerations

As presented in the Introduction, Electronic Attack (EA) is the use of electromagnetic or directed energy to attack personnel, facilities, or equipment. There are four basic sub-divisions of EA; jamming, deception, anti-radiation missiles (ARMs), and directed energy weapons. Jamming is generally defined as deliberate radiation, re-radiation, or reflection of energy for the purpose of preventing or reducing an enemy's effective use of the electromagnetic spectrum. With recent advances in technology and more frequent use of spectra outside the electromagnetic range, this definition can be extended to cover similar action against infrared (IR), ultraviolet (UV), and electro-optical (EO) systems. This section will discuss RF countermeasure systems, IR countermeasure systems, and the associated dispensers and expendables.

3.2 RF Countermeasures System Description

An RF Defensive Electronic Countermeasures (DECM) system has four basic components. Similar to the RWR it has some type of sensor to capture the environment, in this case an antenna, a receiver/processor to analyze the data, and a pilot interface, even though it may be very simple. However, in addition to these components, the DECM system has a modulator/transmitter module used to modulate and amplify the jamming waveform. The system also includes a transmit antenna or antenna array to radiate the appropriate jamming. Figure 3-1 is a simplified block diagram of an RF DECM system.

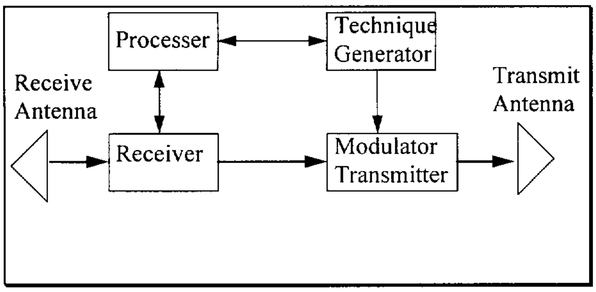

Figure 3-1 Simplified Jammer Block Diagram

3.2.1 Sensors

The sensor collecting the RF energy is sensed using antennas. Typically two antennas for each band of interest are employed, one pointing fore and the other aft.

3.2.2 Receiver/Processor

The receiver/processor must do all the same type of sorting as is done in an RWR to uniquely identify a threat so it knows what response to make. The receiver/processor must also "track" the incoming signals in time or Doppler position to know the targets "location" in range or velocity relative to the aircraft. The receiver/processor must also generate "techniques" that will disrupt the tracking of the threat. Major categories of jamming techniques include range, Doppler, and angle techniques. The techniques are selected from another section of the user data file (UDF). Developing the techniques in the UDF is a major task in itself. The technique generator may use oscillators, or a part of the incoming signal, and time, frequency, and/or amplitude modulate the signal to achieve the desired technique.

3.2.3 Displays & Controls

The pilot interface usually consists of a control pane for selection of system operating modes and indicator lights identifying the threat environment. Typical operational modes for the jammer consist of standby, receive only, and transmit.

3.2.4 Transmitters

The transmitter module amplifies the technique selected and is connected such that it radiates the response either through a separate set of antennas or uses the receive antennas in a timesharing fashion.

3.3 RF Countermeasures System Testing

Certain critical capabilities of a jammer must be understood and their parameters measured and evaluated. These capabilities are: antenna performance, receiver performance, transmitter/exciter performance, threat recognition ability, countermeasures generation/effectiveness, multiple signal environment operation, interfaces, ground testing, and flight testing.

3.3.1 Antenna Performance

Antenna performance is highly dependent on antenna position on the host platform. Unfortunately, the jammer antenna position is usually an afterthought in the overall aircraft design and may not have the coverage required to adequately protect the aircraft. The distance the antennas are from the internally mounted system will also effect the coverage because of line losses to simply reach the antenna. In most applications, coverage is best fore and aft of the aircraft with lower gain broadside. This may seem unusual because the aircraft will have a larger cross-section broadside and it would appear to be smart to put the best coverage there. However, most engagements end up with the threat in either a fore or aft aspect. In other words, the DECM system is optimized for these end game conditions.

3.3.2 Receiver Performance

Accurate receiver performance is required for an effective DECM system because the receiver output is all the processor has to analyze to both determine what the threat is but also how to counter the threat. It is difficult to talk generically about jammer receivers because each must be uniquely matched to the particular jamming components it is to work with. There are however a few common measurements that need to be performed on the receiver. Receiver sensitivity is a key measurement because it gives a good idea about how well low power signals are received. This will hopefully allow the jammer to correctly identify the threat before the system is within firing range, and therefore be prepared to counter it when it does come into range. In general, more sensitivity is better. However, to achieve higher sensitivity one must look over a smaller bandpass and therefore it may take longer to search the entire RF range of interest. How accurate a receiver measures the frequency of a threat is important in a jammer because the jammer may use this measurement to tune a transmitter to that frequency to generate RF energy that will be received by the threat radar. The measurement must be accurate to within several megahertz to be in the bandpass of the threat radars receiver. Several other general desirable receiver characteristics can be found in Section 2.3.2 on RWRs.

3.3.3 Transmitter/Exciter Performance

The effective radiated power (ERP) of the DECM system is very important because in most cases the more power being radiated the better the effectiveness of the technique. ERP is the power of the transmitter minus the power lost through transmission lines to the antenna plus the gain of the antenna. So ERP of the ECM system installed on the aircraft is frequency dependent and angle dependent and directly proportional to the power of the transmitter. Another calculation that is helpful in evaluating the effectiveness of a jamming technique is the J/S ratio. The "J" is the power of the jammer at the input to the receiver of the threat radar, and the "S" is the power of the radar reflected off the aircraft at the receiver of the radar. It is beyond the scope of this document to thoroughly explain J/S ratio; however, a basic knowledge is required. The J/S ratio is almost always measured in dBs. A positive J/S means that the jammer signal is larger than the skin signal. A jammer with a much smaller ERP than a radar can still achieve positive J/S ratios mainly because power decreases as a function of R squared where R is the range between the aircraft and the radar. The jammer only has a one-way loss ($1/R^2$) whereas the radar has a two-way loss ($1/R^4$). The smaller the cross-section of the aircraft the less energy that can be reflected off of it. This decreases the strength of the radar return. In fact, RCS reduction can be considered another type of countermeasure and needs to be included in overall platform countermeasures capabilities. Types of antenna polarization and the actual frequencies being used also affect the J/S ratio.

The transmitter is supposed to only amplify and output the specific signal injected into it. However, the output of the transmitter needs to be monitored to see that it does not produce "extra" or spurious signals. Spurious signals are most likely to occur at harmonics of the injected signal but they may appear anywhere in the spectrum due to errors in system design, manufacture, or installation. These spurious signals can be used by the threat's counter-countermeasures and waste valuable jammer power intended to defeat the threat.

3.3.4 Threat Recognition Ability

A countermeasures system needs to be able to identify the threat before it can respond with a technique that has been optimized for that threat. Therefore, a major requirement for a countermeasures system is that it be able to uniquely recognize as many radars as possible. This capability is a function of the receiver as well as the processing features of the countermeasures system.

3.3.5 Countermeasures Generation/Effectiveness

Countermeasures generation is one of many functions performed in the processor. Over the last 50 years as radars have evolved, ways to defeat radars called countermeasures "techniques" have also evolved. A countermeasures technique makes the victim radar think the aircraft is somewhere other then where it actually is. This is accomplished by modifying a target return in time, amplitude, or frequency. The jammer may also generate enough power (noise) to simply "hide" behind.

Technique effectiveness must be evaluated with respect to the specific radars to be defeated. These evaluations vary in sophistication based on the data available about the threat radar. Parametric ranges of the technique generator can be defined after the total range is determined based on which radars the system is to be capable of jamming. To perform effectiveness evaluations, a thorough understanding of the threat radar is required. Ideally, this would encompass first having complete documentation of the victim radar to analyze the signal processing and tracking algorithms. Next, analysis on a computer model of the radar is accomplished. Then laboratory testing is conducted to gain a broad understanding of the technique ranges that are effective against the radar. Finally, flight tests against the actual radar are conducted. However, rarely do all these opportunities exist. Either all the test assets do not exist or there is not enough time or money to utilize them.

How effective a jammer is against a specific radar can be measured several ways. The easiest measurement of effectiveness to understand is "miss distance." An effective technique may cause the missile guidance radar to misguide the weapon to the target. The degree of error in missile guidance caused by the EW technique is characterized as miss distance. If it is possible to test against an actual system, you may actually be able to fire a missile. More likely though, even if an actual radar is available, it is too expensive to fire a missile; so tracking error data will be collected from the radar and input into a computer model of the missile to obtain missile miss distance estimates.

These steps would allow you to optimize the technique against a particular radar. It must also be understood that the optimum technique may not be the best solution to actually program in the jammer because the jammer must have enough resources available to respond to multiple signals. Sometimes a less than optimum technique is utilized so the system may work better in a multiple threat environment.

3.3.6 Multiple Threat Environment Operation

The jammer's ability to operate in a multiple threat environment is the most difficult capability to evaluate because many things are occurring at one time. The ECM system's operation in a multiple threat environment is however the best indication of how well the system is operating. The multiple threat environment is what the system will see in combat, and the test scenarios need to be developed to match as closely as possible the environment that the system is expected to see in combat.

3.3.7 Interface/Integration Testing

The ECM system may be designed to interface with other onboard avionics. A likely interface is some kind of communication with the RWR to possibly help resolve ambiguities. A blanking scheme may also be in place. Blanking is where either the ECM system tells the RWR to not look at a certain time because it is transmitting and the RWR will receive bad data or the RWR signals the jammer not to transmit because it is looking for threat signals in the environment. This interface needs to be well thought out because the possibility exists for the RWR to tell the jammer not to transmit right when it is in the process of defeating an incoming missile. Modern interfaces include a communication with the aircraft computer to present either RWR or ECM data to the pilot on a multifunction display.

3.3.8 Ground Testing

There are many different ground tests during the development of a DECM system and many are identical to the tests performed on an RWR as detailed in Section 2.3. Actual antenna performance needs to be characterized at a measurement facility. HITL testing will expose the ECM system to realistic threat signals and a dense threat environment. Parametric testing of the receiver and transmitter are usually conducted at the contractor facility but spot checks should be done in the HITL to assure system is still performing to specification. In the HITL, threat detection, identification, technique generation, and multiple signal environment capabilities are determined. The testing begins by stimulating the ECM system with a single open-loop threat emitter to determine the one-on-one system identification operation. Techniques generated can be monitored on a spectrum analyzer. Technique effectiveness can be tested with closed-loop simulators; first one-on-one and then in a multiple signal environment. After the HITL tests are completed the system moves on to an ISTF where the ECM system is first tested in the actual platform in which it will be used. Electromagnetic interference tests are performed at this time. An ISTF is the best place to perform avionics interface testing for the entire platform databus structure. Interface testing involves exercising every link that will be operational during flight. Again, the rule is to start slow. Test only two systems at a time and then, when basic interfaces are found to be performing correctly, add more systems on line. EMI and EMC testing is also performed at the ISTF. Installed antenna patterns can be investigated in the ISTF environment. Some EW-oriented ISTFs can produce closed loop, high signal density, dynamic test scenarios.

3.3.9 Flight Testing

Flight testing is the final step in the testing process. The ECM system is installed in an operational configuration and flown against actual radars. These radars may be actual threat radars or high fidelity simulations. The tester must thoroughly understand the capabilities of the radar systems employed. Planning flightpaths and maneuvers to take full advantage of the test assets is a critical part of Open-Air Range (OAR) flight tests. Instrumentation and the availability of data products may have a bearing on which flight profiles and test conditions are utilized. Initial flights may consist of only one threat system being turned on at a time to get a baseline capability and correlate in-flight operation with ground test observations. Effectiveness data can be collected and should be compared against laboratory results. More and more threats are turned on as confidence is gained that the system is performing as it should. A wingman scenario may be required to determine if there is any interaction with the on-board avionics between the two aircraft. In particular, an evaluation of the jammer's threat identification capabilities in the presence of other friendly aircraft can be critical.

3.4 IR Countermeasures

Conventional infrared (IR) jammers are electrically powered countermeasures (CM) sets designed to provide aircraft with protection against heat-seeking missiles. They are the electro-optical (EO) analogue of RF jammers. These incoherent IR jammers are "turn-on and forget" pieces of equipment which provide continuous CM protection in flight.

The IR jammer provides CM protection against threats depending upon the particular seeker IR spectrum bandpass and electronic technique of processing the incoming target IR radiation. These IR jammers are generally characterized as having 1) a wide IR spectrum (1 to 5 micrometers) in which pulsed IR radiation is emitted, and 2) a wide field of view (180 to 360 degrees azimuth coverage is nominal). The CM techniques for some of these EW systems can be changed while in flight to provide different protection levels to different threat classes.

A common technique to enhance the IR jammer CM performance is to reduce the IR signature of the target aircraft. This can be accomplished by a variety of means: installing engine exhaust suppressers or by using low IR signature paint on the aircraft fuselage. To further enhance IRCM performance, flare expendables are often used with IR jammers.

Generally, a complete IR jammer system consists of one or several transmitters, a modulated power supply, and pilot control indicator. The system radiates a modulated IR signal designed to disturb the detection and/or tracking functions of an incoming IR guided missile and cause it to miss the intended target aircraft. A complete IR CM system can weigh as little as 40 pounds to more than 200 pounds. The input power requirement can vary anywhere from 1000 watts to over 3000 watts. However, there is a tradeoff in increasing IR jammer radiated output power with increased jammer volume and input power consumption. This limitation effectively restricts the IR jammers in production to the simpler Bands I/II/IV threat classes as opposed to the more complex IR seekers such as IR imaging seekers.

A unique feature of these systems is that there is no sensor. The systems are operating using a priori data. They do not provide any threat missile warning to the pilot or to other electronic devices on board the host aircraft.

3.4.1 Processors

The "processor" of an IR countermeasures system is a modulated power supply that is used to drive the transmitter. Through threat analysis or exploitation, the scanning frequencies of the missile tracking circuits are determined and these frequencies are programmed into circuitry used to modulate the power supply. The modulated power supply is either present as stand alone hardware in the cargo bay area or integrated in the transmitter. In both cases, manual switches are present to allow selection of preprogrammed jam codes. Additional CM codes can be preprogrammed as new threats are defined.

3.4.2 Controls and Displays

The pilot interface is through a control indicator located in the cockpit. The pilot control indicator is either a stand-alone module for the IR jammer or it is shared with an another EW system. The interface is usually quite simple, only providing a means of turning the system on or off and a way to alert the pilot that a malfunction has occurred.

3.4.3 Transmitter

There are several methods to generate the required IR countermeasures pulses. One technology uses heated carbon-material rods and mechanical modulation techniques to generate the pulsed IR radiation to confuse the incoming missile seeker. Another technology uses an arc lamp in a vacuum tube, which is electronically modulated to provide the required pulsed IRCM radiation.

The IR transmitters usually have a wide field of view (180 to 360 degrees in azimuth). The usual placement of the IR transmitter is as close to the engine exhaust as possible since most of the IR threat missile seekers tend to initially acquire and lock onto this 'hot spot.'

3.5 IR Countermeasures System Testing

A major figure of merit for IR jammer effectiveness is the jammer-to-signal ratio that the system can achieve. Specifically, the higher the amount of modulated radiation output (provided by the jammer) over the host aircraft signature, the better the IR countermeasures performance will be in countering the threat of the same IR spectrum bandpass. Depending upon type of jammer and threat seekers, the minimum J/S ratios for 'acceptable IR countermeasures protection' vary from about 2 to 10 dB depending upon jammer type and particular threat.

3.5.1 Ground Tests

In a laboratory environment, the jammer signature can be measured with great precision with a radiometer. In the field, the host aircraft signature can be measured and used to calculate the J/S if the measurement range, angle (azimuth and elevation), and meteorological conditions (barometric pressure, ambient temperature, and relative humidity) are known along the measurement range. Careful instrumentation calibration is essential for repeatability of IR measurement data points.

Air-to-ground testing is another way of obtaining simultaneous measurements of both jammer and signature in the field. Normally, if the target aircraft is a helicopter with an IR jammer on board, several 360 degree azimuth passes at several different altitudes would be conducted for a fixed ground-located J/S radiometer. This test would generate J/S ratio signatures for several elevation look angles and for the IR bands of interest.

3.5.2 Flight Testing

This 'realistic condition' testing is much more expensive and harder to accomplish than air-to-ground testing since it would involve two aircraft [target aircraft plus chase/measurement aircraft]. The resultant IR data can be used in the J/S ratio analyses if the J data parameters are known with certainty for the test conditions which the S-only data were collected.

3.6 Dispensers and Expendables

Dispensers usually consist of a number of modules which when integrated become an operational dispensing system. Typical components include a cockpit control unit, a programmer, sequencers, the actual dispenser and magazine, and a safety switch. Expendables are the items that are literally fired out of the magazine and are designed to present a target-like signature to the attacking missile. Dispensers are somewhat unique in that they usually rely on another system as the sensor that triggers the operation of the dispenser. Either a missile warning system, a radar warning system, or an aircrew member will initiate the command to start dispensing expendables. Figure 3-2 shows a simplified block diagram of a dispenser system.

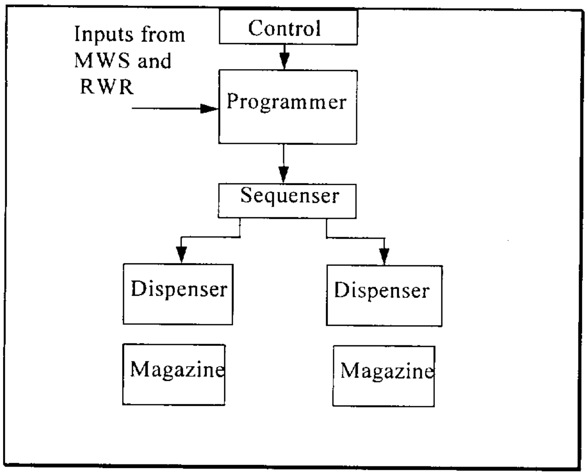

Figure 3-2 Simplified Dispenser Block Diagram

3.6.1 Control

The Cockpit Control Unit provides the operator interface. It may be a separate module providing mode and status control or be provided by interfacing with other EW systems. Dispenser mode and status may be shown on the RWR display. Another option is that the dispenser is interfaced through the aircraft's mission computer to be displayed to the operator via another cockpit display.

3.6.2 Programmer

The programmer receives the inputs from either the MWS or the RWR and automatically decides what dispense technique to use. On most systems, the pilot may also be able to manually program data to dispense a particular number and type of expendables for a known threat. When a missile warning indication is received, the pilot can then press a switch to dispense a predetermined number and type of expendables if he or she does not wish to use the automatic program. In some cases, the dispensing system will be operating on a data bus where it can receive aircraft attitude and navigation data to further help in determining what dispensing program to use. Also, the dispenser may send data to the aircraft's mission computer providing status of the dispenser system.

The programmer is the dispensers' processor and is where both the Operational Flight Program (OFP) and the MDF are located. Typically, dispensers developed today are designed to operate with threat optimization dispensing. This means the OFP and the MDF will tailor the dispensing programs for the environment in which the platform is operating. The OFP contains algorithms that calculate and dispense the expendables as a result of aircraft attitude data and threat data. The OFP works in conjunction with the MDF data to determine appropriate threat responses. Specific data typically included in the MDF are:

Threat Data: Threat data consist of the parametric data that define the threat system. Pulse width, RF frequency range, amplitude or scan modulation, and pulse repetition frequency are typical RF threat parameters.

Response Data: Response data involve the specific dispensing technique against a known or identified threat. Responses consist of IR expendables, RF expendables (chaff), or a combination. Dispense techniques are defined by the quantity and intervals at which the expendables are deployed.

Payload Data: Payload data identify the types of expendables loaded into the dispenser and are available to be dispensed. During flight, the system monitors the magazine to keep track of how many expendables and of what type have been used.

3.6.3 Sequencer

The sequencer distributes power and commands to the dispensers. The sequencers perform payload inventories and determine if a misfire has occurred. Typically, one sequencer is used for every two dispensers.

3.6.4 Dispenser

The dispensers are housings for the magazines and are installed in the aircraft at the location where the expendables are to be released.

The magazines are the modules that actually hold the expendables. Before the individual expendables are inserted into the magazines, the "squibs," the firing mechanisms, are inserted into the magazine; one squib for each expendable. Squibs can only be used once and must be replaced like the expendables. Expendables are then loaded into the magazines in a safe area and then an entire magazine is inserted into a dispenser housing before each flight. Typical magazines on tactical aircraft hold approximately 30 expendables.

The safety switch is specifically mentioned here to highlight the need to be careful around the pyrotechnic devices that make up part of the expendables package. The switch, when engaged, does not allow any current to reach the dispenser, thus eliminating the chance of an accidental squib firing.

3.6.5 Expendables

Expendables exist to defeat both IR and RF threat systems. The most common examples are flares that go against IR missiles and chaff to go against RF systems, both radar and missile. There are numerous configurations for both chaff and flares. Conventional flares are made of various combinations of magnesium, phosphorus, and teflon which is ignited when the flare is dispensed from the magazine and tries to "look" like the aircraft engine radiation. More sophisticated flares using new materials are currently being developed that will more closely represent the signature of the aircraft.

Chaff is made of metal coated glass fibers or aluminum foil strips. When dispensed it separates in the air stream and tries to present a larger cross-section than the aircraft and capture the tracking functions of the threat radar. The radar or missile will then track the chaff and not the aircraft. RF "decoys" that are actually small repeater jammers are the latest entry into the realm of expendables. These devices can be dispensed in flight and towed behind the host aircraft to create a missile to track the decoy and miss the aircraft.

3.7 Dispenser and Expendable Testing

System hardware testing includes verifying that each separate module is functional and operates within system design parameters. Power tests, continuity tests, voltage tests, and built in tests (BITs) are performed. These tests help to isolate any hardware configuration or interface problems. System software tests are performed on the module that contains the system software programs. These tests help to isolate any programming errors or timing errors, and verify that the system software has been correctly programmed and all software functions are performed. Thorough software testing is critical to assure that complex functions are properly executed and that latent coding errors are not introduced. Such errors can not only impact system performance, but may effect safety and survivability. Both manual and automatic dispense "programs" that have been loaded into the MDF are confirmed.

System integration tests are conducted to ensure that all system modules will function as designed when connected together as a complete system. All modules are continuously tested to verify the dispenser system will operate with other avionics systems installed in aircraft. These tests help to isolate system integration problems.

Suite integration testing involves connecting the avionics systems and EW systems that the new dispenser system will be working with, and monitoring the operation. The dispenser system is usually connected via a Mil-Std-1553 or similar data bus. Also, an actual aircraft computer is connected, or the computer is simulated, to help identify any software interface problems. These tests will uncover compatibility problems between systems and also any bus problems that may occur. Suite integration problems may be very subtle and difficult to isolate due to the number of hardware and software systems involved.

Expendables are tested according to design specifications and requirements. Parametric data recorded for IR expendables include time to ignite, total burn time, spectral emission, and intensity. RF expendables are tested to measure RCS, "bloom" rate, which is how fast the expendable can achieve the desired RCS, fall rate, and actual frequency range over which the RCS can be achieved.

3.7.1 Ground Testing

In laboratory tests, system components are cycled through all switch settings. Dispenser outputs are monitored with test equipment to verify output performance as a function of input parameters. Initial interface testing is also conducted with other avionics/EW systems to verify correct interface operation between systems.

Laboratory tests provide simulated threat parameters to be injected into operational integrated dispenser suites to verify that the EW Suite will perform as specified in a near-real environment. Operational dispenser programs are monitored and verified against known threat input to ensure threat detection, identification, and countermeasure techniques are correct. Dispense techniques may require that several expendables be launched in a specific pattern to be effective against certain threats. Timing sequences are measured for accuracy.

During installed system test facility testing, dispenser systems are installed in an aircraft and all functional tests are repeated to verify the system operates properly in an operational environment. These tests are conducted to verify electrical, mechanical, software, and EMC/EMI issues have been resolved.

3.7.3 Flight Testing

Unlike jammers, RWRs, and Electronic Support Systems, dispensers, and their associated expendables can only be fully evaluated in flight. Their overall effectiveness is dependent on not only the characteristics of the countermeasure but also on the aerodynamic effects at the time of launch. In addition to characterizing the effectiveness of these countermeasures, testing must be accomplished to ensure that the performance and utility of the aircraft are not adversely effected. Flight tests are conducted with EW dispenser systems installed in or on the aircraft for which they are intended. Flight tests are performed to verify all systems are integrated and performing to design specifications. Aircraft are flown against real and simulated threats at an appropriate OAR.

4.0 TEST AND EVALUATION OF ELECTRONIC PROTECT (EP) SYSTEM

4.1 General Considerations

EP is that action taken to negate the effects of either enemy or friendly EA that would degrade, neutralize, or destroy friendly combat capability. This section discusses several examples of EP systems and offer examples of test objectives, test methods, and analysis that can be applied.

4.2 Electronic Counter Countermeasures (ECCM)

In general, the major component of EP is what is often called electronic counter-countermeasures (ECCM). These ECCM techniques are most often part of a non-EW system that designers hope to protect from EA. For instance, an airborne intercept (AI) radar in a fighter aircraft will frequently be the victim of jamming attempts. If the radar designer can predict the types of jamming that will be. applied to the radar, then he/she may be able to design a 'fix' to negate the jamming effects. These techniques are called ECCM or EP.

Testing ECCM usually requires the application of various threat EA techniques. This becomes a particularly difficult problem in most cases since potential adversaries tend to protect their EA techniques at high security levels. On the other hand, generic EA techniques are well known so testing against classes of EA is practical.

4.2.1 EP Techniques

EP techniques tend to be the result of developments of EA capabilities. Most EP techniques are defined in relation to how they counter a specific EA threat. Usually, the EP technique is some improvement in the system design that counteracts the effect of a specific EA technique; therefore, it is difficult to understand the purpose of a specific EP technique without knowing the EA technique that it is designed to counteract. This close relationship between EA and EP means that EP testers must plan, conduct, and evaluate testing based on a complete understanding of both the system under test and the threats that challenge it.

4.2.2 ECCM Techniques

The most often encountered EP test requirements will involve ECCM of airborne radars. Figure 4-1 shows a block diagram of a generic airborne radar. Each element of this radar is a potential victim of EA; therefore, some EP technique should be considered. The antenna's greatest vulnerability may be to stand-off jamming introduced through the sidelobes. The associated EP technique is to reduce sidelobes to the lowest possible level. A similar relationship exists with the antenna's sensitivity to cross-polarized signals. If the antenna is designed for low cross-polarization response, then it will be more robust against EA techniques that rely on jamming with cross-polarized signals.

The radar transmitter can protect against some EA techniques by having features such as frequency hopping, PRF stager or jitter, pulse width modulation or compression, or other parametric diversity; a broad tuning range; or high transmit power. Each of these features are valid EP techniques and will require specific testing in order to characterize the radar transmitter's overall performance in a jamming environment.

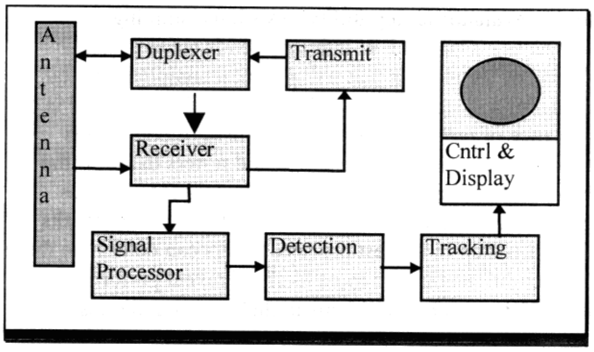

Figure 4-1 Generic Radar Block Diagram

Similarly, the radar receiver design can incorporate features to reduce its vulnerability to common EA techniques. High local oscillator and first IF frequency will result in increased image frequency rejection thus improving the receiver's ability to operate in a jamming scenario. Recent improvements in signal processing have led to major improvements in EP and pose significant new challenges for the EA designer. As digital signal processor components have increased in both speed and density, functions within radar signal processors have become more resistant to both deceptive and power-based EA techniques. Some features of signal processing found in modern airborne radars include programmability, high range and Doppler resolution, and signal processing reserve capability in both memory and computing resource timeline. Each of these features can result in important improvements to a radar's EP capability. The primary objective of our EP test and evaluation will be to characterize the radar's resistance to various EA techniques and assess its suitability for operation in an electronic warfare environment.

4.3 Testing ECCM Techniques

The constant evolution of ECM and ECCM provides some interesting challenges to the tester. As with ECM, detailed knowledge of the threat is the tester's greatest resource. The following paragraphs show how we can use our test facilities at each level to assess the probability that the ECCM techniques will offer sufficient protection.

4.3.1 Modeling and Simulation

Many ECCM techniques are based on complex and sensitive circuitry in the system being protected. As such, all elements of the EW test process should be considered in planning ECCM tests. Models and simulations will be of particular value in both the test planning and evaluation portions of the test process. A digital model of the system under test can be used to analyze potential effects of jamming or other EA techniques. Antenna designs can be evaluated for their sidelobe characteristics that in turn will provide insight into the system's vulnerability to noise jamming introduced into the side lobes.

The signal processing circuits of radar systems are excellent candidates for digital models. These models can be used both in the design of the signal processing circuits and as a tool to evaluate susceptibility to various jamming techniques. Current EW industry trends are to establish standards for models that will permit a compliant digital model of a system in the design phase to be evaluated in the presence of previously established threat models. This approach permits both designers and testers to assess the behavior of a new radar system with respect to various generic and specific EA techniques. Based on the results from this step in the test process, testers can determine those test conditions that are most likely to reveal performance limitations or other problems in the system under test.

4.3.2 Ground Test Facilities

Various laboratory or ground facility tests will prove invaluable in developmental testing of EP functions. The majority of the EA techniques that may be overcome through some form of ECCM are based on the characteristics of electromagnetic waveforms, not on the dynamic properties of ships, land vehicles, aircraft, or missiles. Therefore, if the system under test (let us assume an airborne radar) is subjected to jamming signals while in a laboratory or spread-bench environment, the results observed will, for most cases, be indicative of the eventual installed system performance. Tests in System Integration Laboratories (SILs) and Hardware-in-the-Loop (HITL) facilities will permit a large number of trials, with a high degree of repeatability at a low cost. Results from these tests can be quickly and easily compared with results from the digital modeling and simulation previously completed. Differences between the model results and those obtained in the SIL or HITL should be investigated and resolved. Appropriate updates to the models used are made before progressing to more expensive and complex test conditions.

One portion of nearly all EW and avionics systems that is particularly sensitive to installed performance is the antenna or sensor aperture. For the case of RF systems, antenna performance can be significantly altered due to installation effects such as other nearby antennas acting as parasitic oscillators or other parts of the aircraft causing blockages to the antenna pattern. Tests in Installed Systems Test Facilities (ISTFs) can efficiently lead to the evaluation of such effects. Not all ISTFs can support the actual radiation of RF signals required for measurement of antenna system performance. The tester must always be careful to select facilities in each test category that can support the specific types of tests deemed necessary for the system of interest. For instance, if the installed performance of the antenna systems is well known but a concern exists about the integration of new signal processing circuits with other elements of an aircraft's avionics, then operation in an ISTF that permits free-space radiation of RF signals may not be necessary. A smaller facility with lesser anechoic properties will suffice. If, on the other hand, the system under test has an uncharacterized antenna system and must operate in a complex radiated electromagnetic environment, then an ISTF with broad anechoic properties and a wide operating frequency range is called for.

4.3.3 Flight Test

Actual flight testing is usually the final step and should hold little potential for surprise if the previously described steps are carried out. It is, however, possible that some aero-mechanical effects not simulated in the earlier stages will cause problems. Movement of antennas due to flutter or aeroelasticity effects can result in erroneous direction finding (DF), ranging, or velocity determinations.

4.3.4 ECCM Example Test Project

To demonstrate the manner in which an EP capability might be tested and evaluated, a simple example is provided. While few, if any, real test programs will be as straight forward as this example, it does demonstrate a methodology for planning and executing a test of ECCM.

4.3.4.1 Assumptions

For this example we will need to make the following assumptions:

1) The system under test (SUT) is an Airborne Intercept (AI) radar.

2) A digital model of the radar and threat jammers exists.

3) The radar antenna pattern has been previously characterized in both azimuth and elevation.

4) The system objective we are concerned with is its vulnerability to barrage noise jamming from stand-off jammers (SOJs).

5) The primary EP technique used in the radar to negate the effects of barrage noise jamming is a Sidelobe Canceller.

6) For HITL and ISTF test facilities, a threat jammer simulator is available with adjustable power output.

4.3.4.2 Test Objectives

During test planning meetings between the system user, developer, and testers, we determine that the user is particularly interested in how his/her radar system will perform in the presence of SOJs of the barrage noise type. Barrage noise is an EA technique that produces broad band 'noise' energy to mask the reflected energy from a radar. When applied by an SOJ, the noise is introduced into the radar side lobes to mask returns that are occurring in the main beam. The success of barrage noise jamming is primarily a function of the ratio of jamming power (J) to signal power (S), usually referred to as the J to S ratio (J/S). These factors will help us to determine appropriate test objectives, plan our test activities, and determine the data requirements to support an evaluation.

Step 1 of the EW Test Process is discussed in Section 1.7.1, "Determine Test Objectives." For our case, we will establish one simple test objective to demonstrate the process. The test objective is: **Determine the minimum jamming power required to obtain the specified J/S at the input to the radar receiver at various azimuth angles between 10 and 45 degrees off the nose of the test aircraft.**

4.3.4.3 Pre-Test Analysis

A key to effective testing is to develop an understanding of the SUT, its intended operating environment, and the strengths and weaknesses of the threats it will encounter. Developing this understanding is the first element of pre-test analysis. As shown in Figure 4-2, there are two areas of interest defined; a 35-degree sector on the left and a 35-degree sector on the right. Clearly, to be effective, the jamming signal must be within the bandwidth of the radar receiver. The antenna pattern for the radar antenna will be an important consideration in determining the angular resolution for testing. For our example, we will assume that the antenna pattern is of adequate consistency to permit measurements to be taken at 5-degree increments. The initial characterization of the antenna pattern would have been accomplished in a measurement facility specializing in RF antenna measurements.

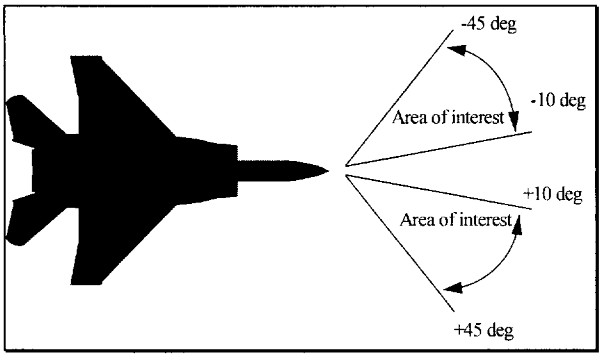

Figure 4-2 Areas of Interest

The EP technique used in our example radar is a Sidelobe Canceller. This technique utilizes auxiliary antenna elements to receive the jamming signal, determine its effect, and cancel that effect in the main antenna channel. In order to evaluate the effectiveness of the sidelobe canceller, we will conduct testing with and without the EP technique enabled. Since the radar antenna is a critical element in the vulnerability of the radar to stand-off jamming, all tests will be conducted at RF radiated through the antenna.

As part of our pre-test analysis we must define our test concept, determine test points, predict outcomes, establish analytical processes that will be applied, and decide what data must be acquired. Since we have a digital model of both the SUT and the threat (jammer), we can use these tools to determine if there are critical angles or frequencies at which the jamming will be particularly effective (or the EP technique is particularly ineffective!). The model will also be helpful in determining what data need to be collected and the requirements for range, resolution, and accuracy of that data.

4.3.4.4 Test Execution

Our next step is to actually execute a test. In reality, we will repeat this step several times, using various test resource categories as our confidence in the SUT increases. After each iteration, we will compare the results obtained to those predicted during the pre-test analysis. We will correct or revise our models to resolve differences between actual results and predicted results.

4.3.4.5 HITL Testing

Our first tests will be accomplished in a HITL. The SUT will be in a 'spread bench' configuration permitting easy access to test points with generic laboratory test equipment such as spectrum analyzers and oscilloscopes. The radar antenna, auxiliary antennas, and the jammer simulator transmit antenna will be located in a small anechoic chamber where actual RF radiation can be accommodated with adjustable power levels. During this testing we will be able to make precision measurements of the actual power levels and J/S ratio at each point of interest in the antenna pattern. Data can be either hand recorded or automatically logged by the test facilities instrumentation support system.

4.3.4.6 ISTF Testing

Testing the radar in its installed configuration under precisely controlled conditions can be accomplished in an ISTF. This will be an important test since it will be the first opportunity to measure the system performance with installation effects accounted for. Both facility and aircraft instrumentation systems should be utilized during this phase of testing. It will provide a correlation between the test aircraft instrumentation system that will be used during flight test and the facility instrumentation that is the primary data acquisition source during the ISTF tests. Large amounts of data can be easily collected in this environment with a high degree of repeatability. These data will form the basis for an accurate statistical baseline of system performance. Both HITL and ISTF testing permit us to maintain tight control of the RF environment. Unwanted signals are generally not present during these tests. This will not be the case when we move in to the flight test phase.

4.3.4.7 Flight Test

The final phase of our test project will be conducted in flight on the open-air range. Here we will plan using three aircraft in our testing. Aircraft 1 will simulate the actions of an adversarial stand-off jammer aircraft. Aircraft 2 will represent a threat target aircraft. Our test aircraft, number 3, will carry the SUT and be instrumented to provide either onboard recording or telemetry of critical parameters needed for evaluation of the SUT. We will also require Time Space Positioning Information (TSPI) for all three aircraft. These data will be used during post test analysis to determine the exact position of the jammer and target with respect to our radar antenna.

We will establish flight profiles for all three aircraft to maintain the jammer aircraft within the 35-degree sector on either the left or right side of the test aircraft. During this phase of testing we can modify our test objective to provide a more operational flavor. The objective is now redefined as: **Determine the minimum jamming power required to defeat the radar's ability to detect, track, and display a 1 square meter target with standoff jamming at various azimuth angles between 10 and 45 degrees off the nose of the test aircraft.**

This revised objective creates a number of new requirements. First, the objective is couched in terms of a target aircraft with a radar cross section (RCS) of 1 square meter. While the aircraft available to serve as a target may not directly meet this requirement, data obtained during testing can be corrected for the difference in RCS. This does however require high accuracy and resolution TSPI capability on the open-air range. Second, the primary indicator of jamming effectiveness will now be the pilot of the test aircraft. When the jamming is sufficient to obscure the target on the pilot's display, then we will consider that the EP technique is ineffective. While the precise data gathered during the previous phases of testing are necessary to efficiently develop and improve the SUT, these operational data will, in the final analysis, determine whether or not the system will be acquired and fielded.

4.3.4.8 Evaluation

So what do the results of each of the tests mean to the developer or the user? Each may have a different view of what the results mean; the developer may use the results of testing to demonstrate that all specifications have been satisfied, while the user may determine that based on test results, the system will not satisfy his/her needs. Due to the differences in interpretation of test results and the potential economic and operational impacts associated with these interpretations, evaluation is the most critical and controversial element of the test process. It is important that, to the greatest extent possible, all parties involved in the development and test of a system reach agreement prior to the start of testing as to what data will be used in the evaluation, and what calculations and statistics will be applied to the data. Finally, everyone must reach agreement as to exactly what constitutes success or failure.

For our example test we bounded the problem to some degree in the statement of our test objectives. For the flight test objective, only data acquired when the jamming aircraft is within the 10 to 45-degree sector on either side of the test aircraft will be used. The evaluation of the test results will generally be communicated through an interim or final report. This report should clearly state any constraints or limitations on the testing, what was observed, what was concluded from those observations, and any recommendations resulting from those conclusions. If, based on the evaluation, the decision makers can verify that any operational risks associated with fielding the system are acceptable, and that user needs are adequately satisfied, then testing can be declared complete. If the evaluation leads to a conclusion that the SUT requires additional improvement prior to acceptance or fielding, then another cycle of the test process will occur.

4.4 Electronic Protect Through Emissions Control Capabilities

In addition to the ECCM techniques discussed above, other passive approaches to EP are used in most modern military systems. The most direct means of limiting an adversary's ability to apply EA techniques is by rigid control of friendly electromagnetic emissions (EMCON). As a simple example of this process, consider an Anti-Radiation Missile (ARM) targeted at a friendly radar site. Since the ARM guides on the RF radiation from the radar, it will loose that guidance if the radar transmissions are ceased. The planned cessation of the radar emissions would be considered a form of EMCON and would clearly be an effective method of EP.

Many systems may rely on detecting, identifying, and tracking targets on the basis of unintended emissions or radiation. The EP technique used to negate this effect is electromagnetic shielding or hardening.

4.5 Testing for Unintentional Emissions and EMCON Capabilities

Virtually all electrical and electronic components on an aircraft have the potential to radiate or re-radiate RF energy which may be detected and intercepted by an adversary. While some of these potential emissions can be observed during early phases of development, it is most often the case that they are discovered after all systems are installed, and integration in the host platform has begun. As a result, Installed System Test Facilities (ISTFs) are frequently brought into play to characterize these unintended emissions.

4.5.1 Ground Tests

Large anechoic chambers are most useful in conducting tests to determine the exact nature and source of all signals radiated from an aircraft during operation. One approach frequently used is to establish a matrix of all possible switch combinations and then step through each configuration while using a calibrated, high sensitivity receiver to sweep through the entire range of frequencies to be evaluated. If energy is detected with a particular combination of aircraft equipment energized, then engineers can isolate the exact source. At this point both the user and designer must determine what action is to be taken to either reduce the emission or accept the condition.

While this type of testing is time consuming and requires specialized facilities and equipment, it has proven to be the most efficient manner to locate specific sources of unintentional emissions. Of course, intentional emissions can also be used to detect, locate, and engage an aircraft and must also be characterized. Again, the anechoic chamber is a most effective location for this task.

Figure 4-3 B-1B Bomber on Open-Air Range During Developmental Test and Evaluation

4.5.2 Flight Tests

In the final analysis, the question to be answered is "can a potential adversary use the intentional and unintentional emissions from my aircraft to detect and target me?" The results from ISTF tests can be used along with digital models of threat systems to analytically determine an aircraft's susceptibility to such threats. In many cases actual flight test against simulated threats can be employed to evaluate susceptibility. While determination of the exact source of the offending radiation may be difficult or impossible in an OAR environment, flight tests do provide the most realistic conditions. It is not unusual to regress to ISTF testing after the first round or two of flight testing. This iterative approach will generally converge on the best balance of emissions reduction and operational utility. Operational tests and some developmental tests on an OAR are accomplished using operationally representative flight profiles against typical threat laydowns. Through careful manipulation of the flight profile relative to the threat simulator placements, specific conditions thought likely to occur in actual combat can be evaluated. The analysis of system performance during such testing provides the best overall assessment of military worth.

5.0 EW SYSTEM ARCHITECTURE

5.1 Architectural Considerations

The approach to testing any specific EW system or function will be dependent to some extent on the architecture it is contained within. The examples in the preceding sections are, for the most part, based on stand-alone EW and avionics systems. Testing and the subsequent evaluation of stand-alone systems are relatively straight forward. When the EW system is combined with other systems and sub-systems on a single platform, both the quantity and nature of interactions which must be considered grow substantially. In this section, we will focus on testing federations of systems and integrated systems.

5.2 Stand-Alone EW Systems

The simplest category of EW systems from a T&E point of view are those which act independently of other systems carried on the same platform. These "stand-alone" systems can usually be evaluated without a rigorous evaluation of the performance of other aircraft functions. Of course, interoperability and Electromagnetic Interference (EMI) issues must be considered for stand-alone systems.

5.2.1 Stand-Alone System Description

Stand-alone EW systems are those systems that do not depend on data, information, cueing, or other functions from other EW or avionics systems on the platform. Most EW systems developed during the 1950's and 1960's fit into this category. These systems generally have a specific and singular function such as radar warning, jamming, or chaff dispensing. Testing of such systems is relatively simple; the system is exposed to the expected threat environment and observed for the correct response.

5.2.2 Stand-Alone System Test Example

As an example, we will look at the case of a stand-alone radar warning receiver (RWR) designed to provide the pilot with a visual and audio warning in the event that his/her aircraft is illuminated by any of several threat radar systems. As discussed in Section 2 of this document, specific tests will be performed in both ground and flight environments to measure the performance of each major functional element of the RWR. The antennas will be characterized individually and in their installed configuration to verify their frequency and spatial coverage and gain performance. Receiver tests will be conducted to determine sensitivity, selectivity, and other key parameters. The signal processing function will be tested to ensure that all threat signals specified for the system are properly categorized. Finally, the man-machine interfaces (MMIs) will be evaluated for correct operation. While this overall process may require hundreds of individual tests, the evaluation of results remains simplistic and the test conditions can be easily obtained. Each element of the system either functions as desired, or not; each test condition is discrete and has little or no dependence on other test conditions.

5.3 Federated EW Systems

From the tester's point of view, federated systems represent the next step in complexity. Additional interfaces will be considered in the design of the test program. A depiction of this architecture is shown in Figure 5-1.

5.3.1 Federated System Description

Federated systems are those systems which maintain their own functional identities or boundaries; but are dependent on data, information, cueing, or other functions from other systems outside of those boundaries. Most avionics and EW systems of the 1970's through the early 1990's have exhibited this characteristic. Testing of such systems becomes considerably more complex than the stand-alone case previously discussed. The causes of this complexity are best understood by reviewing an example test process for a federated RWR and RF jamming system.

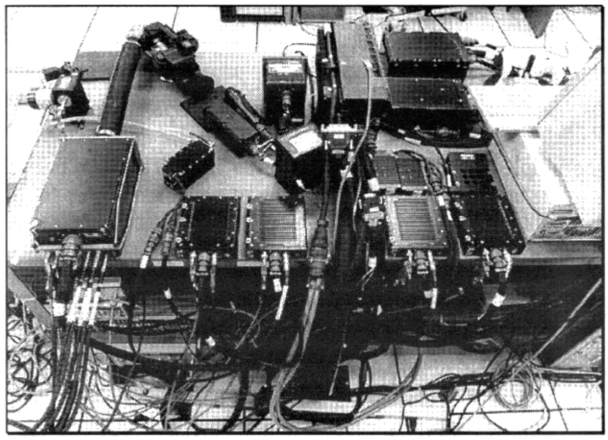

Figure 5-1 Federated System in HITL Test at ECSEL Facility, Pt. Mugu, California

5.3.2 Federated System Test Example

For this example we will assume that the RWR and jammer will be installed on the same platform and that they will both be designed to work against the same set of threats. They will share a common threat database or User Data File (UDF). When a threat is detected by the RWR it will be displayed on the multifunction display in the cockpit. The display will show a unique symbol representing the threat type, azimuth, and estimated lethality. The pilot will also receive a warning tone in his headset. Upon command from the pilot, the threat identification and location data will be passed to the jammer sub-system. The jammer will determine the optimum jamming response for the detected threat, tune a receiver to the proper frequency, and emit the necessary RF energy. If the jamming is effective, the RWR will detect that the radar is no longer tracking the aircraft. From this scenario we can begin to structure our example test program, determine the test resource requirements, and plan an evaluation process.

As with any test, planning is the key to success. Our test planning must start with defining test objectives. For each objective we must then determine the criteria for evaluation (that is, we must establish what is satisfactory performance), a criteria for success of the test (how much testing is enough), and the analysis process that will be applied to test data. For the example system described above we might develop test objectives such as:

- Determine the time for the RWR to detect each threat signal in the UDF.
- Determine the mean time to initiate the optimum jamming waveform.

While many other objectives could be established for this relatively simple system, these will suffice to demonstrate the test approach. The first objective appears to be focused on the stand-alone performance of the RWR. However, on closer inspection, we can see that there is potential for interaction with the jammer through the UDF. If both the jammer and the RWR are attempting to access the UDF simultaneously, there may be a delay in the data needed by the RWR. As a result, testing must be structured to acquire data under various operating conditions for both the RWR and the jammer. Data collected must be categorized to reflect the operating conditions to determine if there is a significant delay imposed by multiple systems sharing a common UDF. This then brings us to the next challenge; a definition of how much delay is acceptable. And we must know what is acceptable before we begin testing in order to establish the range, resolution, and accuracy of our test observations. If a delay greater than 100 milliseconds is unacceptable and our instrumentation system only has a resolution of one second, then we may not be able to distinguish between acceptable and unacceptable performance. Certainly the stand-alone performance of the RWR will be a dominant factor in this objective, but additional testing to ascertain the overall performance of the federated system is of paramount importance to the user.

Our second objective clearly implies evaluation of the fully federated system; the RWR, jammer, shared UDF, multi-function display, and the pilot will all play an important role in overall effectiveness. However, to fully evaluate and understand the results of this test we must also have insight of the performance of each individual component of the system. We will want to know not only if improvements are required, but if so, which part of the system is the best candidate for improvement. This objective also brings into play the human operator; a component with a high degree of variability. In order to appreciate the operator's effect on overall system performance, we will have to collect data under a wide range of operational conditions, and with a range of operators. All of this leads to the conclusion that test of federated systems brings about an increased burden on the test planning and analysis processes over that of the stand-alone systems test. The same facilities will be used, but the number of test runs or flights may increase significantly as the system complexity grows.

5.4 Integrated EW Systems

Some recent combat aircraft designs have moved from the relatively simple federated approach to an extensive integration of EW/avionics functions. The U.S. Air Force F-22 is an example of this integrated approach. Functional integration offers numerous advantages to system designers while creating new challenges to testers.

5.4.1 Integrated System Description

Integrated EW systems are not just a combination of stand-alone systems linked together as is the case with the federated approach. Rather, integrated systems tend to have a homogeneous functional identity. There is no discernible boundary between sub-functions such as radar warning, missile warning, jamming, or other EW activities. Most, if not all, components in the system may be shared between the sub-functions on the basis of complex scheduling and resource control algorithms.

5.4.2 Testing Integrated EW Systems

Testing of isolated functionality becomes difficult, if not impossible, with the operational software in place. Flight tests will reveal little of the source of performance problems with integrated systems. HITL and ISTF test facilities that can make large numbers of test runs with precisely controlled conditions and extensive instrumentation are essential to the test and evaluation of integrated systems.

The OAR remains useful in establishing the overall effectiveness of integrated EW systems (Figure 5-2). However, in order to evaluate the system effectiveness in conditions outside that which can be demonstrated with OAR resources, the tester must rely on digital modeling and simulation and ground-based resources. The current trend is to combine digital models with hardware threat and environment simulations to provide controllable, repeatable stimulation of the entire test aircraft in an ISTF.

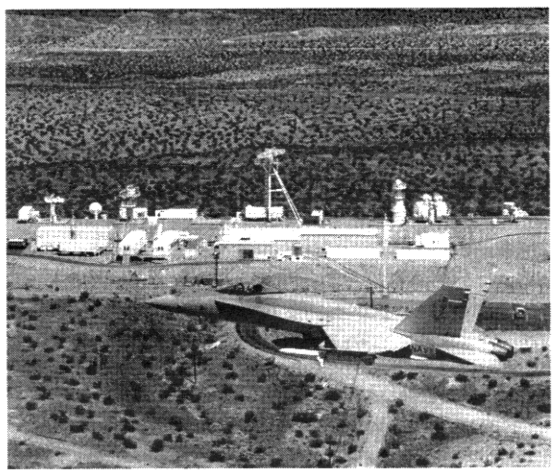

Figure 5-2 US Navy F/A-18 Conducting Flight Test of Integrated EW System at Electronic Combat Range, China Lake, California

This capability to immerse the entire aircraft in a controlled and representative EW environment requires that all signals of interest (RF, IR, UV) be simultaneously generated in a coherent manner. Information content must be consistent among and between emissions from both the system under test (SUT) and the simulated environment. All objects used in the test scenario must appear to exist at the right time and place; that is, coherency must exist in all domains detectable by the SUT.

These requirements drive ISTF signal and scene generation and scenario control software to the far extreme of our current technical capability. A simple example serves to help understand this demand on the test facility. Let us assume the integrated EW system being tested can sense both RF and IR emissions from a potential threat aircraft and correlate this sensor data with its own radar detections and tracks. The test facility will then be required to generate a radar return (of the correct RCS), an IR scene, and other RF emissions all coming from the intended target position. As we look at this requirement in the time domain, we see that all simulations must reflect realistic target motion and the resulting changes in the physical characteristics of each signal. Radar target returns must be modulated with the correct Doppler, scintillation, and other characteristics to permit a viable test of a coherent processing airborne intercept radar. If, due to minor time or space positioning errors in the simulation, the IR emissions from the target were displaced from the radar target simulation, then the SUT may declare two targets rather than one. Clearly, the eventual outcome of a 1 versus 1 engagement should be different than a 1 versus 2 engagement. This difference would invalidate the planned test. For ISTF testing of modern integrated EW systems, this simple example must be replicated many times to represent realistic threat densities. Very sophisticated and costly threat and signal generation systems, scenario control software, digital models, and instrumentation are needed to accomplish these high density, high fidelity simulations. However, in spite of the cost and complexity involved, such test capability can pay great dividends in understanding the behavior of integrated EW systems and isolating hardware and software failures.

6.0 MODELING AND SIMULATION FOR EW TEST AND EVALUATION

6.1 General Considerations for Modeling and Simulation (M&S)

The application of models and simulations throughout the EW test process has been long recognized as a critical adjunct to both ground and flight test. In many cases, models of unverified fidelity have been used, only to lead to speculation or even confusion. In this section a rigorous, yet pragmatic approach to use of M&S in test and evaluation (T&E) is suggested.

6.1.1 Introduction

Use of M&S is a critical part of the EW Test Process. It can be argued that all testing is in fact a simulation of war. This chapter focuses on the application of digital M&S to the EW Test Process. Digital M&S is the representation of "reality" through the use of models and computers. Digital M&S can no longer be considered solely a tool for determining EW system requirements from campaign and mission requirements—it is the thread that binds and shapes the EW Test Process. This section describes how digital M&S may provide unique and practical benefits to the EW tester. Digital models and computer simulations are used to represent systems, host platforms, other friendly players, the combat environment, and threat systems. They can be used to help design and define EW systems and testing with threat simulations and missile flyout models. Due to the relatively low cost of exercising these models, this type of activity can be run many times to check **what ifs** and explore the widest possible range of system parameters without concern for flight safety. These models may run interactively in real or simulated time and space domains, along with other factors of a combat environment, to support the entire T&E process.

6.1.2 Levels of Complexity

Computer simulations are constructed to the following levels of technical complexity.

6.1.2.1 Engineering

Component level model used to examine technical performance of an individual component or sub-system in accordance with its intended design.

6.1.2.2 Engagement

Weapon system level models used to evaluate effectiveness, including associated tactics and doctrine, in the context of an integrated weapon system engaged with a single (one-on-one) or a few (one on few) enemy threats (i.e., Surface-to-Air Missile system) in a simulated scenario.

6.1.2.3 Mission

Multiple weapon systems level models (with varying degrees of detail) combined into a simulated mission to analyze mission effectiveness and force survivability of friendly, multi-platform composite forces opposing numerous threats (many on many). Mission level models frequently include the impact of the enemy's command and control capability on the outcome.

6.1.3 Campaign

Campaign level is similar to mission level except that a campaign is a many-on-many simulation including the impacts of having to sustain the mission for an extended period of time. It evaluates effectiveness and force survivability of friendly, multi-platform composite forces opposing numerous threats, but also includes the issues associated with human factors, logistics, and attrition.

6.1.4 Theater

This level incorporates the C4I contributions of joint-Service (i.e., Army-Air Force-Navy) and allied forces operations against a combined threat force (force on force). It integrates the various missions into regional, day and night, and joint operations, and assesses the input of electronic warfare on force effectiveness.

6.1.5 Objectives

The objectives of M&S in the test process are to:

- Define safety footprints or limits.
- Extrapolate test data into un-testable or unavailable regimes.
- Increase sample size once confidence in the model is established.
- Define test facility requirements (e.g., number and types of threats, airspace required, control of background noise and emitters, and instrumentation).
- Define and optimize test scenarios.
- Select test points (i.e., successful results would not indicate the need for additional heart-of-the-envelope testing).
- Predict test results for each test objective.

6.1.6 Purpose

The EW T&E Process uses M&S and analysis prior to testing to help design tests and predict test results, and after testing to extrapolate test results to other conditions. At each stage of the test process, models in the simulation are replaced with hardware to achieve increasing fidelity to support evaluation. In this way M&S is part of all six resource categories. M&S should also be used to provide constant feedback for system development/improvement.

6.2 Applying Digital M&S in the EW Test Process

Digital M&S supports EW testing throughout the EW Test Process as shown in Figures 1-1 and 1-2 to plan (predict), conduct (test), and analyze (compare) the test program and evaluate the performance of the system under test (SUT). M&S tools consist of two parts: the battle environment and the SUT. The battle environment includes software representations (models) such as the enemy's weapon system (threat) and the propagation environment. The SUT (often referred to as the digital system model, DSM) includes software representation of the friendly weapon system such as the aircraft including any electronics critical to the evaluation.

6.2.1 Defining System Requirements

Digital M&S tools are used to examine theater, campaign, and mission needs to determine the requirements for new EW capabilities. Once a requirement is established, digital M&S tools are used to determine performance characteristics required in the EW system. EW system performance requirements are stated as measures of effectiveness (MOEs) that are decomposed into measures of performance (MOPs) from which test objectives can be derived. Digital M&S plays a key role in the process of defining test requirements based on what information is needed about the EW system. MOEs and MOPs become the basis for planning an EW test program, and digital M&S provides the tool to feed back the EW performance observed during testing into the original simulations used for determining EW performance requirements.

6.2.2 Digital M&S In The EW Test Process

With MOEs in hand, the test team begins the test process designed to gain incremental information on the EW system's performance, increasing confidence the system will perform effectively in combat. Figure 6-1, similar to Figure 1-8, shows a logical flow of test activity from left to right. Measurement Facilities (such as radar cross section and antenna pattern measurement ranges) support the process continuously as needed. The majority of activity at these facilities occurs early in the process. All digital computer simulation also begins early in the process. It is used to assist in design, trade-off studies, system integration decisions, and test planning. As this section will show, digital M&S provides support throughout the EW test process. System/Software Integration Laboratories (SILs) provide the capability of testing individual EW system components (for instance, in "brassboard" configurations) and subassemblies in a laboratory environment. Hardware-in-the-Loop (HITL) facilities allow testing the interactions of assembled EW systems with a simulated environment representing the threat situation. Frequently, the simulated environment at the HITL will include threat hardware integrated with digital simulation to create the battle environment. Once the EW system is integrated with other avionics on the aircraft, the integrated systems are tested in the Installed System Test Facilities (ISTF) to ensure compatibility of the various systems involved and that the EW system performs as expected when connected with other aircraft systems. The final test phase is flight testing at an Open-Air Range (OAR).

Figure 1-8 emphasizes the continuing role of digital M&S throughout the EW Test Process. At each test facility, software tools play important roles in supporting test conduct and interpreting results. The roles of digital M&S at each test phase are very similar. Figure 6-1 graphically depicts how digital M&S fits in to these test phases. Not all M&S activities make sense at all test phases, so the functions shown are turned on and off depending on the specific needs of the test.

A "seamless" test process greatly benefits from continuity in the M&S functions shown in Figure 6-1. The digital M&S tools used for test support should be used to support simulations used at each facility. For instance, the target representation used at the HITL should be traceable to the target representation in the digital M&S. Models must have the appropriate fidelity to achieve the test objectives for a given phase of testing. The functions shown in Figure 6-1 apply generically to any EW test facility, but the model fidelity required can vary from facility to facility. For instance, in early phases—such as the SIL, a basic model of the SUT may be sufficient. In subsequent phases, a more detailed and higher-fidelity system model may be required, depending on the evaluation objectives.

An overview of how digital M&S facilitates and shapes EW testing is shown in Figure 6-2. The M&S function in each block are briefly explained later in this chapter along with a short example of each. Digital M&S plays key roles before, during, and following each phase of testing. Digital M&S allows system characteristics measured and reported in engineering units to be translated into terms reflecting overall system effectiveness. Through analysis using digital M&S, results from one phase of testing can be used to define and optimize testing at subsequent facilities. This makes digital M&S an excellent risk reduction tool in the development of a friendly weapon system. This is a valuable capability since, in general, the expense of test hours increases as testing progresses from SILs, through HITL facilities and ISTFs to OARs. At the conclusion of the "test" phases, digital M&S plays a major role in extrapolating performance observed in test to operationally realistic scenarios as defined in the requirements document for the system. During the test process, confidence grows in the conclusions concerning the weapon system's performance. Confidence is also increased in the digital M&S tools since measured results provide feedback for model refinement and validation. The completed set of digital M&S can then be used to explore the EW system's performance in conditions that cannot be tested at the various facilities. At completion of testing, the validated M&S tools are available for a wide variety of analysis applications.

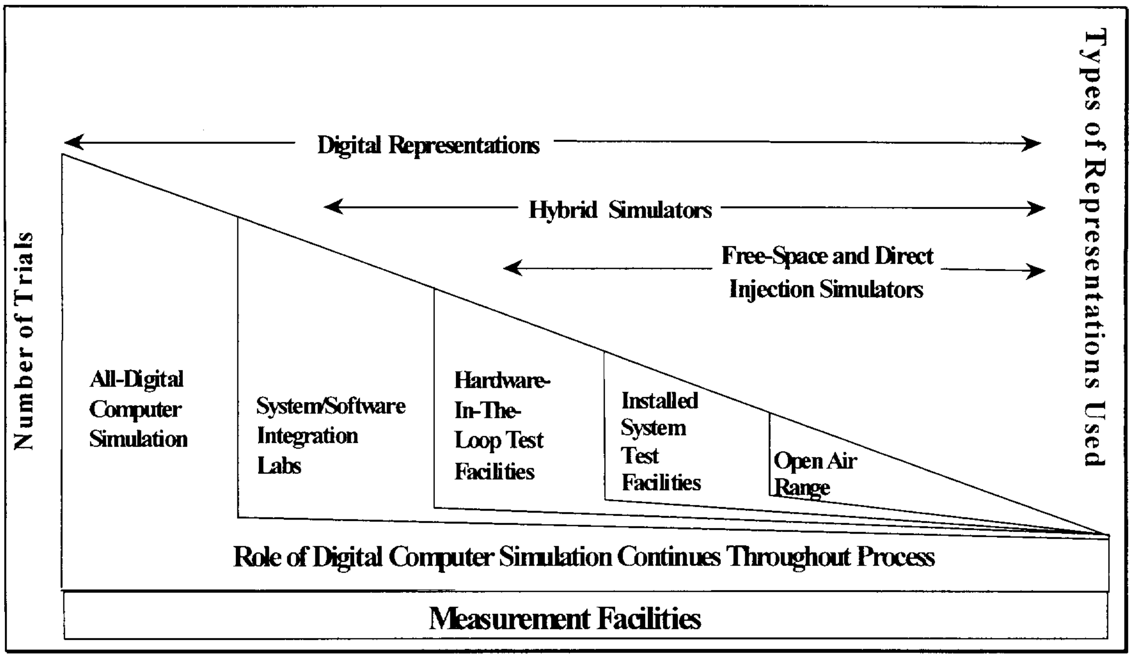

Figure 6-1 Activities Within the Digital M&S Interface

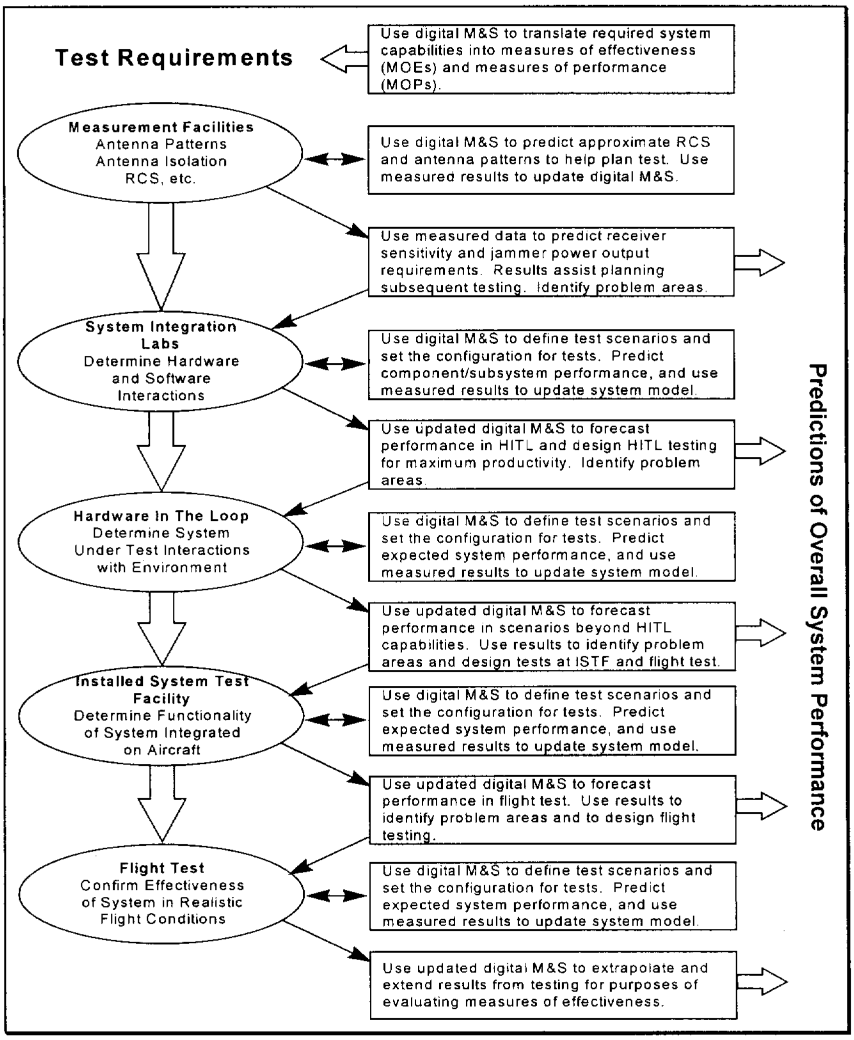

Figure 6-2 M&S Activities at Test Phases

6.2.3 M&S Activities Supporting T&E

The following paragraphs provide a brief description of each of the key M&S applications.

6.2.3.1 Quantify Test Conditions

The use of M&S to quantify test conditions provides a firm foundation for subsequent testing using the EW Test Process. An Analysis of Alternatives (AOA) is conducted to develop mission scenarios and evaluate effectiveness and cost tradeoffs. At this stage, there are no detailed system parameters available (for example, known performance in terms of response times, jamming waveforms, and the like) nor specific system performance requirements. The AOA first determines if future defense strategies require the development of a new weapon system or subsystem. The AOA process develops operational mission scenarios including target analysis, threat system deployment, and development of realistic mission profiles. The missions are simulated and analysis of the resulting interactions between the weapon system and the threat quantifies the frequency of occurrence that specific threats engage the aircraft. The parameters of the engagement conditions such as range, offset, and the presence of other threat systems and their emissions are also predicted. The predominant and most stressing conditions challenging system performance are identified by the M&S analysis. These provide quantified descriptions of candidate test conditions that are used to design test configurations for each of the test facility categories and specific test runs.

6.2.3.2 Design Tests

Based on the candidate test conditions, M&S is used to design and plan tests which obtain the most usable test points per test hour. The candidate test conditions are refined to account for limitations of the test facilities to define Reference Test Conditions (RTCs). Digital M&S tools are then configured to simulate the RTCs for designing a set of test runs that vary key aspects of the test conditions. These are the Planned Test Conditions (PTCs) which result in the most test points for the test run matrix. This use of M&S helps the test team to define an efficient test matrix by identifying conditions where MOP values change so no more sample test points than are needed will be planned. This improves overall test efficiency by concentrating test resources productively. Because flight test hours are usually limited based on funding constraints, using M&S for test design will not always reduce flight test hours, but it does help focus the flight test on critical data requirements.

6.2.3.3 Predict Test Results

The test team can use M&S to predict the expected values for each MOP in the test matrix. The predicted values support "Quick Look" analysis to detect problems with the test execution if the test results differ significantly from the predictions. Test prediction is not a new concept nor is the use of M&S to help design and predict results. For years, M&S has been used in this fashion for flight performance testing and for space programs. In their application to the EW Test Process, M&S tools become more detailed and accurate as they are validated with test data. The test team can also use the M&S tools to control the instrumentation and data reduction process by identifying essential data acquisition points. In many cases, data obtained from digital M&S can be used to test the analysis process to be used for actual test results. This can uncover problems in the analysis processes before actual testing begins.

6.2.3.4 Simulate Elements

Simulation plays a key role in many phases of testing. For instance, accurate simulations of threat radars and background emitters are necessary to provide sources of realistic signals used to test the SUT capabilities in a dense signal environment in the SIL. Another important element usually available only in a simulation is the threat missile seeker hardware. For HITL testing of the SUT interaction with seeker-dependent missiles, accurate models of the missile flyout are necessary to obtain proper seeker geometry and RF conditions for the test. M&S supports these and other requirements to construct meaningful test conditions by providing suitable output representations of threat activity from validated modules representing their hardware counterparts.

6.2.3.5 Quantify Test Results

M&S provides the link between what can be measured from testing and what must be known about the associated impact on aircraft survivability at all phases of testing. Digital M&S can aggregate measured data from testing and project it into predicted system effectiveness terms that allow more direct evaluation of system capabilities.

6.2.3.6 Compare Predicted and Test Results

It is important to compare results predicted for the test using digital M&S with actual results. One reason for doing this is to gain confidence in or refine the digital M&S. Perhaps a more important reason is to "sanity check" test results. In cases where measured results disagree with predictions, there is always a chance that problems with the test setup, execution, or data collection are the cause. Having confidence in the predicted results allows problems with the test to be quickly identified and corrected.

6.2.3.7 Extrapolate Test Results

For various reasons (cost, time, resource limitations, or safety), testing cannot collect measured data at every possible point in the region of interest. M&S can be used to increase the sample size by simulating those events that could be encountered operationally but could not be included in the test design. M&S is also used to extrapolate results to higher level MOEs than can be directly tested. For example, tracking error, which is a MOP, is extrapolated to miss distance by simulating the missile flyout. The miss distance for numerous test runs is then analyzed to obtain the Reduction in Lethality (1 - # of hits with ECM/ # of hits with no ECM) MOE.

Validation of the M&S models and extrapolation of results provide the test team with tools to connect the MOPs to system effectiveness, which make test results meaningful to program management in reaching decisions concerning the program.

6.2.4 Examples of Applying Digital M&S During Test Phases

This section describes how a test team can use digital M&S at each test phase. This is not a comprehensive description of M&S throughout the EW T&E Process—just a sampling of how M&S can be used. One example MOP is selected for each phase of the process to illustrate contributions of M&S at each test phase. As testing progresses through the process, the test team collects more measured data. As a result, there will be a reduction in remaining MOEs/MOPs to be predicted through simulation. As a specific example of this process, the measured installed antenna patterns obtained at the measurement facility will replace the engineering estimated antenna patterns in the DSM. The MOEs/MOPs will be computed or re-computed using the updated model(s).

6.2.4.1 Measurement Facility Example: Antenna Pattern Measurement for Field-of-View MOP Assessment

The system's antennas must provide visibility throughout the required range of azimuth and elevation. If the achieved field-of-view coverage is inadequate, the system will not provide warning for threats located outside the achieved field of view.

Design Test: The DSM will be used to specify sampling intervals and resolution required in measurements to ensure the resulting collected data are sufficient (but not wasteful "overkill") for supporting subsequent modeling which uses the measurements as input data.

Extrapolate Test Results: The DSM will be stimulated with analytically combined measured antenna pattern data to observe predicted SUT performance in response to frequency and polarization combinations not actually part of the measurement plan.

6.2.4.2 System Integration Laboratory Example: Detection Range MOP

The system's Radar Warning Receiver (RWR) must warn the aircrew at a range from the threat that allows employment of suitable countermeasures. If the achieved detection range is inadequate, warning time will not be adequate to allow effective countermeasures.

Design Tests: Surface-to-Air Missile and Airborne Interceptor systems, emitters, and environment models can be used to generate expected power levels for testing jammer and RWR threat detection capabilities. The corresponding values of power will be used to design the test setup and data collection efforts. In other words, the test team will use this power as the starting point and proceed up or down in the scale as necessary to characterize detection capability.

Predict Test Results: The DSM, threat, environment, and aircraft models will be used to predict the range between the aircraft and threat at which the system under test (SUT) initially detects each threat along the test scenario.

Extrapolate Test Results: Validated DSM models will be used to extend the measured results to include assessment of detection range performance against emitters not available in the SIL. This allows follow-on analysis to incorporate newly assessed threat capabilities or deployments without revisiting the SIL facility.

6.2.4.3 Hardware In The Loop Example: Track Error MOP

Output jamming waveforms must cause sufficient degradation in threat tracking of the aircraft or effects of missile engagements will be unacceptable.

Design Tests: Threat models capable of predicting threat radar responses to electronic countermeasures (called "EC capable" models) are used to evaluate the capability of the self-protection system to achieve a given degradation in threat tracking performance at various target offsets and altitudes. Resultant effectiveness estimates will be used to design the HITL test setup and to specify offsets and altitudes.

Predict Test Results: DSM, threat, and environmental models will be used to establish expected values of the resultant track error. Threat models used for this must be EC capable.

Extrapolate Test Results: DSM and EC capable threat models will be used to extend results measured in the HITL to include assessment of SUT-threat interactions in conditions not actually measured at the HITL to show SUT sensitivity to changes in environmental and/or threat factors that influence tracking error.

6.2.4.4 Installed System Test Facility Example: Pulse Density MOP

Systems must be capable of collecting and processing all incident pulses expected in the aircraft scenario. If achieved pulse processing capability is inadequate, the system cannot effectively perform when conditions of pulse density are above the achieved capability.

Design Tests: Emitter, threat, and environmental models will be used to establish incident signal conditions at representative pulse densities for an operational scenario. These signal conditions will be used to design the test set-up and data collection effort at the ISTF.

Predict Test Results: The aircraft, DSM, emitter, threat, and environmental models will be used to predict SUT performance in the presence of the signal conditions derived above.

Simulate Elements: Aircraft motion and motion of other moving platforms of interest is simulated using digital M&S in the ISTF.

Extrapolate Test Results: Full simulation including the aircraft, DSM, emitter, threat, and environmental models will expand the scope of SUT evaluation by extending it to combinations of laydown, scan schedules, mission profiles, and other conditions not actually measured at the ISTF.

6.2.4.5 Open-Air Range Example: Reduction in Shots MOP

Jammers must sufficiently decrease the opportunity for missile launches with ECM versus without it. If a sufficient number of shot opportunities cannot be denied, overall jamming effectiveness will be inadequate.

Design Tests: Aircraft, DSM, and threat models will be used to design flight tests that provide shot opportunities covering each tested threat system's engagement envelope and the mission envelope of the aircraft. Results of simulation will be used to design data collection, select threat rules of engagement (such as cueing and firing interval), and reference time space position information (TSPI) coverage requirements.

Predict Test Results: Simulations used to design the flight tests will be run using derived test conditions to produce expected shot rates achievable by the threats under ECM and non-ECM conditions.

Extrapolate Test Results: Full simulation is used to extend results achieved at the OAR to include threat density and combinations that are not available at the OAR, and to include the effects of tactics that were not employed during flight testing due to test restrictions.

6.3 Conclusion

Digital M&S plays a critical role in the process of acquiring and testing EW systems. Digital M&S is the thread that binds the various phases of the EW Test Process into a comprehensive conclusion about the effectiveness of the EW system. Digital M&S improves with use in the EW Test Process since test results fold back into the M&S tools to improve their capabilities and the confidence of their users.

7.0 EW GROUND-BASED TEST AND EVALUATION RESOURCES AND FACILITIES

7.1 Introduction to Ground-Based Test Resources

Sections 7 and 8 provide generic descriptions of ground and flight test resources commonly utilized in test and evaluation of EW systems and components. Detailed descriptions of selected test facilities in the U.S. and Europe are included in the annex of this document. While the annex does not fully describe every resource that a project may wish to utilize, it does represent a valuable resource for understanding the range of facilities available to meet the goals of a structured test process.

Ground-based test resources are frequently categorized by their primary function such as measurement facility (MF), hardware-in-the-loop (HITL) facility, or installed systems test facility (ISTF). However, in many cases these definitions are overly and inappropriately restrictive. For example, large anechoic chambers are generally classified as ISTFs and yet they frequently provide superior support in the role of measurement facilities. The following paragraphs explain the role of each of the commonly encountered facility categories but are not meant to imply that facilities otherwise defined should not be utilized in a role outside their primary designation.

7.2 Measurement Facilities (MFs)

Measurement facilities establish the character of an EW related system/subsystem or technology. They provide capabilities to explore and evaluate advanced technologies such as those involved with various sensors and multi-spectral signature reduction.

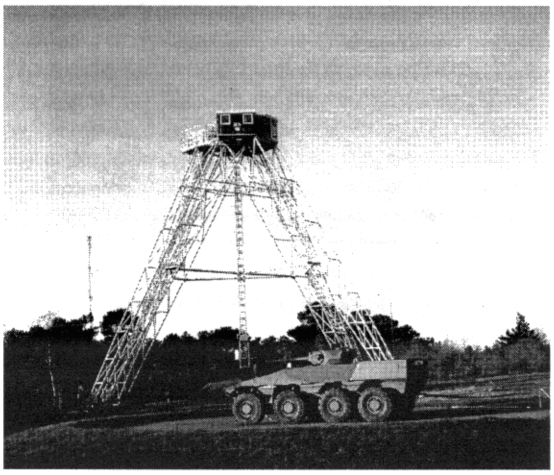

Figure 7-1 STRADI Radar Static Signature Evaluation Facility at CELAR Facility in France

7.2.1 Measurement Facility Subcategories

Measurement facilities generally fall into the sub-categories of antenna characterization, radar cross section (RCS) measurement, infrared/laser signature measurement, and electromagnetic interference, and electromagnetic compatibility (EMI/EMC) test capabilities. Measurement facilities provide EW and platform antenna pattern descriptions and platform signature data critical for system design and refinement, computer simulation, and HITL testing.

7.3 System Integration Laboratories (SILs)

SILs are facilities designed to test the performance and compatibility of components, subsystems, and systems when integrated with other systems or functions. They are used to evaluate individual hardware and software interactions and, at times, involve the entire weapon system avionics suite. A variety of computer simulations and test equipment are used to generate scenarios and environments to test for functional performance, reliability, and safety. SILs are generally weapon system specific and are found in both contractor and Government facilities.

SILs often employ a variety of real-time/near-real-time digital models and computer simulations to generate scenarios and multi-spectral backgrounds. These models are interfaced with brassboard, prototype, or actual production hardware and software of the systems under test. SILs are used from the beginning of an EW system's development through avionics integration and fielding. Moreover, SILs continue to be used to support the testing of hardware and software modifications or updates occurring throughout an EW system's operational life.

7.4 Hardware-in-the-Loop (HITL) Facilities

HITL facilities are an important test category because they frequently represent the first opportunity to test uninstalled system components (breadboard, brassboard, pre-production prototypes, etc.) in a realistic RF, laser, or IR environment. HITL operating environments can provide simulated terrain effects, high signal/threat density, and realistic interactive scenarios. Some HITLs offer multi-spectral capability and background noise. Modern threat representation via closed-loop hybrid threat simulators can be employed for EC effectiveness testing, man-in-the-loop interaction, and Integrated Air Defense System (IADS) networking. Secure (shield/screen room) operations, test condition repeatability, and high capacity data collection and recording are common attributes of the HITL test venue.

7.4.1 HITL Features

HITL facilities are ground-based test facilities that provide a controlled and frequently secure environment to test EW techniques and hardware against simulations of threat systems. Primary EW HITL facilities contain simulations of hostile weapon system hardware or the actual hostile weapon system hardware. They are used to determine threat system susceptibility and to evaluate the performance and effectiveness of EW systems and techniques.

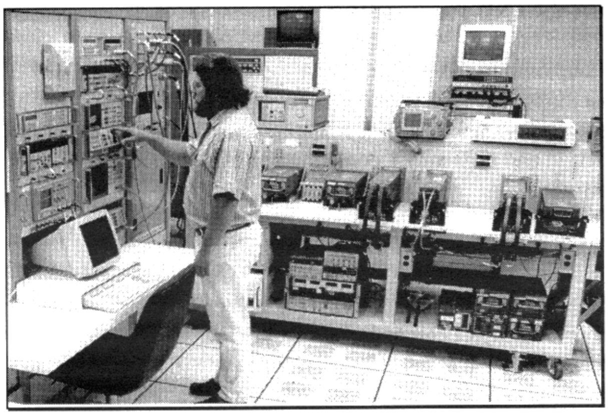

Figure 7-2 Hardware-in-the-Loop (HITL) Facility

Some EW HITL facilities contain friendly weapon system hardware. They are used to evaluate and improve the performance of friendly weapon systems in the presence of various EW activities. These HITL facilities can also be used to test EW systems where the friendly weapon system represents a potential threat technology.

7.4.2 Use of HITL Facilities

HITL testing should be conducted as early in the development process as possible - even if that means using a brassboard configuration. Too often preproduction hardware is developed late in a program, making identification and correction of problems difficult. EW HITL testing provides repeatable measurements and verification of protection techniques and EW system effectiveness. Results obtained from HITL tests should be compared to predicted results from previous M&S activities. Differences discovered in this comparison are then analyzed and the appropriate models are updated.

7.5 Installed System Test Facilities (ISTFs)

ISTFs provide a ground-based capability to evaluate EW systems that are installed on or integrated with host platforms. These test facilities may consist of anechoic or shielded chambers in which free-space radiation measurements are made during the simultaneous operation of EW systems and host platform avionics and munitions. Threat signal generators stimulate the EW SUT, and its responses are evaluated to provide critical, integrated system performance information. Their primary purpose is to evaluate integrated avionics systems (e.g., radar, infrared, communications, navigation, identification, EW systems or subsystems, and integrated controls and displays) in installed configurations to test specific functions of complete, full-scale weapon systems. Such testing may determine if any EMI/EMC problems exist. Testing may also determine system reactions to electromagnetic environments of hostile and/or friendly systems whose signals cannot be radiated in free space on open-air test ranges for security reasons. Support of flight testing by providing pre-flight and post-flight checkout capabilities is yet another role for HITLs. This ground testing can aid in isolating component, subsystem, or system problems not observable in other ground test facilities but crucial to system checkout prior to open-air testing. Failure to evaluate installed EW system performance adequately on the ground typically results in significantly increased flight test cost and lengthened schedules.

7.5.1 Categories of ISTFs

A Category I ISTF performs end-to-end systems effectiveness testing on installed multi-sensor/multi-spectral EW and other avionics systems under a wide range of realistic threat and operational conditions. These conditions require the appropriate types and numbers of players. Test events range from concept exploration and developmental tests to operational effectiveness testing. Specific tests include EW effectiveness (especially multi-sensor cued countermeasures), platform susceptibility, human factors, electronic protection performance, weapon systems integration performance, electronic support systems performance, and systems integration testing.

A Category II ISTF performs end-to-end systems integration testing on installed multi-sensor/multi-spectral EW and other avionics systems under conditions necessary to prove system performance. Test events are primarily DT&E oriented with some applications to operational testing. Specific tests include: human factors, electronic protection, avionics systems performance, and systems integration testing.

A Category III ISTF performs specialized testing such as: RCS measurements, antenna pattern measurements, susceptibility to high powered microwave, electromagnetic environmental effects (E^3), and limited systems installation and checkout on aircraft, ground vehicles, and components.

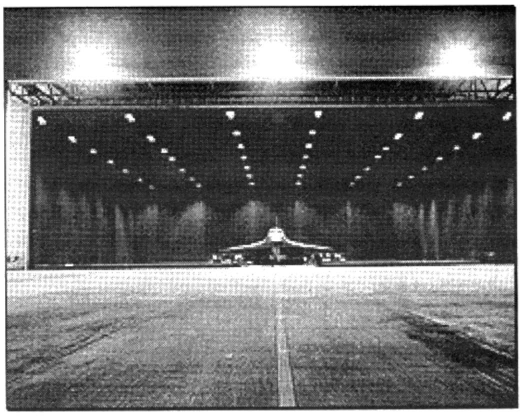

Figure 7-3 B-1 Bomber in Large Anechoic Chamber for Installed Systems Testing

7.6 Distinguishing Factors of Test Facilities

While the primary designation (e.g., HITL, ISTF, etc.) of a test facility can be used to describe it at a generic level, the test engineer must consider a number of other characteristics to determine the applicability of the facility to a particular test effort. The test plan should define the approximate characteristics that must be simulated or measured during each phase of testing. This is the starting point for selection of test resources. As preliminary choices for test resources are made, more specific detail can be included in the test plan, and then some refinement of actual tests to be accomplished at each stage or facility is possible. This iterative approach to define, refine, and finally confirm test resource utilization should be expected for most test activities. Some of the key parameters that distinguish one facility from another are discussed in the following paragraphs.

7.6.1 Number of Players

The total quantity of friendly and adversary players that can be synthesized during testing is important in accessing SUT performance in conditions of varying density and complexity. In most cases, simulated players are sub-divided into two categories; foreground and background. The foreground players can usually be precisely controlled to follow specific flightpaths and have well defined physical characteristics. The background players generally are of lower fidelity and simply add to the overall scenario density.

7.6.2 Fidelity of Models

Digital models of threats, geography, meteorology, phenomenology, and the players in a test scenario can differ greatly in their availability, accuracy, and capability to interact with the system under test (SUT). Some models may permit interaction with a human operator (operator in the loop), others may be able to accurately account for the effects of electronic countermeasures (EC capable). Some models are predicated on extensive analysis and reverse engineering of the threats they represent while others are based on limited intelligence collection. The pedigree of a model is frequently defined through a rigorous process of validation, verification, and accreditation (VV&A). The tester must research the attributes of the models to be used and fully appreciate the implications of various levels of fidelity on the results, conclusions, and recommendations to be reported out of the test process.

7.6.3 Time, Space, and Frequency Resolution and Accuracy

From the test planning process we should determine what analysis will eventually be accomplished. Data acquired at each stage of testing must be sufficient to support the specified analysis. Data analysis will set the baseline for both the accuracy and resolution of data to be used in evaluation of the SUT. The tester must understand the effects of data errors in time, space, or frequency on the evaluation of system performance and effectiveness.

7.6.4 Signal/Scene Generation

A dominant factor in the selection of test facilities will be the capability to generate the various signals (RF) and scenes (IR/UV) to which the SUT must be exposed. This characteristic includes the frequency range, amplitude range, and dynamics of the objects included in the signal/scene set. Of equal importance to the generation of signals and scenes is the manner in which these characteristics are imposed upon the SUT. In some cases they must be injected into the SUT electronics while other facilities can actually radiate the signals or scenes through free space. The tester must also consider the importance of the scenario generation process to respond to the SUT (closed loop versus open loop). The importance of these distinctions will be dependent on specific test objectives and SUT architecture.

7.6.5 Instrumentation

The ability to accurately capture the activities of both the test facility and the SUT during a test is primarily established by the type and amount of test instrumentation available. An important, but often overlooked, concern in this area is the undesired (and sometimes unknown) effects that the instrumentation may have on the test environment. The instrumentation must accurately measure and record what the SUT was exposed to, not just what was intended.

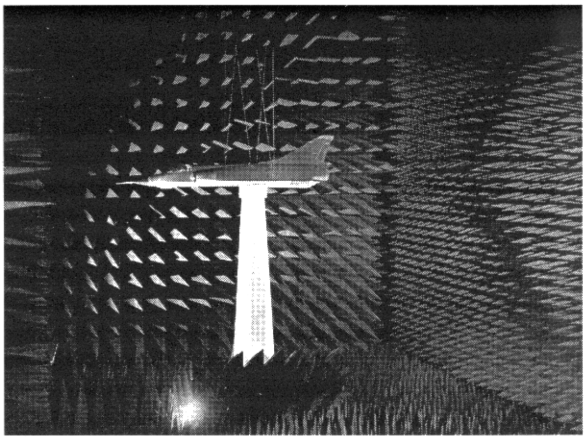

Figure 7-4 CHEOPS Anechoic Facility, France

7.6.6 Security

Some tests may require that all test conditions and resulting data be protected at very high security levels. This requirement may impose special constraints on how test systems are controlled and interconnected, or how data acquired during a test is processed. For software intensive facilities, security must be designed into the software, not accommodated as an afterthought.

7.6.7 SUT Support

This characteristic defines what power, cooling, and physical positioning capabilities are offered by the test facility. It is of primary importance in ISTFs and Measurement Facilities.

7.7 EMI/EMC

As mentioned earlier in this section, ISTFs are frequently used to conduct EMI/EMC (electromagnetic interference/ electromagnetic compatibility) tests. While these tests are not uniquely associated with EW systems, they are crucial to the overall weapons system performance. Numerous specifications and standards dictate system design maximum EMC. To the EW engineer, EMI can result in a vulnerability that can be exploited by EA systems. On the other hand, the EW engineer must be concerned with the compatibility of the EW systems with other aircraft avionics. For instance, if the aircraft jammer produces false alarms on the pilot's RWR, it would be unsuitable for combat use. The following paragraphs will discuss in some detail some of the types of EW tests EW testers should be familiar with.

7.7.1 EMI/EMC Tests

There are four types of Electromagnetic Interference (EMI) tests: Radiated Susceptibility (RS), Radiated Emission (RE), Conducted Susceptibility (CS), and Conducted Emission (CE). During radiated testing a test antenna is used to transmit RF at the test object to see if it is susceptibility (RS test), or a test antenna is used to see if RF emanations from the test object exceed a certain level (RE test). The "R" series of tests require a shielded room/anechoic chamber. The "C" series of tests are usually performed in a shielded room but can be performed in system labs. During conducted "C" series of testing a current probe or similar direct coupling device is used to couple RF into the SUT. Electromagnetic energy is injected to characterize the susceptibility (CS test) of the SUT. Similarly, the probe or direct connection can be connected to a receiver or laboratory test equipment to measure RF emanations directly from the test object (CE test).

During emissions testing all modes of the SUT should be exercised. During susceptibility tests, an end-to-end test in addition to exercising a Build-in-test (BIT) should be performed to verify proper operation. For receiver testing the input should be a mixture of various power levels within the receiver band-pass, the lowest power level being used for the highest priority signals. The goal is to determine if the receiver can process weak input RF signals while interference is being picked up by control lines, etc. The emission tests are non-destructive, whereas the susceptibility series of tests always run the risk of causing damage if systems are not properly designed.

During development tests, it is advisable to perform EMI/EMC testing as early in the program as possible. Quite often EMI tests are delayed to the end because problems in other disciplines are still being resolved. The rationale is to wait and do EMI tests on the system in its final configuration. EMI tests are expensive, and there are logistic problems in moving the systems and its interfacing equipment to the EMI lab. But if EMI failures are detected early, they can be fixed at relatively low cost and little impact to the system schedule.

7.7.2 EMC Testing

EMC testing can be further defined as Intrasystem and Intersystem EMC tests. Intrasystem EMC tests are used to evaluate the SUT's ability to operate in the presence of other systems installed on the platform. Intersystem tests are used to evaluate the SUT's ability to operate in the presence of external emitters representative of the intended operational environment.

7.7.2.1 Intrasystem EMC Tests

Generally, the SUT's performance will be monitored while each other platform system is cycled through its modes, then all systems are operated together. If the SUT exhibits adverse response to the operation of other onboard systems, then an EMC issue has been identified. Whenever the systems being tested include explosive devices such as squibs for chaff and flares, adequate safety margins must be considered. Typical margins for systems containing explosives are on the order of 20 dB. A 6 dB safety margin for non-explosive systems is common.

7.7.2.2 Intersystem EMC Tests

For these tests the SUT performance will be monitored while the platform is radiated with RF at power levels, and modulations of radar signals that may be present in the intended operational electromagnetic environment (EME). Staircase levels of EME and system performance should be part of the system specification. Full system performance would then be required in the operational environment.

8.0 EW FLIGHT TEST RESOURCES AND FACILITIES

8.1 Introduction to Open-Air Range Facilities

When one thinks of test and evaluation of aircraft systems, they usually focus on the actual in-flight testing accomplished at open-air test ranges. These open-air ranges (OARs) may provide features such as airspace control, time space positioning information (TSPI), telemetry reception, and threat environment simulation. The increasing complexity of modern avionics and EW systems along with the growing cost of aircraft operations has driven most test organizations to reduce the use of OAR testing. The extensive capabilities of ground-based test facilities, increased effectiveness of modeling and simulation, and improved analytical processes discussed in earlier sections have enabled this reduced reliance on OARs. In spite of these factors, it is at the OAR and only the OAR where all elements of the EW system's operating environment can be accurately and simultaneously exposed to the testers' scrutiny. For this reason, the OAR will remain an important component of the testers' arsenal.

8.2 Open-Air Range Description

OAR test facilities are used to evaluate EW systems in background, clutter, noise, and dynamic environments. Typically, these resources are divided into sub-categories of test ranges and airborne testbeds.

OARs focused on EW testing are populated with high fidelity threat simulators in addition to basic range instrumentation and airspace control capabilities. In order to be useful for most test conditions, these threat simulators are instrumented to establish a record of EW system effects on the threat. The instrumentation of threat simulators must be carefully planned prior to the start of flight testing to ensure that operating modes, pointing angles, receiver and/or transmitter performance, and signal processing features are accurately archived for post-test analysis of EW system performance. In some cases, additional emitter-only threat simulators are provided to create the high signal density characterizing typical operational EW environments. OARs vary considerably in the quantity, quality, and flexibility of their threat simulation capability. The tester must establish precise test objectives and evaluation procedures prior to the selection of an OAR to ensure that these high-cost tests generate meaningful results.

8.3 Open-Air Range Uses

Obviously the OAR has great utility in confirming or denying the validity of measurements and analyses performed earlier in the test process. However, OARs can be used throughout the test process to establish a consistent threat baseline, act in the role of a HITL or ISTF, or provide initial "seed" data for requirements generation.

The primary purpose of open-air testing is to evaluate the system under real-world representative environment and operating conditions. OAR testing is used to validate system operational performance/effectiveness at a high level of confidence. Both developmental and operational tests are conducted in the OAR environment. The overall objective of developmental tests at this stage is to verify that system performance characterized in earlier test events is representative of performance in the intended operational environment. Results of OAR tests are compared to results obtained in measurement facilities, SILs, HITLs, and ISTFs to arrive at a complete and consistent evaluation of system performance and predicted effectiveness. This is also an opportunity to gain an early understanding of operational features such as supportability, utility, and reliability.

8.3.1 EW Effectiveness Testing

When the EW system is of the Electronic Attack (EA) category, effectiveness trials may be accomplished by flying the host aircraft with the EW system inhibited (dry) and then re-flying the same profile against the same threat scenario with the system enabled (wet). The ability of the threats to detect, track, and fire upon the host aircraft in the dry case are then compared to similar results in the wet case to evaluate the overall military worth of the EW system. A number of possible measures of effectiveness (MOEs) for such tests may be considered for use. The effectiveness of a jammer may be seen as its ability to preclude the adversary's opportunity to shoot at the protected aircraft. This can be expressed as reduction in shot (RIS) probability and is mathematically expressed as:

$$RiS = \frac{\dfrac{DryShots}{DryPasses} - \dfrac{WetShots}{WetPasses}}{\dfrac{DryShots}{WetShots}} \times 100$$

Another frequently used MOE is reduction in lethality (RIL). This MOE is calculated as:

$$RiL = \frac{\dfrac{DryHits}{DryPasses} - \dfrac{WetHits}{WetPasses}}{\dfrac{DryHits}{WetHits}} \times 100$$

As can be seen from this equation, determination of RIL imposes a significant measurement and analysis burden on the testers and the test range instrumentation. While this measurement is appealing from an operational perspective, it requires extensive knowledge of the flightpath and dynamic characteristics of the threat missile. A combination of OAR and HITL testing can be used to predict the probability of a particular missile engagement resulting in a hit on the protected aircraft. While a complete description of this procedure is well beyond the scope of this document, suffice it to say that such analytical processes are often employed to gain insight of the overall operational effectiveness of EW techniques and systems without actually performing live fire tests.

8.3.2 HITL Testing On the OAR

Since EW OARs typically possess a variety of threat simulation systems, they may be able to support HITL testing. While the physical configuration of a range differs considerably from our notion of a HITL facility, the equipment available on the OAR frequently meets the testers needs for such tests. The SUT may be located in some form of mobile laboratory (a van or trailer is common) and located near the victim hardware against which it is to be evaluated. This approach can result in several advantages. First, duplication of expensive threat simulators at multiple locations is unnecessary. Second, since the same threat hardware is employed in both the HITL and OAR test phases, an important variable is removed. Finally, an economy of scale is realized; overhead costs are shared between both OAR and HITL tests, and utilization rates are improved.

8.4 Correlation of Test Resources

One of the most troublesome and difficult parts of the EW test process is the correlation of data between different test stages. For instance, if results from a HITL test disagree with results obtained during ISTF testing, the test engineers must understand the cause of the varying observations. The OAR is often viewed as the most authoritative source of test data and so correlation of all subordinate test venues to the OAR is desirable. If properly structured, flight testing can be used to validate/calibrate ground test facilities and models. EW components, subsystems, systems, and entire avionics suites can be installed in either a ground or airborne testbed or in the intended operational platform and tested on OARs. Real-world phenomena such as terrain effects, multi-path propagation, and electromagnetic interference from commercial systems (television and radio broadcasts, microwave transmissions, etc.) will be encountered during OAR testing. The correlation process requires an understanding of each of these effects along with the behavior of the SUT and any threat or victim systems in play. While such an analysis is technically challenging, time consuming, and costly, it will lead to a consistent evaluation of the EW system.

8.5 Airborne Testbeds

Two distinct applications of these flying resources exist. First are those which serve as flying laboratories to carry the system under test (SUT), test support personnel, and instrumentation into the test environment. A second subcategory includes airframe or pod-mounted systems used to simulate an adversary weapon system, armament, or EW capability. Airborne testbeds range from small aircraft with pod-mounted components or systems to large aircraft designed for spread-bench installation and testing of EW and avionics systems. They permit the flight testing of components, subsystems, systems, or functions of EW or avionics suites in early development and modification often before the availability of prototype or production hardware.

8.5.1 Flying Laboratories

This resource has become increasingly important as EW/avionics systems have grown in cost and complexity. It offers an in-flight "shirt-sleeves" environment to testers and development engineers alike to make first-hand observations of system performance under realistic conditions. When assessing the flying laboratory facility for its applicability to a specific test project, one must consider the space available for installing antennas and sensor apertures, other components of the SUT, and instrumentation sufficient to accomplish the desired testing. Access to the SUT or the ability to modify software in flight may be an important consideration for some tests. In addition, the testbed platform capability to provide adequate power and cooling will always be a factor for consideration.

8.5.2 Threat Simulation Testbeds

Threat systems and components may be hosted on range support aircraft to support flight tests and gather data to be used in other test venues. Due to the expense and operational difficulty associated with live fire tests of threat missiles against friendly platforms to evaluate end-game performance of EW techniques, "captive carry" missile seekers are often utilized. In this process a host aircraft carries aloft an actual or simulated threat missile seeker. The pilot of the aircraft follows, to the greatest extent possible, the flight profile commanded by the missile seeker. The actual seeker may be mounted within the host airframe or in a pod to be carried on the wing of the host. This technique permits engineers to access the effectiveness of various EW techniques as the missile closes to close proximity of the target. In some applications multiple seekers may be carried simultaneously so that the net effects of ECM can be compared.

9.0 LESSONS LEARNED

9.1 Lessons Learned from System Integration Testing

The following sections give examples of problems encountered during EW as well as other avionics integration. These examples have been collected directly from test engineers in the field. They provide useful insight to the types of failures or anomalies that are frequently experienced in the course of testing. While the examples are very specific and may seem too unique to be of any help, they are presented here to give further insight into the large range of problems that may occur.

9.1.1 Airframe Harmonic Effects

The energy radiated by higher order harmonics of a high power transmitter on an aircraft would interfere with the operation of other onboard systems. To solve the problem two changes were made. A low-pass filter was incorporated into the system output design and the system's antenna was designed to minimize the generation of second, third, etc. harmonics. Anechoic chamber tests indicated the design objectives were met, but when the system was installed on the airframe, interference was still seen on other onboard systems. The problem was determined to be that the dissimilar metal surfaces of the airframe acted as non-linear devices and induced harmonics onto the reflected signal. In an attempt to change the characteristics of the reflections, the wing surface was pounded with a rubber mallet! The harmonics disappeared but shortly thereafter they reappeared.

9.1.2 Determination of Test Point Limits

As part of acceptance testing a high power microwave (HPM) signal was applied to a system and no damage occurred. When a low power signal was input into the system, normal system operation was observed. However, during middle-level power testing the system suffered damage. The reason was that a Sub-Miniature A (SMA) elbow connector between the system's antenna and receiver caused the HPM signal to arc. This arcing dissipated the high amplitude energy before it reached the receiver. A middle power level did not arc across the SMA elbow connector, but the power was high enough to burn out electronic components in the receiver.

In another instance, the ability of the automatic recovery circuitry of a system to respond to the loss of power for short intervals was tested for losses of aircraft power for a duration of one microsecond and 1 and 10 milliseconds. The system continued to operate properly through the short microsecond dropout of power. Its operation ceased during the 10-millisecond dropout of power but it automatically recovered when power was reapplied. The system never recovered after a 1-millisecond dropout of power. The reason was that the system logic was programmed to handle one thing at a time and it was still sequencing through its powering down routine when it received a signal to power up; the logic was not in place to accept this command so the system just hung up. During the 10 ms power drop out test, the system had already completed its power down cycle when the command was received to power up, so it properly followed the command.

9.1.3 Effects of Component Response Time

A component manufacturer made an assembly change that resulted in an integrated circuit (IC) having a faster response time. The static discharge that occurs during airborne refueling was now sensed by the IC and caused system susceptibility. Therefore, units with the same part number worked differently due to a subtle change in a replacement component.

In another instance, a comparison path in the receiver of a jammer would occasionally have inconsistent results. The problem was traced to a manufacturing change made by a supplier on an IC that resulted in a faster response time. Therefore, signals from one path were arriving at the comparison circuit too soon to be compared with signals from another path.

In yet another instance, a new blanker box in an airplane did not work as well as an older version. The newer components operated significantly quicker than the older components. The original blanker box specification only stipulated the maximum delay through the circuitry; there was no minimum delay requirement because the "state of the art" at the time of the original design would not allow a problem to occur.

9.1.4 Radome Repairs Should Be Tested

A radome serves several purposes. First, it provides an aerodynamically correct shape to the aircraft nose. Second, it shields the internal radar and other avionics from the effects of weather such as rain, sand, etc.

It must perform these tasks and remain electrically transparent to radar energy, both while transmitting and while receiving. The measure of this "transparency" is known as transmission efficiency.

The radome must be designed for the particular radar frequency by matching the cross section structure, thickness, dielectric constant, and materials. Final testing is performed in an anechoic chamber with and without the radome.

If a radome is poorly designed or is damaged, and then is repaired without using proper procedures or testing, the transmission efficiency may be impaired. Figure 9-1 shows the transmission of a radome which had been improperly repaired in the nose area. The "curve" should normally be flat.

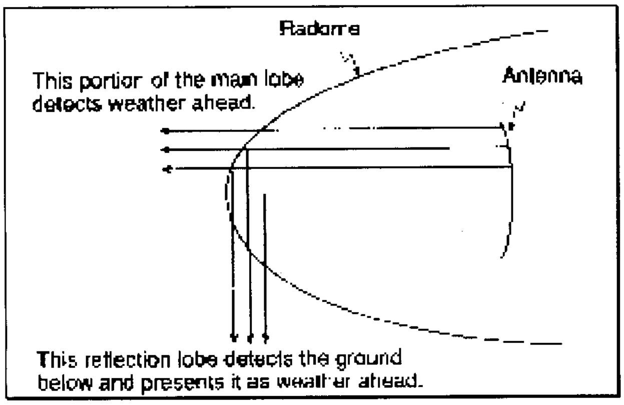

Figure 9-1 Radome Ground Return

As can be seen, the area directly ahead has a poorer transmission efficiency. This can have a major operational impact because an aircraft could be flown into a bad storm, thinking that better weather (weaker return) was in the direction straight ahead. It is postulated that this is what caused at least one aircraft accident several years ago.

In addition to not "seeing" weather or targets in selected directions, an improperly designed or repaired radome can create false targets as shown in Figure 9-2. In this particular case, ground return may depict a false "storm" ahead which is at a distance that the aircraft is above ground level.

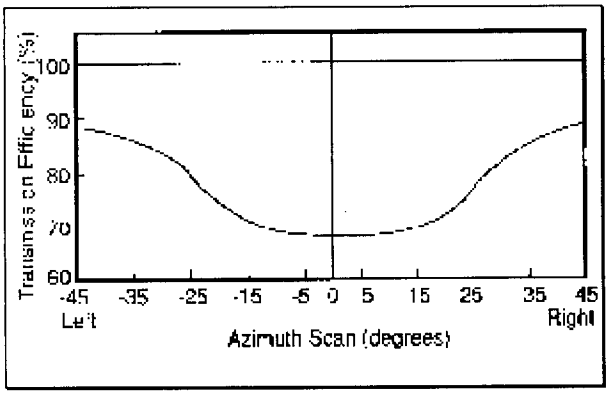

Figure 9-2 Transmission Efficiency

When newer radars are fitted into older aircraft, the radomes need to be checked to ensure proper transmission of the new RF energy and the new radiation pattern.

Note: Figures and background material contributed by Ben MacKenzie, Director, Technology and Engineering, Norton Performance Plastics Corp., Ravenna, Ohio.

9.1.5 Don't Make Assumptions When Reporting Problems

When a countermeasures (CM) system was initially deployed on an aircraft, it was reported to have transmitted on the carrier deck while in the receive mode. What actually occurred was the transmit light illuminated when the CM system was in the receive mode. The witness assumed that since the transmit light was on, the CM system was transmitting. The CM system was found to have circuitry for the transmit light that would inadvertently illuminate in either the presence of certain high power RF or certain types of vibration.

In another case, test personnel reported a jammer continued to transmit long after the input signal was withdrawn. What actually occurred was the system would go into a ring-around condition after the signal was withdrawn, and instead of transmitting a high level signal, only low level noise was transmitted. The transmit light illuminated the same but the output power was significantly different. Finding the solution to the problem was delayed due to assuming the transmission was the same because the light didn't change intensity.

9.1.6 Tape Recordings Can Help Pinpoint Audio Interference

When audio interference was heard on an aircraft internal communication set (ICS), a tape recorder with high frequency metallic tape capability was used to record the sounds with the interfering system on and with it off. The recording was then played back into a spectrum analyzer with the "max hold" function selected. By comparing the two spectrum analyzer presentations, the frequency of the interference was calculated which then enabled engineers to determine the specific circuits causing the interference.

9.1.7 RF Coupling (Interference) On an Aircraft May Not Be Symmetrical

RF coupling, which may cause interference, from the fire control radar (FCR) in the nose of the aircraft to symmetrically located EW (or other) antennas on each wing may not be identical. If the radome for the radar is hinged on one side, the radome material will be thicker on that side and will cause more attenuation to the backlobe of the FCR signal that could couple to other aircraft antennas. If measurements are only performed on that side, no interference or reduced interference could be measured whereas the "mirror image" antenna on the other wing could be receiving more signal and therefore more interference.

9.1.8 Aperture Size Can Change Susceptibility

Life preserver jackets with salt water activated circuitry which allowed them to automatically inflate when immersed in salt water were inadvertently inflating on some pilots flying close to an aircraft carrier and on some sailors on the flight deck. The problem was determined to be a change to the battery system of the life preserver. A design change used a longer single battery container which replaced two individual batteries. The longer "aperture" was a more effective "antenna" and received energy from aircraft carrier radar signals. The received signal arced across an electrical gap that was only supposed to close when exposed to salt water. This caused the inflation of the life jacket. The battery change had not been extensively tested because it wasn't supposed to affect performance!

9.1.9 Set Time Limits On Troubleshooting

When a problem is encountered during part of a test, set a prudent amount of time to investigate, then continue the original test procedure because if the initial problem cannot be readily understood, subsequent testing and results may provide a clearer understanding or solution of the original problem.

As an example, weeks were spent trying to uncover a problem which was caused by an avionics system contractor tying one side of a multiplex bus to a pin labeled "no connection" at the systems, and the airframer grounding the wire going to the "no connection" pin at the airframe end. When the cable was attached to both connectors, the bus was being shorted to ground. All testing was stopped until the problem was found. It would have been better to have spent a day or so, then continue with the original tests, and try to solve the problems in parallel.

9.1.10 Know the Expected Results

During planning for tests, you should identify the expected test results so the differences are readily recognized and, if necessary, more data can be taken. Generally, it is too late after tests are conducted and data are analyzed to try to get additional information about a failure. It is good to prepare blank data sheets ahead of time and perhaps make a mental or dry run, as may have been done during college physics lab so you don't waste critical lab test time or assets.

When out-of-band frequency measurements were made on a jammer's transmission signal, spurious signals at low frequencies with powers exceeding those allowed by the specification were detected. These measurements were discounted since only very low level signals were expected because the band being measured had a waveguide output which acted as an excellent high pass filter. The tests were repeated with a low pass filter (LPF) inserted, and the spurious signals disappeared. The LPF attenuated the strong inband signal which was saturating the spectrum analyzer. If the expected results were not postulated, extensive measurements would have been recorded on the phantom signals and it may have been erroneously reported that the jammer design didn't meet specification.

9.1.11 Investigate Test Response When the System Is Not Hooked Up

A test result may not be what you expect when a system is not hooked up. For example, while evaluating the effectiveness of intermediate level tests of a jammer on a piece of ground support equipment (GSE), the tests were run on the GSE without the jammer hooked up. Surprisingly, five of the 100+ tests passed! It turned out that the noise floor of the measurement instruments in the GSE was being measured and its power level was within the limits of these tests for the jammer. Therefore, these particular tests could never fail and they needed to be changed.

9.1.12 How To Know If the Problem Is the Avionics System Or the Platform

When a system passes I-level tests, then fails in an aircraft, and fails a repeat I-level test, suspect aircraft wiring if this sequence reoccurs in the same aircraft.

For example, on one aircraft carrier, seven jammers were tried in an aircraft and none of them passed self-test. All failed subsequent I-level tests. Finally, aircraft wiring was checked and a short was found which was damaging the jammer interface circuitry.

When a system passes I-level tests, and fails in an aircraft, then repasses I-level tests, suspect aircraft wiring, physical or environmental considerations.

In one case, a keying connector wasn't hooked up and the extra sensitivity that was supposed to be activated in this installation wasn't obtained; consequently the jammer failed flight tests against a certain radar.

In another case, the system power supply coolant was low; so when the jammer was flown, the sloshing, shifting coolant uncovered high voltage electronic components that arced thereby causing a failure. In the I-level test facility, the jammer was always tested in a level position and no failure occurred. As a result, future tests now include testing with one end slightly elevated if a sloshing fluid noise is heard during handling.

9.1.13 Airframers Need To Know What the Avionics Contractor Is Thinking

In one case, the jammer manufacturer assumed that the system's cooling exhaust fans would not be engaged in a ram air-cooled aircraft because a fan disable switch would be depressed when the cooling plenum was attached to the front of the jammer. The airframe manufacturer didn't know that and designed the cooling plenum with a cutout to leave the switch alone. The jammer contractor didn't realize it until one tech rep reported hearing the fans running while the aircraft was on the ground.

In another case, an older jammer relied on the external coupling of the jammer output to the receiver to completely fill the internal loop delay line with RF energy. The jammer installation only specified the minimum external ring-around attenuation and delay but not the maximum values; therefore, some airframers thought that more attenuation/delay was better and none of the transmitted signal filled up the delay line. As a result, the transmitted signals had gaps between each recirculated segment used to build up the transmitted pulse. It should be noted that in this case, even if the optimum attenuation and delay had been obtained, the combining of out-of-phase pulses/pulse segments caused spreading. Nevertheless, the airframer needs the complete information from the system designer when the characteristics of the aircraft installation affect the system design.

9.1.14 Record Serial Equipment Being Tested Along With the Time and Date of Test

It is amazing how quick measurement data becomes worthless when a question arises later and the exact test configuration cannot be ascertained or recreated.

9.1.15 Look at Data Crossover Regions

During testing, data are frequently taken with several test setups (or layouts) in order to accommodate different measurement scales or instruments covering a different frequency range (or some other variable parameter). It is wise to ensure that data points overlap the ranges of data measurements and that the results in this crossover region are consistent (identical). In cases where different bandwidths are used in the amplitude measurement of pulsed signals, there may be a loss in amplitude since one bandwidth may be narrower, but the difference should be explainable. If there is an unexplained difference in the crossover region, the spectrum analyzer may be saturated by a strong out-of-band signal. If an external 10 dB attenuator is inserted, all data should drop by 10 dB. If not, an RF filter needs to be added to reject the interfering out-of-band signal in order to obtain valid measurements.

9.1.16 Try To Arrange Measurements So Measurement Errors Are Obvious

When multiple frequency measurements were made of a jammer's frequency spectrum, three measurements were necessary, i.e., in band, out of band at higher frequencies, and out of band at lower frequencies. To preclude saturation of the spectrum analyzer when lower power measurements were made at the lower frequencies, it was necessary to use a low pass filter (LPF) to attenuate the strong inband signal. To preclude measurement data being used when the filter was inadvertently not inserted, the frequency measurement range was extended high enough to include part of the roll-off portion where the LPF was starting to filter. Therefore, all valid measurements showed a decreasing slope in the jammer's thermal noise at the upper limit of the measurement range.

When antenna to antenna isolation tests were performed on jammer antennas on an aircraft, the engineer always performed the test twice. The first test had the energy sent directly into the spectrum analyzer. During the second test an external 10 dB attenuator was attached to the analyzer. Therefore, if the analyzer's noise floor was being measured in the first set of data (without an attenuator), there wouldn't be a 10 dB difference with the second set (with the attenuator), i.e., data were invalid and the isolation was greater than measured.

9.1.17 Know Your System's Performance

Always run a complete intermediate level repair test on your system (including sensitivity and power levels) before it is tested on an aircraft, and repeat the diagnostic after taking aircraft data. If a system fails part of the second intermediate level test, it may explain why that system failed aircraft tests. For example, an RWR missed identifying emitters in a certain quadrant during an operational test. After repeating an intermediate level test, it was later determined that a hardware failure had occurred and there was not a design deficiency with the system.

9.1.18 Monitor the Power Line During Tests

Power fluctuations on the power line due to other laboratory equipment being turned on or off may affect the performance of the system being tested. If the surges are outside the permitted limits of MIL-STD-704 or the particular system specification, full system performance is probably not required and it shouldn't be classified as a test failure. The same is true when ground tests are performed on an aircraft using an auxiliary power unit versus running the aircraft engines. If the power isn't automatically monitored using external equipment, the wrong conclusions about the system's performance may result. Also, ensure that your monitoring equipment works. A disturbance analyzer was flown in an FA-18 to try to determine why the jammer and RWR were occasionally resetting. After 20 minutes, extensive transients were recorded on phase C of the aircraft power. Since some of the transients seemed too high, the disturbance analyzer was tested on the ground. After letting it run for 20 minutes with nothing connected to the input, it started dispensing a tape documenting all kinds of erroneous "transients" on phase C. The disturbance analyzer had an overheating problem and we were back to square one on identifying the aircraft problem.

9.1.19 Don't Forget Multipath!

During the development phase of a radar warning receiver (RWR) in the 1970's, the system was thoroughly tested using an open-loop radar environment simulator in a HITL laboratory. The RWR utilized a four-port amplitude comparison system, and the antenna pattern values measured from actual antennas tested at an antenna measurement facility were programmed into the simulator as a function of angle and frequency. Dynamic test scenarios were developed to exercise the system to its specification limits. The test scenarios were put into a digital model that predicted the display for the entire 6-minute scenario. The system was designed to only look for six different kinds of threats. Threat frequency ranges and scan and PRI values were varied over the radar limits. When the display presented something different than the digital model, the contractor was allowed to change the system algorithms until the system was optimized. This took 3 weeks of extensive laboratory test time. The system software was then "frozen" and parametric data were recorded on the capability of the RWR. When the system left the laboratory everyone felt the system would perform outstanding during flight test. However, during the first flight when only one threat was radiating, the RWR displayed two and sometimes three symbols at greatly varying angles and ranges! After analysis it was determined that the radar signals were not only going directly into the antenna to be processed but the antennas were receiving the signal reflected off various parts of the aircraft body. The antennas were receiving the same signal from multiple paths! Since the signals were received at slightly different times and amplitudes, the system processed them as separate signals. A great deal of time and money was spent fixing the algorithms to correlate the signals to a single emitter. Don't forget to test the system for multipath correlation!

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ANNEX 1

ELECTRONIC WARFARE TEST FACILITY DESCRIPTIONS

MEASUREMENT FACILITIES

PASSIVE RECEIVING, PROCESSING AND STORAGE SYSTEM (CERES)

Capability:

Measurement Facility

Location:

DERA, Farnborough, UK

Narrative Description:

CERES is a self-contained transportable laboratory that detects and measures electromagnetic radiation between 0.5 to 18 GHz. Its primary application is the measurement of radar signal characteristics in real environments, and to act as a ground truth laboratory in support of research exercises and equipment evaluations.

CERES accurately measures all the primary radar characteristics including radio frequency, pulse repetition interval, pulse width, polarization, scan patterns, signal stability, and any interfering signals. It also has a coarse direction-of-arrival system. When operated in dense environments, it can isolate individual signals for detailed analysis or provide a more general picture of the complete environment. Computer systems control the antenna positioners, various RF receivers, RF component selection, and the data processing and display.

Primary system components are:

- Two major and several minor antenna systems, (dishes, homs, omni's, etc.);
- A TV and computer tracking system which controls the antenna positioners on CERES and MEDUSA;
- A Cossor IFF interrogator to aid or control antenna steering at long ranges;
- RF amplification, filtering, and distribution networks;
- Two Instantaneous Frequency Measuring receivers, a spectrum analyzer, a crystal video receiver, and a high speed digital oscilloscope;
- A 2000 pulse capture and analysis unit; and
- TV cameras, video overlays, monitors, and video recorder systems; all controlled by a dedicated computer system.

CERES also contains specialized analogue and digital hardware for data capture and processing. Various DC power supplies, a 400 Hz static inverter, UHF/VHF communications, intercoms, and audio systems are installed.

Contact:

Mr. C.T.Moffatt and Mr. A.T.Hill
Defence Evaluation and Research Agency
Farnborough, UK

HARDWARE-IN-THE-LOOP FACILITIES

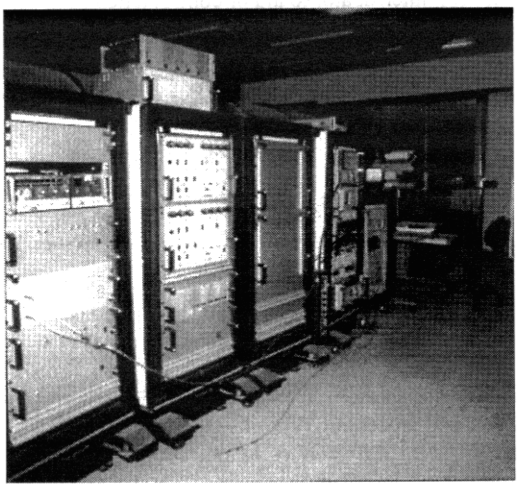
BAGUERA

Capability:

Ground Hardware-In-The-Loop Simulator

Location:

le Centre D'electronique De L'armement(CELAR)
Rennes, France



Narrative Description:

The BAGUERA test bed is a hardware-in-the-loop simulator that allows radar and seeker jamming vulnerability to be assessed. It is entirely transportable, which enables it to conduct on-site assessments. It carries out dynamic, parametric tests on both targets and jammers (deception, confusion).

BAGUERA is intended to test material in a simulated environment representative of that which it is likely to encounter in an operational context (targets, jamming signals, landscape of various mobile craft).

The test bed is composed of an HP 9000 360 series computer which interfaces with the user. This computer allows all parameters to be recorded as well as driving the four racks housing the hyper generation. Using these commands and reference data provided by the unit under test, the BAGUERA test bed creates the hyper-frequency signals representing the target and jammer echoes, then manages them in terms of distance, acceleration, velocity, and amplitude.

The test equipment works on receiving transmissions in an anechoic chamber or in a natural broadcasting environment. Note that as regards semi-active seekers, BAGUERA simulates the illumination signal.

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BEDYRA

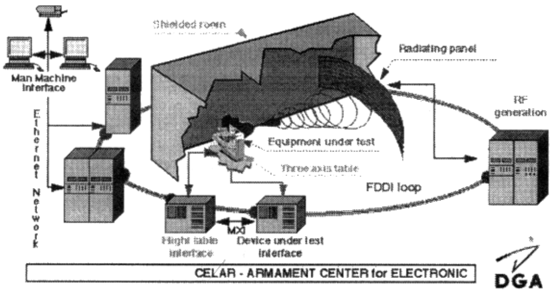
Capability:

Laboratory Hardware-In-The-Loop Simulator

Location:

le Centre D'electronique De L'armement(CELAR)
Rennes, France

BEDYRA : Architecture



Narrative Description:

The BEDYRA test bench was designed for lab testing electromagnetic seekers and airborne tracking radars in an electronic warfare environment. It allows users to explore a large number of operational situations in which such equipment might be involved, and to test environments that because of technical, economic, and security constraints, cannot be carried out in flight testing. The scenarios encountered by the material are perfectly controlled and infinitely reproducible.

The BEDYRA is a hardware-in-the-loop simulator. It combines digital simulation, a frequency generator, and a three axis table, so as to reproduce as faithfully as possible the mechanical and electromagnetic environment which a radar or seeker might actually encounter. The material to be evaluated is set up on a three-axis table, the goal of which is to simulate its vectorial movement. It is positioned opposite a luminescent point scatterer model panel reprocessing the electromagnetic scene. The whole setup is then placed in a screened anechoic chamber. The commands directed to the bench are computed in real-time, thereby offering a closed loop function option. Using these commands and reference data supplied by the tested material, the BEDYRA bench creates the hyper-frequency signals representative of target and jammer echoing, and manages distance, speed acceleration, and level factors. The trajectories followed by the various echoes are simulated on the display panel. This facility is always equipped with tools allowing users to view and record in real-time the commands directed to the bench as well as the parameters reflecting seeker or radar behavior. The user may view them either in real-time in order to check whether the whole setup is working properly or in delayed time to fine-tune the evaluation in progress.

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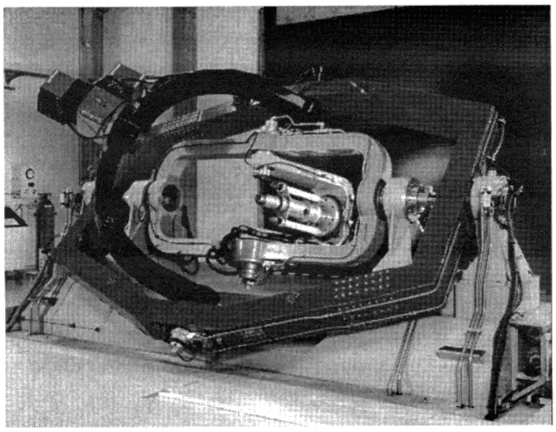
BEDYSSO

Capability:

Laboratory Hardware-in-the-Loop

Location:

CELAR
Bruz, France



Narrative Description:

The Dynamic test bed for electro-optical systems (BEDYSSO) is designed to assess the behavior of missile seeker systems and electro-optical guidance and assignment systems, as well as evaluating the effectiveness of any countermeasures. It is particularly geared toward evaluating infrared seekers.

The characterization of infrared missile seekers is obtained through the parametric evaluation of the search/lock-on function, the tracking function, and the optical war resistance capability. Defining electro-optical countermeasures is based on quantizing the kinematic and electromagnetic features of the sources to be used and research into potentially useful concepts.

Tests are carried out through real-time simulation using hardware in the loop. The whole test bench aims at realistically stimulating the equipment under test. The system simulates the carrier (or missile) environment and the electromagnetic environment.

The whole setup includes:

- A test flight table with three internal axes carrying the tested material and two external axes carrying the infrared targets;
- A control computer ensuring real-time operation of the closed loop;
- Infrared signature generation facilities; and
- Countermeasure simulators.

Generation of the electromagnetic environment is obtained through:

- Simple-, punctual- or circular-shaped variable intensity sources in the three usual spectrum bands:
- Two independent sources for research into multi-target or decoy situation behavior;
- An intense modulatable source for jamming studies; and
- A bi-dimensional source for the generation of a sequence of animated images adapted to air-to-surface applications.

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SPARTE

Capability:

Laboratory Open-Loop Simulator

Location:

le Centre D'electronique De L'armement(CELAR)
Rennes, France

Narrative Description:

The SPARTE bench is designed to assess under laboratory conditions the receivers of countermeasure systems, radar warning receivers, and ESM systems. It tests the assessed behavior of a receiver in various operational situations by generating environments which cannot be carried out in flight due to technical, economic, or confidentiality constraints. The use of SPARTE can encompass all the periods in the life of a system from the feasibility study of a new concept, with a mock-up, validation of various development in stages, then qualification using the prototypes, to preparation of operational missions with systems already used by the armed forces.

SPARTE is a real-time hardware-in-the-loop simulator. It generates signals that correspond to the tested receiver environment. The signals are directly injected into the receiver of the system under test. SPARTE simulates the waveforms of radars and weapons systems performed in a scenario, as well as the conditions of signal propagation, antenna diagrams of the assessed receiver, and the carrier's kinematics and attitude. The material being tested is therefore assessed in the whole spatial sphere. In order to carry out a simulation, the operator describes the operational situation to be performed with a workstation. This environment is automatically rendered into a succession of waveforms representative of the transmitters used in the scenario. The activity detected by the receiver is recorded using several instruments, both analog and digital, and compared with the stage performed. This comparison gives the result of the assessment. It can be done immediately for the most obvious aspects, or afterwards by record analysis. The scenarios used with the material are perfectly controlled, and therefore, can be reproduced ad infinitum.

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RES

Capability:

Laboratory Open-Loop Simulator

Location:

NATO C3 AGENCY
The Hague The Netherlands

Narrative Description:

The NATO C3 Agency Radar Environment Simulator (RES) has been developed for the purpose of evaluation and testing of electronic support measure receivers such as radar warning receivers, ELINT receivers, and receivers of responsive jammers. The simulator is located in a totally shielded facility, permitting secure operations. Up to 50 real radio frequency signals can be generated simultaneously in the frequency band 0.5 to 18 GHz. These signals are generated from 5 multiplexed and nominally 10 dedicated radio frequency sources. The ground-based emitters react preprogrammed to the simulated range to the receiver under test. Range attenuation is taken into account. Emitters are deployed on a 4/3 earth radius sphere. The antennae of the receiver under test are modeled in aircraft coordinates, allowing for freedom of maneuver such as banking, rolling, and pitching of the aircraft. Up to four antenna patterns can be programmed permitting for direction of arrival testing of receivers having four quadrature antenna ports. The flightpath can be executed in a preprogrammed fashion or manually controlled. Any flightpath can be repeated exactly or halted at any point permitting evaluation of potential problems with the receiver under test. Future upgrades to the system include: improved user interface, display upgrades, and the inclusion of airborne emitters into the simulation. The facility can be made available to NATO Nations (except France) for testing of receivers at no cost with technical support provided by NATO C3 Agency personnel. Instrumentation of the receiver under test however has to be provided by the nation bringing the equipment to be tested. Release of test results is exclusively controlled by the nation testing their receiver. The NATO C3 Agency will not release any information relevant to the test without explicit prior consent of the testing nation.

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STARS

Capability:

Hardware-in-the-Loop Simulator

Location:

NATO C3 AGENCY
The Hague The Netherlands

Narrative Description:

The STC Adaptable Radar/EW Simulator (STARS) is used to simulate SAM and AAA systems at radar frequencies, providing real radar receiver components, software simulated tracking and guidance functions, simulated missile fly-out, or gun projectile patterns around the engaged target. Current simulations include SA-8B, SA-6B, SA-11, ZSU 23/4, 2S6(SA-19,ZSU 30/2) as well as a generic search radar and generic SA-2,3,4 simulations.

One weapon system at a time can be simulated. For semi-active missile simulations, perfect illumination of the target is assumed. The target can be described by its radar cross section, its self-protection equipment, etc. Flightpaths relative to the SAM or gun site have to be specified. Effects of countermeasures deployed by the target against the air-defense site can be evaluated.

Real operational or laboratory jammers can be introduced and evaluated in their effectiveness against the simulated threats. A ground-clutter simulation is also available, adding realism to the simulation. The weapon system simulations can be operated with men in the loop to also be able to evaluate the effects of human operators during an engagement. The radar frequencies used for the simulation are limited to the range of 4.0 to 8.0 GHz. Appropriate scaling for Doppler, etc., is applied. Point chaff, stand-off, or escort jamming can be simulated as required. In summary, STARS can be used to develop countermeasures techniques, tactics, and to test laboratory type, prototype, or operational jammers against the simulated threats. STARS can be made available to NATO nations (except France) for technique development, testing of radar countermeasure equipment, etc., at no cost. Instrumentation for the equipment under test must be provided by the user. Release authority of test or other data developed during national use of STARS rests exclusively with the user nation. STC will not release any such information without explicit consent of the user nation.

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THE ANTI-RADAR TARGET SIMULATOR (ARTS)

Capability:

Hardware-in-the-Loop Threat Simulator

Location:

DERA, Farnborough, UK

Narrative Description:

The Anti-Radar Target Simulator (ARTS) is used to simulate target radar for the evaluation of passive anti-radar missiles or drones (ARMs or ARDs). It can represent both conventionally modulated emissions and complex radar transmissions such as spread spectru signals.

ARTS can generate two simultaneous simulated target waveforms, representing either two independent target radar or a main radar and a cooperating decoy or a multi-path reflection. It is aimed at evaluating the performance of ARMs in the final stages of engagements against specific targets. To enhance this capability, the signal modulations arising from the sidelobe structure of the target radar are simulated in detail. The transmitted linear polarization of one of the signals can be modulated electronically and linked to the instantaneous scan position of the radar and the relative position of the seeker. Overlapping pulses and unintentional modulations on the transmitted pulses of both radar can also be simulated. Other facilities such as PEER can then be used to test ARMs against multiple emitters. The ARTS consists of hardware and software components. Two signal generation systems operate side by side through a central controller which connects to all components in the system. The target radar signals are generated within the range 10 MHz to 18 GHz and can be either directly coupled into the seeker or transmitted into an anechoic chamber.

The primary elements of ARTS are:

A Fast Agile Signal Simulator (FASS) and a Vector Arbitrary Waveform Generator (VAWS), two proprietary agile programmable signal generators which provide the two basic signal sources;

- Microwave elements which provide up to 20 watts of power between 2 and 18 GHz;
- Pulse and scan pattern modulators to simulate the pulse and antenna patterns of target radar;
- An electronically controlled polarization controller to rotate the plane of linearly polarized signals;
- A four channel amplitude modulator to 'steer' the signal source between four transmitting antennas; and
- A transmitter-based computer for programming and real-time control of the ARTS facility.

Contact:

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Defence Evaluation and Research Agency
Farnborough, UK

PROGRAMMABLE ELECTRONIC ENVIRONMENT REPLICATOR (PEER)

Capability:

Hardware-in-the-Loop Threat Simulator

Location:

DERA, Farnborough, UK

Narrative Description:

The PEER is an equipment stimulator which will generate, and inject into an ESM or ECM receiver, the large numbers of RF signals that would be encountered in real life operations. PEER can simulate up to 320 pulsed radar by using 32 microprocessors and 3 rapidly re-tunable RF sources. PEER's purpose is to measure the ability of RF receivers and processors to respond to signals from potential threats when combined with large numbers of non-threatening signals in realistic signal environments.

The digital subsystem contains 32 identical microprocessors. Each microprocessor can represent a complete (foreground) weapon system with surveillance, tracking, and command guidance emissions, or up to 10 simple scanning (background) radar. Thus, the total scenario can contain up to 320 radar. Each microprocessor examines the pulse and scan patterns of the radar it is modeling to produce digital descriptors containing the parameters of each pulse. The pulse descriptors from all 32 micro-processors are then arranged in time-of-arrival order and used to control the RF subsystem.

The RF subsystem has three channels each with a digitally controlled RF source and attenuators, enabling three simultaneous signals to be generated. The pulse descriptors pre-set the RF sources and attenuators to determine the signals that will appear at the stimulator outputs. Fast acting switches then generate the RF pulses at the correct time. A ranking system ensures that high priority signals are always generated whenever the scenario demands more than three simultaneous signals. This subsystem can generate over 600,000 pulses per second and can evaluate receivers that measure angle of arrival by amplitude comparison in up to eight channels. The RF power output is approximately 2 mW per channel which is adequate for direct coupling behind the antennae of receivers under test.

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AF ELECTRONIC WARFARE EVALUATION SIMULATOR (AFEWES)

Capability:

Hardware-in-the-Loop (HITL) Facility

Location:

Air Force Plant 4, Fort-Worth, Texas, USA

Narrative Description:

AFEWES provides technical evaluation of the performance and effectiveness of Electronic Warfare systems and techniques in a simulated RF and IR threat environment. The facility can generate a high density signal environment in a secure facility, and test ECM techniques during DT&E/OT&E using manned threat simulators.

Capability Summary:

- Can test systems, sub-systems, and brassboards during different phases of system development to reduce flight test requirements.
- RF signals are controlled to simulate effects of range and aircraft movement.
- Can measure effectiveness in terms of: Tracking error, Missed distance, P_k (Probability of Kill), and P_s (Probability of Survival).
- Can generate the following threats:
  - AI--Airborne Interceptor
  - SAM--Surface to Air Missiles
  - GCI/ACQ Radar
  - Ground Control Interceptor Radar
  - IR--Infrared
  - AAA--Anti-Aircraft Artillery
- Can operate in open-loop and closed-loop modes.

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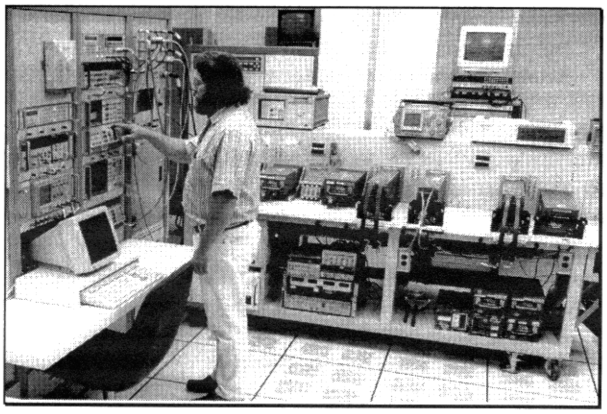
ECSEL

Capability:

Hardware-In-The-Loop Ground Facility

Location:

Naval Air Warfare Center Weapons Division
Pt. Mugu, California, USA



Narrative Description:

Occupying 10,000 square feet of high security radio frequency (RF) shielded space, the ECSEL houses threat simulation, instrumentation, and computer resources required to perform developmental test and evaluation of new EW systems and techniques, integration of EW components and subsystems, and testing of new software revisions for EW systems presently deployed. Commonality between simulations on the ECR range and in the ECSEL make the ECSEL an efficient facility for troubleshooting EW system problems revealed during flight test.

The test approach used in the laboratory is one that incorporates actual EW system hardware interacting with the threat simulator. The threat simulators operate in real-time at actual frequencies and receiver power levels. Open-loop RF environment simulators provide high signal densities which model emitter characteristics of threat systems such as airborne, land-based, and shipboard radars, as well as active command guidance signals for missile systems. Closed-loop simulators provide high fidelity replication of complete radar directed weapons systems such that the effectiveness of active jamming responses can be measured. Closed-loop simulations also include missile hardware simulation for semi-active threat systems. A scenario control computer, with associated aircraft cockpit and flight controls, provides the means to coordinate the simulators and incorporate realistic flight dynamics in the test process. This allows the EW system to be "flown" in laboratory scenarios that represent the electromagnetic environment encountered in actual combat or scenarios that will stress the EW system to its limits.

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INTEGRATED FACILITY FOR AVIONICS TEST (IFAST)

Capability:

Hardware-in-the-Loop Facility

Location:

Edwards Air Force Base, CA

Narrative Description:

IFAST provides six weapons system specific laboratories. Each of the labs or bays is configured to provide a combined software integration and hardware-in-the-loop environment for a particular platform such as B-1B, F-16, or F-22. These bays are used to perform radar and integrated avionics ground test and evaluation to verify functional performance, avionics and weapons integration, and software changes.

Each bay is individually shielded, with isolated electrical power and physical security controls. These features permit testing and development of the most sensitive EW capabilities. Its location, adjacent to the flight line at Edwards AFB, California, fosters the use of an organized and disciplined test process.

Capability Summary:

- Six shielded bays for avionics spread bench testing.
- Single and multiple sub-system and integrated offensive and defensive avionics testing.
- Radar jamming--signal insertion and external transmission (fixed and airborne pods) for defensive avionics transmission and reception.

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INSTALLED SYSTEM TEST FACILITIES

HERF TEST FACILITY

Capability:

Installed System Test Facility

Location:

Daimler-Benz Aerospace
Manching, Germany

Narrative Description:

As a result of recent an extensive investigations on aircraft RF hardness with conventional but inadequate test methods, MBB developed an efficient RF illumination test site for the most problematic High Frequency (HF) range, which allows realistic full threat RF susceptibility tests of large test items.

The basic elements of the High Energy Radiated Electromagnetic Fields (HERF) Test Site include:

- An RF signal generator feeding a 100kW linear RF amplifier (5-30 MHz) for all kinds of modulations;
- Three high power broad-band antennas for the generation of horizontally and vertically polarized electromagnetic fields in the frequency range 5-30 MHz;
- A wooden rotating and lifting platform for the transfer of heavy large test items into homogeneous zones of the horizontally polarized electromagnetic fields;
- HERF resistant multipurpose probes and data acquisition units for installation into the test item as required by the customer;
- HERF resistant signal converters for Fiber Optic Link (FOL) for the transmission of all standard data bus systems; and
- An RF shielded laboratory with all necessary fiber optic link front ends, computer networks, 500 MB hard disk, quick look facilities, and recording systems.

Electromagnetic Field Characteristic

The test range is able to generate almost homogenous high density plan waves corresponding to the actual RF threat conditions for fixed wing aircraft and helicopters or any other object passing powerful HF broadcast stations or equivalent RF sources. Computer graphics of all relevant electromagnetic field parameters as they are distributed over the test volume can be made available for any irradiation situation.

Capabilities Overview

Frequency range	5-30 MHz
High energy radiated electromagnetic field strength	150 V/m
Distance between test volume center and radiating antenna	> [illegible] /2
Max. test item volume for: ▪ Vertically polar. HERF test site ▪ Horizontally polar. HERF test site	 40 x 35 x 12 m (L x W x H) 20 x 15 x 6 m (L x W x H)
RF Source ▪ Max. RF output power ▪ Modulation	 100 kW any kind
Max. height of rotating and lifting platform of the horizontally polarized HERF test site	20m
Max. weight of the test item on the platform	300 kN

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ACETEF

Capability:

Installed System Test Facility

Location:

Naval Air Warfare Center Aircraft Division Patuxent River, Maryland, USA

Narrative Description:

ACETEF is a fully integrated ground test facility which supports test and evaluation of highly integrated aircraft and aircraft systems in a secure and controlled engineering environment. The facility uses state-of-the-art simulation and simulation techniques to provide test scenarios which reproduce conditions approaching actual combat. In ACETEF, a fully integrated weapons system, incorporating vehicle, avionics weapons, crew, other platforms, and critical elements of the operational command/control hierarchy can be immersed in a simulated environment that deceives both the aircraft and flight crew into believing that they are in actual combat. Aircraft systems are deceived through a combination of simulation by digital computers and simulation by computer controlled environment generators that provide radio frequency, electro-optical stimuli which duplicate, as closely as possible, real signals. The flight crew is provided very high fidelity visual, aural, and tactical workload. The following paragraphs give a brief description of the ACETEF subprogram elements.

Anechoic Test Facility - The current NAWCAD anechoic test facility is a tactical aircraft size chamber (100 ft. X 60 ft. X 40 ft.). The aircraft or system under test is suspended in the chamber in a configuration representing actual flight conditions. The chamber provides a secure (over 100dB) and realistic (anechoic, or “no echo”) test environment for system stimulation.

Electronic Warfare Integrated Systems Test Laboratory (EWISTL) - The EWISTL is an open loop, radio frequency generating facility used primarily to stimulate aircraft electronic warfare (EW) systems. The facility can simulate up to 1024 threat radar systems. These radar systems can be located on up to 26 moving platforms to simulate surface combatants, aircraft, or missile systems. EWISTL has the unique capability of providing “threat rich” environments that approximate the threat densities envisioned in actual combat scenarios. Modifications to the EWISTL currently underway will incorporate portable and millimeter wave open loop simulators, jammer simulators, communications environment stimulation, additional background environment simulation, and missile launch simulators.

Closed Loop Threat Facility (CL) - The Closed Loop facility provides specific simulations of a few threat systems to a very high level of fidelity. These systems allow test asset countermeasures to be coupled back into the threat for determinations of effectiveness. Two specific closed loop systems are now operational in the Closed Loop. Closed Loop is linked to EWISTL in real-time.

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BENNEFIELD ANECHOIC FACILITY (BAF)

Capability:

Installed System Test Facility

Location:

Edwards Air Force Base, California, USA

Narrative Description:

The BAF provides realistic, free-space RF environment for evaluation of both uninstalled and installed, federated and integrated avionics, and electronic combat systems on single/multiple host platforms.

Capability Summary:

- The BAF is DoD's largest anechoic chamber (250' x 264' x 70') collocated with air vehicle modeling/simulation (TEMS) and systems integration laboratories (IFAST).
- In excess of 130 dB of isolation/attenuation from the outside world.
- 115 VAC 400 Hz/115 VAC 60 Hz/480 VAC 60Hz power.
- Aircraft cooling and hydraulics.
- Monitoring/recording of two Pulse Code Modulated and five MIL-STD 1553B mux bus data streams.
- An 80-foot diameter turntable and two 40-ton man-rated hoists. The turntable is capable of rotating in excess of a 250,000 pound test article 380 degrees (+/- 190 degrees) with a 0.1 degree positional accuracy. The turntable is capable of rotating at rates varying from 0.1 degrees per second to 0.6 degrees per second. The 40-ton man-rated hoists are capable of lifting and rotating test articles as high as 55 feet above the floor of the facility.

The BAF has three threat sites (TS) that house the current threat generation systems. TS 1 houses the Combat Electromagnetic Environment Simulator (CEESIM) 8000 and 14 RF channels. TS 2 and 3 each house two remote CEESIM 8000 controlled channels and one hybrid threat simulator. Some threat generation capabilities are:

- Simulates surface based, sea based, and airborne RF threat system signals.
- Generates in excess of 64 million pulses per second (MPPS).
- Generates 3-5 MPPS in a coordinated coherent scenario.
- Simulates 640 emitters simultaneously at the digital level.
- 22 RF hardware channels (22 instantaneous RF signals).
- Simulate eight time-coincident beams.
- Various pulse repetition intervals and pulse widths.
- Various frequency modulations.
- Various scan and antenna patterns.
- Terrain occlusion.
- Updates eight channels each microsecond.

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OPEN AIR RANGE

HYPERBRAHMS

Capability:

Flight Test ground station

Location:

Flight test Centre

Bretigny, France

Narrative Description

HYPERBRAHMS measures the Radar Cross Section (RCS) of aircraft, ships, or land vehicles.

HYPERBRAHMS can perform an analysis of the Doppler signatures, the characterization of electromagnetic decoys, and an analysis of the capabilities of jammers. The system has a real-time processing capability allowing the tests to be validated immediately with finer processing available in non real-time. The systems' antenna can be designated externally. HYPERBRAHMS can be set up by three operators with an on-site installation time of 2 to 4 days.

Main Parameters

- Simultaneous measurement in seven frequency bands between 0.5 and 38 GHz in 10-kHz steps
- Dual polarization (H and V) transmission, 14 measurement channels in receive mode
- 10 measurement channels in pulse mode (2 to 18 GHz and 32 to 38 GHz) in 3.3 -ns to 10 pulses (minimum range resolution: 50 cm)
- Power requirements: three-phase 380V 110kVA

Contact:

Flight Test Centre
Bretigny
Tel. (33) 01 69 88 25 20

HYPERCERBERE

Capability

Flight test ground station

Location

Flight Test Centre

Bretigny, France

Narrative Description

HYPERCERBERE is a ground station for acquisition and pre-processing of measurements of the infrared (IR) radiation emitted by air targets. HYPERCERBERE consists of an air-transportable shelter with a measurement compartment and turret room: length: 8m, weight: 7 t.

By measuring the IR signature, HYPERCERBERE is used to enhance the performance and stealth characteristics of airborne weapon systems to improve their effectiveness and provide them with improved survival capability in operation. It can also be used to correct radiation models by precisely identifying the IR signature of the target as seen by the weapon system as well as to enhance the performance characteristics of self-protection systems.

Main performance characteristics:

- Turret:

  Traverse clearance: 360o

  Elevation clearance: -5o and +90o

  Speed: 2 rad/s

  Acceleration: 8 rad/s

  Equipped weight: 900kg

- Measurement sensors:

  Band I, II, III radiation meters (1.5 to 14.5 mm)

  Band II thermal imaging camera

  (2.5 to 5.2 mm).

- Equipment:

  One real-time supervision computer

  Three VME-based computers

  Turret control

  Measurement acquisition

  Image processing

There are internal and external ETHERNET networks for non-real-time data transmission to CEV station (MATISSE network).

Contact:

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THE ANTI-RADAR MISSILE AIRBORNE DATA ANALYSIS SYSTEM (ARMADAS)

Capability:

RF Threat Simulator

Location:

DERA, Farnborough, UK

Narrative Description:

ARMADAS's primary function is the recording and analysis of the emission characteristics of modem complex radar systems and multi-path effects within their operational environment.

The equipment is installed in an Andover with the microwave receiving antenna mounted in a stabilized steerable pod mounted in the nose of the aircraft. The pod also contains a TV camera which feeds a tracking system and TV monitor within the aircraft. This allows the pod to be aligned with the target by a number of alternative methods. The principal method is by the TV camera and optical tracker maintaining the target radar in the center of the image.

The direction of the line of sight to the target aircraft is calculated by knowing the position of the Andover aircraft from its navigation system and the target aircraft from a GPS system. The pod is then steered to the desired line of sight. This facility allows the system to operate independently of instrumented ranges, against any target of opportunity, and can therefore be operated during normal military exercise in order to obtain results from realistic complex scenarios.

Additional modes of control are manual steering of the pod, and finally, suitably processed signals from the microwave receiving equipment itself.

The Tracker system receives data from the TV camera mounted in the steerable pod. The operator identifies the object to be tracked in the first instance by steering the pod manually if necessary and selecting the target on the TV monitor. The tracker will then steer the pod so as to maintain the target on the boresight of the TV camera. The scene from the camera is recorded using the VCR and the picture is overlaid with various markers indicating parameters such as boresight and tracked object position. If the tracker is unable to track the target, then it is possible to steer the pod using data from the PC which calculates the position by using the data from the GPS input and the aircraft data. ARMADAS has been recently upgraded by the addition of a narrow band signal demodulator and a differential GPS system to provide accurate time and position references.

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THE ACTIVE MULTIPLE RADAR SIMULATION SYSTEM (MEDUSA)

Capability:

RF Threat Simulator

Location:

DERA, Farnborough, UK

Narrative Description:

MEDUSA is a self-contained mobile laboratory for the transmission of medium to high power RF signals between 0.5 to 18 GHz. Its purpose is to generate test and simulated radar signals in free space during trials.

MEDUSA contains RF simulation, distribution, and transmission and monitoring hardware. It can generate ERPs capable of exercising the full dynamic range of receivers at short ranges, and capable of detection at ranges beyond 10 km on flight trials. All the primary radar characteristics can be simulated, plus engagement sequences and multiple signals. Linear polarization changes are also possible.

The primary system components of MEDUSA are:

- three dish antennae and turntables;
- multiple hardware (PROM) or software (FURIES) programmable pulse generators;
- multiple RF sources, modulators and amplifiers (up to 4 kW);
- signal monitoring equipment including power meters, spectrum analyzer, and oscilloscopes;
- plus various power supplies, and 400 Hz static inverters.

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ELECTRONIC COMBAT RANGE (ECR)

Capability:

Open-Air Range

Location:

Naval Air Warfare Center Weapons Division
China Lake, California, USA

Narrative Description:

The ECR provides a comprehensive electronic warfare (EW) stand-alone test environment and permits multiple tests to be conducted concurrently. The ECR provides realistic representations of Russia and ROW air defense systems and instrumentation for test and evaluation of electronic warfare systems, devices, and tactics. The ECR performs EW tests to support exploratory development, engineering development, technical and operational evaluations, and training. In addition, live fire tests can be conducted in coordination with the other ranges at the China Lake Complex. The ECR contains both shipboard and land-based air defense threats as well as blue and gray systems.

ECR currently provides numerous threat simulator and real world systems of various types employing a large spectrum of technologies and techniques employed in radar system design including multi-object tracking phased array designs. All of these systems are instrumented with audio and video instrumentation and a number of the systems are instrumented to collect extensive digital data about the operation of the systems. The Command and Control (C2) system can be used to control the operation of the threat simulations as they would be operated if they were part of an integrated air defense network. The ECR C2 systems enable various combinations of the ECR's numerous air defense assets to represent surface and naval air-defense systems found around the world.

In addition to the threat systems, ECR maintains time, space, and position information (TSPI) reference systems, a computer and operations center, a telemetry facility, a facility for static ground testing and RF monitoring, and a data processing capability. The ECR has an extensive instrumentation infrastructure consisting of fiber optic communications, telemetry reception, recording, and an extensive real-time presentation of audio, video, and digital data for monitoring the execution of tests involving the threat systems. These data are collected in a central location on the range and presented collectively in the Test Operations Center. The Operations Center interfaces with data collecting and video recording systems, allowing a test to be controlled and monitored by a test operations team and customer representatives. The Operations Center includes a digital display system to permit range users to view real-time data including tracking errors, radar status data, missile intercept data, and gun system lethality. Video displays are available to view visual images from cameras mounted on the threat system antenna pedestals. In addition, various radar displays are available including type-A, type-B, and Plan Position Indicator (PPI) displays. The data are recorded and available immediately to the user and post-test data processing team. Reference systems at ECR include Nike target tracking radars and the Global Positioning based TSPI System. In addition, laser, optical, and IR tracking systems can be obtained for specific tests from other organizations at China Lake.

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MODELING AND SIMULATION

LIGASE

Capability:

Laboratory Digital Model

Location:

le Centre D'electronique De L'armement(CELAR)
Rennes, France

Narrative Description:

LIGASE is a response to problems encountered in integrating a group of models within an armament system. This software allows system status to be interactively prepared and visualized for analytical purposes in the course of time. LIGASE allows findings from various simulations of one and the same case to be processed for statistical use.

The digital simulations of MICA fire control systems in MIRAGE 2000-5 and RAFALE aircraft were instrumental in causing this software tool to be produced. The models comprising the fabric of the system are the responsibility of different manufacturers: Dassault Aviation, Thomson-CSF/RCM and TTD, Matra Defense, GIE RBE2, SAT. For reasons of industrial confidentiality, no manufacturer has access to the models developed by the other contractors.

LIGASE is a host structure composed of a model management core and an MMI (Man Machine Interface). Models exist for the environment, radar, radar warning receiver, jammer, aircraft, target, and missile. Various activation modes are batch, statistical, and interactive. The management core governs the models' temporal activation and data interchange. The models are written in Fortran, C, and C++. The MMI allows simulation to be controlled while displaying system status through overviews or cut-out views such as a radar display, an infrared picture, or an alert detection display from a workstation.

Contact:

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GEOS/MPE
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VHEDAA

Capability:

Laboratory digital model

Location:

CELAR
GEOS
Bruz, France

Narrative Description:

The VHEDAA application is a study environment for helicopter vulnerability using simulation tools and statistical computation. Helicopters are characterized by their ability to take advantage of the protection provided by geographical relief and micro-relief against the threats placed in an operational environment. They represent an effective tool to get closer to the target while keeping hidden from the potential surface-to-air threat (optical, infrared, electromagnetic). Helicopter vulnerability studies have to take into account these specific behavior patterns and to deal as much as possible with digitized maps; the interrelationships between the threat and the helicopter, nap-of-the earth flights and so on. This constraint, which is not sufficiently emphasized in aircraft studies, needs to constantly control the interaction of each involved "object" (helicopters, threats, projectiles, flares) with the ground environment. VHEDAA allows the user to do this.

A man-machine interface allows the user to create a scenario on a digitized map easily (either a genuine map or one obtained by the user from a statistical model). The definition of the scenario is established by selecting the starting and destination points for the helicopter's trajectory and after that the number and type of threats involved in the scenario. The man-machine interface provides the user with a broad range of possibilities:

Selection of the map in a database: statistical or realistic (DLMS altimeter and planimeter). The resolution of a mesh is variable depending on the need.

Selection of the helicopter, the signature and the selfscreening system (Radar Warning Receiver, Missile Launch Detector, Missile Approach Detector, flares, chaffs...), selection of its reaction (rerouting, evasion) and its trajectory (very low altitude flight, map-of-the-earth flight).

Selection of a threat: infrared, electromagnetic coupled with a missile or a gun. The threat is modeled with a high level of accuracy; validated models are included, such as seekers and radars, which enable the user to carry out efficiency studies in an electronic warfare environment. Each integrated threat has its own system behavior and all the targets for system engagement states. The user can control all the steps of acquisition and tracking; the scene projected on the field of view of the seeker can be seen during the simulation. The signal-to-noise ratio is computed, as is the radiance for the infrared seeker.

The methodology: a realistic scenario in a multiple-threat environment or duel configurations between the helicopter and the chosen threat with a view to establishing a comprehensive statistical study are available.

Two types of studies can be conducted with VHEDAA: an operational scenario or statistical. Both solutions are complementary and allow the blanks left by either one to be covered by the other. The operational study aims at a high degree of realism in a tactical scenario. The helicopter has a mission and has to face numerous threats of different types. All the criteria are defined, including number, types, and positions of threats. The precise trajectory is defined by a computer model or by pilots in a helicopter-man-in-the-loop simulator. This study enables the user to make a precise vulnerability study, the results of which are not applied to another configuration. These results are useful to validate a concept. The statistical study has been defined to avoid the dependence of the results obtained with the operational study. The aim of the study is to get results such as delectability or vulnerability for each helicopter evaluation without having to define the type of map or the position of the threat.

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TEST AND EVALUATION MODELING AND SIMULATION FACILITY (TEMS)

Capability:

Modeling and Simulation Facility

Location:

Edwards Air Force Base, California,. USA

Narrative Description:

The Test and Evaluation Modeling and Simulation (TEMS) facility provides constructive, non-real-time and virtual, piloted real-time simulations. While the primary focus of TEMS is on support of operational and developmental testing, its utility has been demonstrated throughout the entire lifecycle of aerospace systems. TEMS routinely supports testing, mission rehearsal, training, and analysis for aircraft flying qualities, performance, propulsion, avionics, and electronic warfare. The precise control, flexibility, and repeatability of these simulations are paramount in implementing a predict-test-compare-update philosophy leveraging knowledge gained through ground testing before implementing a flight test methodology.

The full range of constructive, non-real-time simulations ranging from Campaign to Mission, Engagement, and Engineering levels is supported by TEMS. Based on customer needs, TEMS can model a myriad of simulations focusing on different types of evaluations. TEMS can model a multi-day, theater level campaign, simulating force-on-force, air-land battle using the THUNDER model.

Where mission level metrics are required, TEMS has the ability to model air superiority and survivability to simulate a many-on-many, air-land battle using SUPRESSOR and DIADS. SUPRESSOR allows the capability to evaluate mission level metrics such as effects due to weapon and sensor systems, tactics, command and control vulnerabilities, and susceptibility to countermeasures. DIADS uniquely provides users with a tool for the evaluation of the effectiveness of the enemy integrated air defense system, as well as its susceptibility.

At the Engagement level, TEMS has both ESAMS and JMASS simulations available. These simulations model engagement level, one-on-one, air-land battle simulations. Engagement level metrics include missile and target flightpaths, detailed end game analysis, and statistically analyzed data.

TEMS also provides a full range of virtual, real-time, operator-in-the-loop, simulations ranging from engineering level, stand-alone, to multiple aircraft simulations linked together to provide a one-on-one engagement or many-on-many mission level simulations. These simulations offer support to a wide range of activities that include aircraft envelope expansion, EW blue/red man in the loop, anomaly investigation, incident/accident investigation, mission rehearsal, and aircrew system familiarization.

Modeling and Simulation verification and validation is an integral part of TEMS' configuration management plan. Correlation and consistency of data are paramount to achieve the highest fidelity of models and simulations. The ultimate source of validation data is open-air range data and TEMS, being part of the overall test process, is uniquely postured to incorporate actual flight test data to update models. In this way, the model and simulations achieve "real-world" validation that is mandatory in today's test and evaluation environment.

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Annex

AGARD and RTO Flight Test Instrumentation and Flight Test Techniques Series

1. Volumes in the AGARD and RTO Flight Test Instrumentation Series, AGARDograph 160

Volume Number	Title	Publication Date
1.	Basic Principles of Flight Test Instrumentation Engineering (Issue 2) Issue 1: edited by A. Pool and D. Bosman Issue 2: edited by R. Borek and A. Pool	 1974 1994
2.	In-Flight Temperature Measurements by F. Trenkle and M. Reinhardt	1973
3.	The Measurements of Fuel Flow by J.T. France	1972
4.	The Measurements of Engine Rotation Speed by M. Vedrunes	1973
5.	Magnetic Recording of Flight Test Data by G.E. Bennett	1974
6.	Open and Closed Loop Accelerometers by I. Mclaren	1974
7.	Strain Gauge Measurements on Aircraft by E. Kottkamp, H. Wilhelm and D. Kohl	1976
8.	Linear and Angular Position Measurement of Aircraft Components by J.C. van der Linden and H.A. Mensink	1977
9.	Aeroelastic Flight Test Techniques and Instrumentation by J.W.G. van Nunen and G. Piazzoli	1979
10.	Helicopter Flight Test Instrumentation by K.R. Ferrell	1980
11.	Pressure and Flow Measurement by W. Wuest	1980
12.	Aircraft Flight Test Data Processing - A Review of the State of the Art by L.J. Smith and N.O. Matthews	1980
13.	Practical Aspects of Instrumentation System Installation by R.W. Borek	1981
14.	The Analysis of Random Data by D.A. Williams	1981
15.	Gyroscopic Instruments and their Application to Flight Testing by B. Stieler and H. Winter	1982
16.	Trajectory Measurements for Take-off and Landing Test and Other Short-Range Applications by P. de Benque D'Agut, H. Riebeek and A. Pool	1985
17.	Analogue Signal Conditioning for Flight Test Instrumentation by D.W. Veatch and R.K. Bogue	1986
18.	Microprocessor Applications in Airborne Flight Test Instrumentation by M.J. Prickett	1987
19.	Digital Signal Conditioning for Flight Test by G.A. Bever	1991

2. Volumes in the AGARD and RTO Flight Test Techniques Series

Volume Number	Title	Publication Date
AG237	Guide to In-Flight Thrust Measurement of Turbojets and Fan Engines by the MIDAP Study Group (UK)	1979

The remaining volumes are published as a sequence of Volume Numbers of AGARDograph 300.

Volume Number	Title	Publication Date
1.	Calibration of Air-Data Systems and Flow Direction Sensors by J.A. Lawford and K.R. Nippress	1988
2.	Identification of Dynamic Systems by R.E. Maine and K.W. Iliff	1988
3.	Identification of Dynamic Systems - Applications to Aircraft Part 1: The Output Error Approach by R.E. Maine and K.W. Iliff	1986
	Part 2: Nonlinear Analysis and Manoeuvre Design by J.A. Mulder, J.K. Sridhar and J.H. Breeman	1994
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5.	Store Separation Flight Testing by R.J. Arnold and C.S. Epstein	1986
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8.	Flight Testing under Extreme Environmental Conditions by C.L. Henrickson	1988
9.	Aircraft Exterior Noise Measurement and Analysis Techniques by H. Heller	1991
10.	Weapon Delivery Analysis and Ballistic Flight Testing by R.J. Arnold and J.B. Knight	1992
11.	The Testing of Fixed Wing Tanker & Receiver Aircraft to Establish their Air-to-Air Refuelling Capabilities by J. Bradley and K. Emerson	1992
12.	The Principles of Flight Test Assessment of Flight-Safety-Critical Systems in Helicopters by J.D.L. Gregory	1994
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17.	Electronic Warfare Test and Evaluation by H. Banks and R. McQuillan	2000
18.	Flight Testing of Radio Navigation Systems by H. Bothe and H.J. Hotop	2000
19.	Simulation in Support of Flight Testing by D. Hines	2000

At the time of publication of the present volume the following volumes were in preparation:

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by F. Webster

Flight Testing of Missiles
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Flight Testing of Night Vision Systems
by J. Dumoulim

Flight Testing of Radio Navigation Systems
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Simulation in Support of Flight Testing
by D. Hines

Rotorcraft/Ship Compatibility Testing
by W. Geyer Jr, R. Finch, R. Fang, D. Carico, K. Long and H.W. Krijns

Flight Test Measurement Techniques for Laminar Flow
by Horstman nad D. Fisher

The Integration of Logistics Test and Evaluation in Flight Testing
by M. Bourcier

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14. Abstract

The past decade has seen an enormous increase in the use and importance of the "electronic battlefield." As a result of the continuing growth in this area, this volume has been prepared to serve as an introductory reference to the process of testing and evaluating Electronic Warfare Systems. Electronic Warfare (EW) is the mission area responsible for establishing and maintaining a favorable position in the electromagnetic domain.

Test and evaluation (T&E) of those devices used on modern military aircraft to prosecute this critical mission area requires the use of a wide range of test techniques and analytical methods to assure users of the readiness of EW systems to meet the challenges of the combat environment. Actual in-flight testing comprises a relatively small portion of the EW T&E process. Today's tester makes judicious use of a plethora of models, simulations, and hardware-in-the-loop test facilities prior to and during the more realistic open-air range and installed system test facility events. Analysis of data derived from each of these test opportunities leads to the overall evaluation of the EW system.

This volume will introduce the concept of the EW Test Process and subsequently show how it is applied in each class of test facility and to each major division of EW systems. The reader will find that the concentration in this document is far broader than "flight test" - ranging from laboratory efforts to establish the system performance baseline through complex ground-based simulations and finally the limited, but vitally important, verification accomplished in the open-air range environment.

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