Chapter 6 – EW T&E RESOURCES AND FACILITIES

6.1 INTRODUCTION

This chapter provides generic descriptions of ground and flight test resources and facilities commonly utilised in the T&E of EW systems and components. EW T&E capability types are introduced and their primary functional categories explained. Distinguishing factors of facilities are discussed. The chapter concludes with a section on the common use of many of the test facility types for EMC and EMI testing of EW and other systems.

Descriptions of known EW and related test facilities in NATO Nations are given in Annex A. Whilst this annex does not fully describe every resource that a project may wish to utilise, it represents a valuable resource for understanding the range of facilities available to meet the goals of a structured test process.

6.2 SCOPE OF EW T&E CAPABILITIES

A number of T&E facilities and resources, or 'capabilities,' are required to support:

- EW system design, development and performance verification against its specification;
- Government acquisition agency ('customer') and military end user acceptance; and
- Operational use of the platform.

There are various definitions of T&E capabilities across NATO Nations and these are typical:

- 'A Test and Evaluation (T&E) capability is a combination of facilities, equipment, people, skills and methods, which enable the demonstration, measurement and analysis of the performance of a system and the assessment of the results.' [1]
- 'The people, assets and processes to undertake evaluation with sufficient accuracy and timeliness to assure provision of through-life military capability.' [2]

Throughout this Handbook the human aspect of EW T&E capabilities is considered to be implicit. The operation of many of the facilities described in this chapter depends upon a high degree of specialist engineering knowledge and expertise in the Electromagnetics and Systems Engineering domains.

Facilities and equipment are described with reference to terminology used in the first issue of this Handbook and [3], with commentary and examples. The range of facilities is shown in Figure 1-6 and a non-exhaustive list of strengths and limitations of each is given elsewhere. [3]

Test capabilities are frequently categorised by their primary function, as given below:

- Modelling and Simulation (M&S);
- Measurement Facilities (MF);
- System Integration Laboratories (SIL);
- Hardware-In-The-Loop facilities (HITL);
- Installed Systems Test Facilities (ISTF); and
- Open Air Range (OAR).

In many cases, however, these definitions are overly and inappropriately restrictive. For example, large anechoic chambers are generally classified as ISTFs and yet they often provide excellent support in the role of MFs. The following sections explain the role of each of the above categories but are not meant to imply that facilities otherwise defined should not be utilised in a role outside their primary designation.

Test missions by location are summarised in Table 6-1.

Table 6-1: Test Missions by Facility Type.

Test Location	Primary Test Mission
SIL/HITL (Digital, RF and Intermediate Frequency)	R&D and concept development. Note: Often need simulation capability enhancement to be able to develop new or 'next generation' EW receiver systems/upgrades
	Requirements definition and system performance modelling
	HITL: Equipment/sub-system development and qualification
	Uninstalled sub-system performance verification (usually over full range of performance)
	Integration with other platform avionics; further development and sub-system performance verification, conducted in SIL
	ESM-ECM performance optimisation vs. specified threat environment
	Evaluation of new/upgraded threats and countermeasures development
	Development, evaluation and clearance of EW upgrades
ISTF (Anechoic Chamber and Other)	Platform-system integration. Further sub-system and avionics system development
	Installed system performance verification, including SUT irradiation with 'war mode' and other signals now allowed to be transmitted in the open air
	Fault/anomaly investigation, isolation and solution confirmation
	Airframe-systems aspects of EW upgrades' development, evaluation and clearance
Open Air Test Site	Free space, far field, illumination of aircraft-installed SUTs for cases where anechoic chamber tests not viable or unacceptably limited, e.g., antenna polar diagrams and ESM/ECM beam-forming measurements (far-field)
	Whole platform EMC tests
	Platform radar cross-section measurements
OAR and Other Flight Test Facilities	Residual installed performance verification tests for aspects not acceptably testable using above locations and methods
	Development and performance verification of aspects not ground-testable, e.g., combinations of tactics, flare/chaff dispensing, on-board RF jamming and towed RF decoys
	Evaluation/optimisation of EW system man-machine interface under flight conditions
In-Service Support – a.k.a. 'Sustainment' (Laboratories and OARs)	Mission Data Validation prior to and during training, operational evaluation and combat
	EW hardware/firmware and algorithmic software performance optimisation
	Post-maintenance and pre-flight check-out
	Evaluation and resolution of operational problems
	EW and countermeasures/tactics effectiveness evaluation/optimisation
	Mission rehearsal and aircrew/operator/maintainer training

An important distinction, especially relevant to RF EW systems, is the difference between 'un-installed' and 'installed' sensor and system performance. In the former case the sensor is not mounted on the platform, e.g., a stand-alone RWR antenna. In the latter case the sensor is mounted correctly on the platform, i.e., for the above example the RWR antenna would be mounted in a RAM-lined cavity in a fin-tip pod and covered by a radome made of dielectric material. The EM performance difference between the two cases can be large, in particular where the airframe is non-metallic (e.g., Carbon Fibre Composite), and this can result in system-level performance that requires modification to successfully meet the system's specification. Such modification can be expensive and time-consuming if not detected until the flight test and production phases. This risk can be adequately managed via validated modelling of installed performance of RF sensors, a topic mentioned in the next section 'Modelling and Simulation'.

6.3 MODELLING AND SIMULATION

M&S, which is also known as Modelling, Simulation and Synthetic Environments (MS&SE), is used to:

- Demonstrate system performance for aspects too complex or too expensive to verify by testing.
- Estimate error bounds where test repeatability is difficult or where tests alone would yield unacceptable error bounds.
- Supplement testing by interpolation between sparse data points or to extrapolate from measured data.
- Prove design concepts prior to final testing.

Most M&S undertaken as part of the design verification process is currently performed by equipment suppliers, who provide outcomes as acceptance evidence to the PSI. An area of promise is Computational EM Modelling (CEM), where modern computing power and innovative codes offer useful design optimisation and risk reduction for RF antenna installations on platforms. Table 6-2 indicates typical example M&S tools used in EW Design and Development (D&D) and T&E.

Table 6-2: Typical M&S Tools Applicable to EW D&D and T&E.

MODELS (Examples)		MODELLING LEVEL	TYPICAL MOEs	TYPICAL MOPs	VALIDATION
THUNDER	REFINEMENT OF MODELLING ASSUMPTIONS	Campaign	Campaign length	Aircraft availability	Wartime experience
EADSIM		Mission	Attrition levels	Number of encounters	Wartime experience
AWSEM, SAMOCLES		Engagement	Pk reduction factor	Miss distance	Trials data, including live fire
CEESIM/EGA		System	Jam-to-signal requirements, installed sensor coverage	Pulse characteristics, RF communications link success probability	Experimental data, including whole aircraft test
TLM, GTD/UTD		Sub-system and equipment	Impulse response, uninstalled antenna patterns	Circuit voltages, antenna gain, impedance, RF currents and voltages	Above + EM theory, physics textbooks, standard problems, other validated codes

Notable issues with M&S as relevant to EW T&E are:

- Simulation fidelity and model validation, i.e., how faithfully they represent real threats and EW equipments and their performance.
- Modelling of EW antennas, systems and intra-platform cabling is not sufficiently robust to maximise contribution to acceptance.

There is a continuing US and European thrust to move EW T&E toward ground test and M&S. This work, which requires extensive scenario modelling and the increasing use of EW equipment models, offers great promise in reducing not only the expensive flight testing phase, but also overall EW system development and Mission Data validation timescales and costs. There remains, however, doubt that some aspects, e.g., RF and IR jamming and other countermeasure effectiveness, will ever be fully cleared by M&S alone, i.e., without some residual element of flight trials. This is particularly true of simulations involving a 'man in the loop.' While M&S has become quite good at modelling phenomenology, it doesn't generally handle humans very well.

The topic of M&S, as applied to EW T&E, is expanded in Chapter 7.

6.4 MEASUREMENT FACILITIES

MFs establish the character of an EW-related system/sub-system or technology. They provide:

- EW and platform antenna pattern descriptions and platform signature data critical for system design and refinement, computer simulation, and EW equipment/system testing in HITLs, SILs and ISTFs.
- Capabilities to explore and evaluate advanced technologies such as those involved with various sensors and multi-spectral signature reduction. These are used to provide data that cannot be modelled adequately. In some cases, for example antenna pattern measurement, they provide data for validation of M&S used in the Verification and Validation (V&V) process.

Measurement facilities generally fall into the sub-categories:

- Antenna characterisation.
- Signatures measurement: RCS, IR, UV, and laser.
- EMC and EMI, on open air test sites and in anechoic chambers.

Platform-level examples of MF types are given in Figure 6-1.

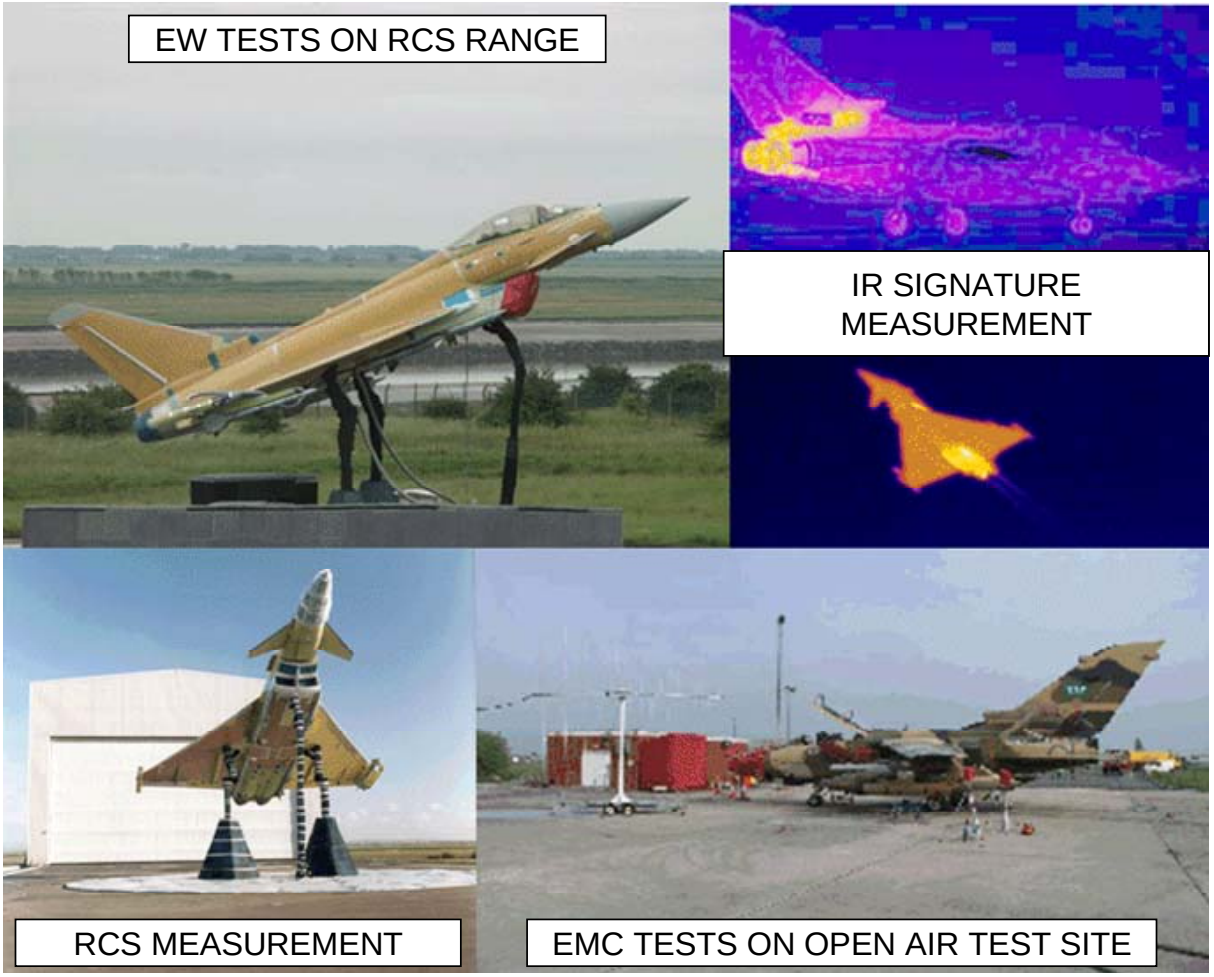

Figure 6-1: Measurement Facility Examples – (© BAE SYSTEMS 2010, All Rights Reserved).

6.5 SYSTEM INTEGRATION LABORATORIES

SILs are facilities designed to test the performance and compatibility of components, sub-systems, 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 contractor (EW equipment supplier and platform/systems integrator) 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 SUT production hardware and software. SILs are used from the beginning of an EW system's development through avionics integration and fielding. Moreover, SILs continue to be used throughout an EW system's operational life to support:

- Investigation and resolution of in-service problems; and
- Testing of hardware and software modifications and updates.

Whilst the term 'SIL' is US-originated, equivalents in the UK and elsewhere are:

- Sub-System (SS) Rig, where individual EW equipments are integrated into a sub-system and developed prior to integration with other platform avionics.
- Avionic Integration (AI) or System Integration (SI) Rig, where – prior to release for aircraft use:
  - The EW sub-system is integrated with the rest of the platform's avionics and other systems; and
  - Those tests of EW sub-system performance required to be conducted by the project's qualification and verification test plan are executed.

Conventional SILs and SS rigs are usually found at the facilities of EW and DAS equipment supplier's and Platform and Systems Integrators. AI and SI Rigs are located at Platform and Systems Integrator facilities and, as they mostly have real avionic equipment fitted, are in fact hybrids of the generic SIL and HITL facility categories. EW testing performed in SILs and on SS/AI/SI rigs generally utilise EW/DAS equipments in a laboratory environment on a 'spread bench,' as in Figure 6-2, with all other aircraft data supplied via simulations generated by an external control computer. These computers often serve as master test controllers and also provide non-RF data acquisition and analysis, e.g., of data bus traffic.

Figure 6-2: EW Equipment on Avionics Integration Rig –
(© BAE SYSTEMS 2010, All Rights Reserved).

EW Receiver stimulation is performed by RF threat emitter simulators such as the widely used Combat EM Environment Simulator (CEESIM). Characterisation of signals at RF can be executed by the use of various test equipments, e.g., spectrum and pulse domain analysers. However, for optimum measurement, recording and analysis of complex RF jamming waveforms from modern EA systems, EW T&E equipment such as the Signal Measurement System (SMS) is required. CEESIM and SMS[1], which are shown in Figure 6-3, are but one example of this high performance EW T&E equipment.

[1] CEESIM and SMS are products of Northrop Grumman, Amherst Systems Inc.

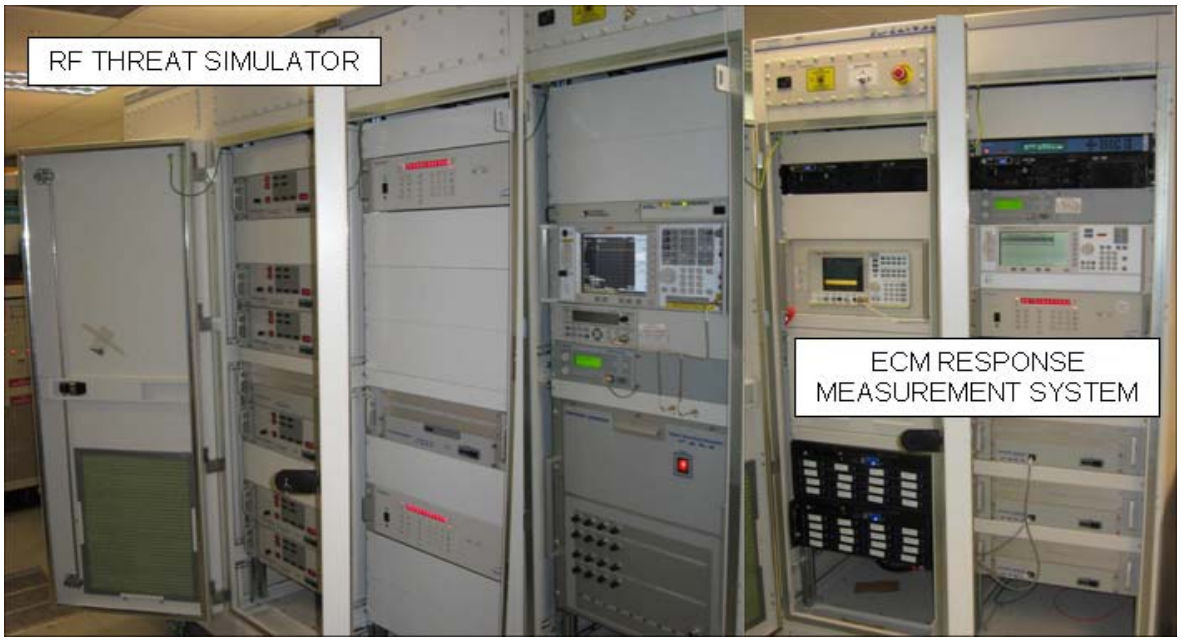

Figure 6-3: RF Threat Emitter Simulator and EA/ECM Signal Measurement System – (BAE SYSTEMS Photograph).

Once the DAS has reached suitable maturity it is integrated with other sub-systems, e.g., Displays and Controls, on an avionic integration rig. System-level performance verification testing is conducted using the EW equipments once integrated with the other real aircraft equipment on the rig. Once again EW receiver stimulation is performed by a threat simulator but the level of testing is reduced as most of the individual equipment and sub-system performance has already been proven by the earlier verification and qualification phases at the platform/systems integrator and equipment supplier.

All verification tests conducted on these rigs is traceable back to the original customer requirement through the Verification and Validation Requirements Matrix. Integration rigs are continually utilised throughout the platform's life to prove software and hardware changes and to re-test system fixes prior to release to the aircraft or to the customer.

6.6 HARDWARE-IN-THE-LOOP FACILITIES

HITL facilities are ground-based test facilities that provide a controlled and usually secure environment to test EW techniques and hardware against real or simulated 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 for evaluating the performance and effectiveness of EW systems and countermeasure techniques.
- 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 hostile and friendly EW activities. These HITL facilities can also be used to test EW systems where the friendly weapon system represents a potential threat technology.

Although SS, AI and SI rigs include, by definition, real hardware-in-the-loop, generally understood HITL facilities are secure (usually screened or anechoic) indoor facilities that enable un-installed testing of EW techniques against simulation of threats or real threat hardware. Whereas sub-system and avionic integration rigs generally do open-loop EW testing, primary HITL facilities have the capability to do

closed-loop testing, where own EW system effectiveness can be assessed and optimised against threat system sensor systems, and the EP of own EW systems and sensors can be assessed against hostile jamming equipment.

Examples of HITLs are shown in Figure 6-4 and Figure 6-5.

Figure 6-4: EW HITL Facility Example (1): US Navy EC Systems Evaluation Laboratory.

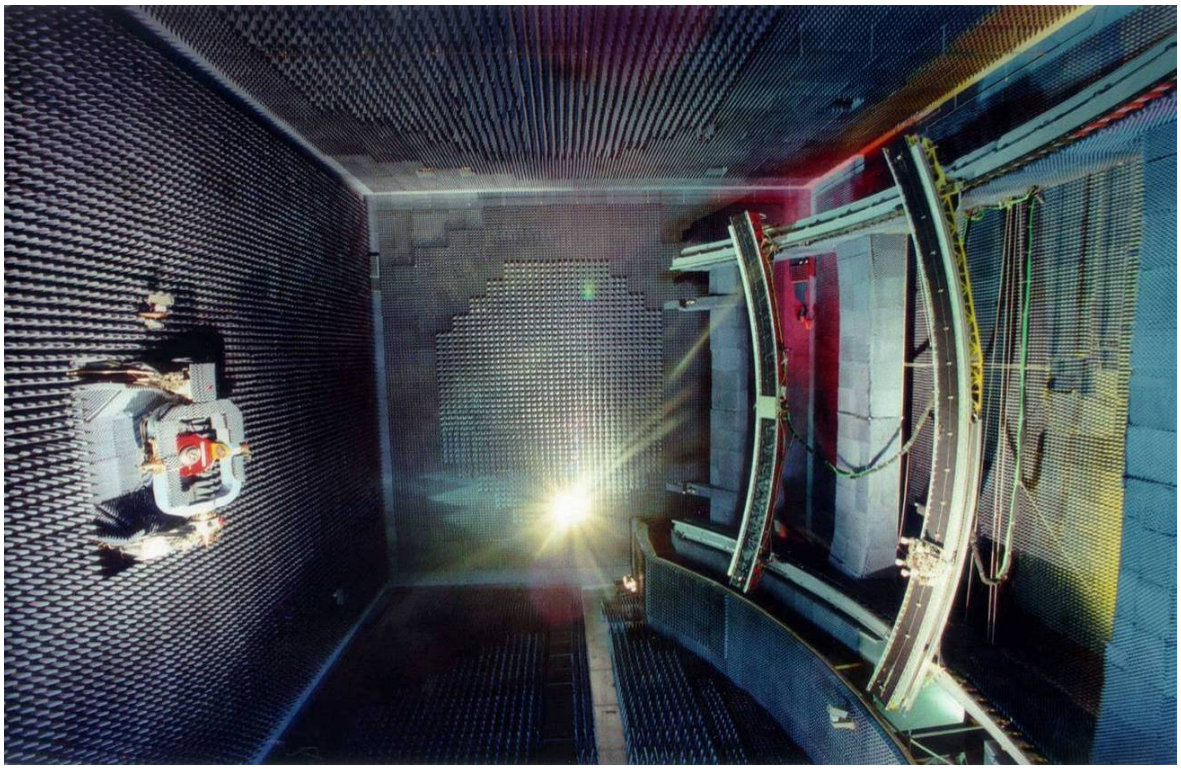

Figure 6-5: HITL Facility Example (2): UK Dstl Missile Seeker Test Facility – (Defence Science and Test Laboratory Photograph).

HITL facilities are an important test facility category because they frequently represent the first opportunity to test un-installed system components, for example breadboard, brassboard and pre-production prototypes, 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 EW effectiveness testing, man-in-the-loop interaction, and Integrated Air Defence System (IADS) networking. Secure (shielded/screened room) operations, test condition repeatability and high capacity data collection and recording are common attributes of the HITL test venue.

HITL testing should be conducted as early in the development process as possible – even if that means using a brassboard configuration. Too often pre-production hardware is developed late in a programme, 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. Any differences discovered in this comparison can then be analysed and the appropriate models updated and validated.

6.7 INSTALLED SYSTEM TEST FACILITIES

EW ISTFs provide a ground-based capability to evaluate EW systems that are installed on or integrated with host platforms. These test facilities 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, which are discussed further in Section 6.9, stimulate the EW SUT and its responses are evaluated to provide critical, integrated system performance information.

The purposes of ISTFs are:

- (Primary purpose) Evaluation of integrated avionics systems (e.g., radar, IR, communications, navigation, identification, EW systems or sub-systems, and integrated controls and displays) in installed configurations, to:
  - Test specific functions of complete, full-scale weapon systems; and to
  - Verify specific, platform-level performance against specification.
- Development and evaluation of individual uninstalled EW components, sub-systems or systems in an electromagnetically secure environment.
- Investigation and resolution of any EMI/EMC problems resulting from above.
- Determination of system reactions to EM environments of hostile and/or friendly systems whose signals cannot be radiated in free space on OARs for security reasons.
- Support of flight testing by providing pre-flight checkout and post-flight analysis capabilities (also provided by SILs and HITLs). This ground testing can aid in isolating component, sub-system or system problems not observable in other ground test facilities but crucial to system checkout prior to open-air testing.

Anechoic chamber ISTF cardinal features are indicated in Table 6-3.

Table 6-3: Cardinal Features of EW Anechoic Chamber Facilities.

FEATURE	COMMENT
Chamber size	Minimum size around 28 x 18 x 8 m. Largest known chamber is 80 x 76 x 21 m.
Shielding and quiet zones	Usually ≥100 dB over at least 0.5 – 18 GHz. TEMPEST grade. Quiet zones: one or more, dependent on chamber size.
Turntable and crane	Typically in range 30 – 114 tonnes (turntable) and 30 – 40 tonnes (crane).
Below ground room	Most have laboratory, data collection or services room below the chamber.
RF/IR threat simulators	All have RF threat simulators, usually CEESIM, AMES or by EWsT. Some have communications, navigation, IR scene simulators, radar target generator.
ECM response measurement and analysis	All have some capability, from independent equipment (spectrum, vector network, pulse modulation analysers) to comprehensive systems like the SMS.
Data acquisition and simulation	All have some capability, for RF, digital and other signal recording and to provide signals to the platform to enable ‘flight’ simulation.
Aircraft and other services	• Cooling, hydraulics, pressurised air, ground power for aircraft; • Fire suppression, control room, CCTV and video recording; • RAM temperature monitoring; and • Enclosed aircraft preparation area (some).
Location	Most facilities are adjacent to taxi-way, the flight line or a runway.

ISTFs fall generally into three categories, although some EW test facilities cover more than one:

- **Category I:** End-to-end systems effectiveness testing is performed 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, EP performance, weapon systems integration performance, ES systems performance, and systems integration testing.
- **Category II:** End-to-end systems integration testing is performed 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, EP, avionics systems performance, and systems integration testing.
- **Category III:** Specialised testing is performed such as: RCS measurements, antenna pattern measurements, susceptibility to HPM, EM environmental effects (E3), and limited systems installation and checkout on aircraft, ground vehicles and components.

There are few aircraft-sized EW anechoic chambers in the world. Two examples are shown in Figure 6-6 and Figure 6-7, and others exist within NATO Nations, see Annex A.

Figure 6-6: ISTF Example 1: Benefield Anechoic Facility – (USAF Photograph).

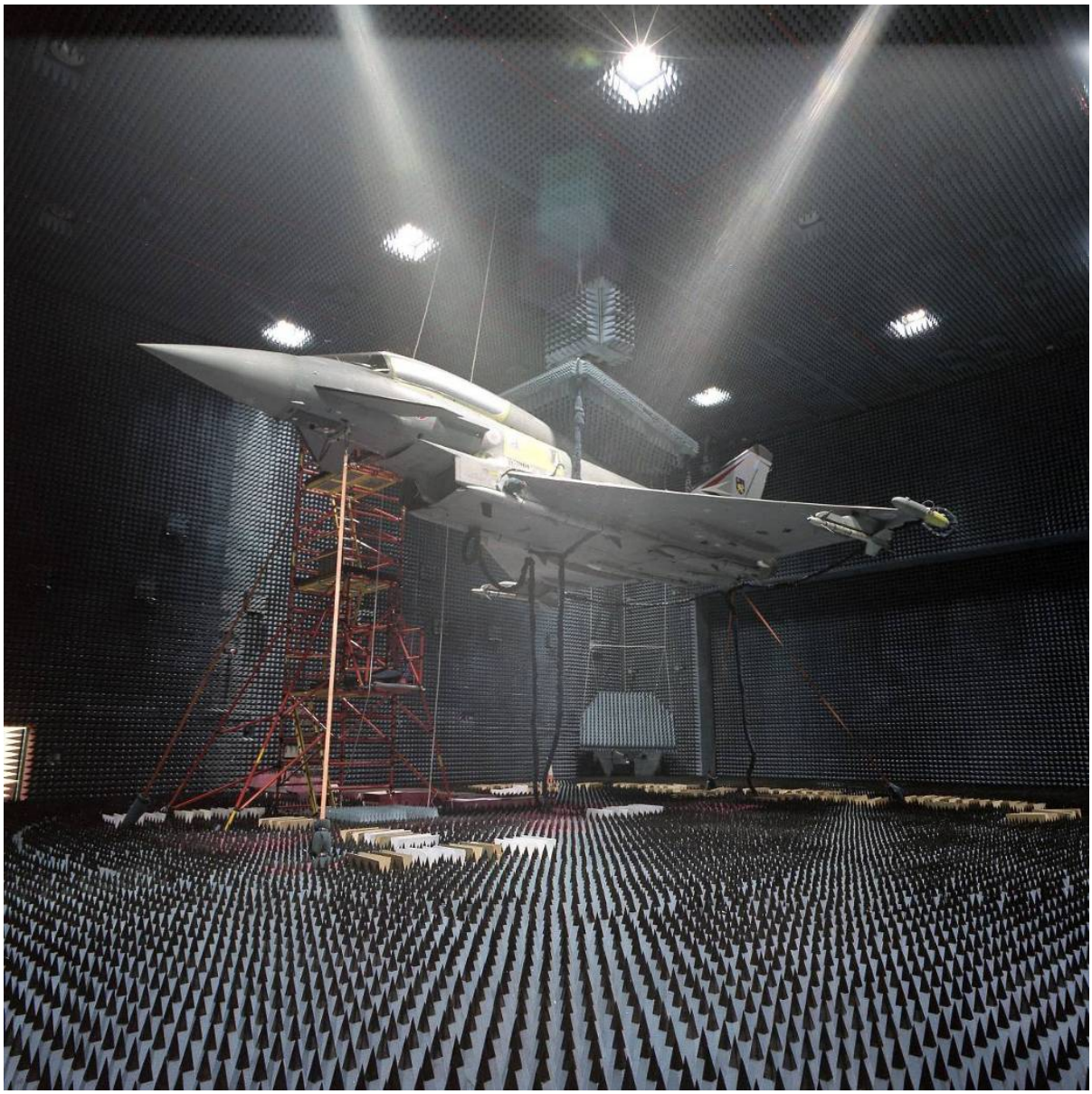

Figure 6-7: ISTF Example 2: EW Test Facility – (© BAE SYSTEMS 2010, All Rights Reserved).

These chambers can also be used:

- For IR/UV/Laser, Lightning Strike, RCS and RF Interoperability (including antenna isolation) testing of installed EW and other RF transmit/receive systems.
- To support evaluation of closed-loop performance against threats in a free-space environment.
- For platform (EW/non-EW) susceptibility testing against HPM and other DE threats.

6.8 OPEN AIR RANGES

6.8.1 Introduction to OAR Facilities

OARs used for EW and related flight testing are described in this section. Their uses are outlined, and benefits and drawbacks listed. Recognising that flight testing requires a greater level of preparation

and generally costs more if a trial has to be repeated – for whatever reason – than ground-based testing, the topic of 'Flight Test Planning, Execution and Operations' is covered separately in Chapter 8.

The increasing complexity of modern avionics and EW systems, along with the growing cost of aircraft operations, has driven most test organisations to reduce the use of OAR testing wherever possible. The extensive capabilities of ground-based test facilities, increased effectiveness of M&S, and improved analytical processes discussed in this Handbook continue to enable this reduced reliance on OARs.

Nevertheless, the OAR remains an important component of the EW system testers' arsenal:

- EW T&E on these ranges is widely agreed to be the next best thing to war-fighting as this is the only 'facility' which provides a wholly realistic flight environment, including multi-spectral background, clutter, and noise.
- 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.

Both DT&E and OT&E are conducted in the OAR environment. All known OARs used for EW T&E are owned and operated by the military, some with civilian contractor support. Most have a combination of multiple real threat systems, manned/un-manned high fidelity threat simulators ('emulators' or 'surrogates') and other (lower fidelity) simulators.

Figure 6-8 shows a typical OAR used for EW T&E, showing threat simulators.

Figure 6-8: Typical OAR Used for EW T&E – China Lake Electronic Combat Range – (NAVAIR Ranges Photograph).

6.8.2 OAR Description

OARs are used to support some or all of the following:

- EW system evaluation (DT&E/OT&E and System/Platform Acceptance), in particular of EW systems that cannot be realistically ground-tested, e.g., chaff, flares, towed/expendable/air-launch decoys.
- Initial, advanced and combat readiness training.
- Single and multi-platform force preparation and mission rehearsal. Aircrews can practice manoeuvres and tactics against a variety of threats and targets that they face in combat operations.
- Tactics and countermeasures development and optimisation.
- Development of and input to Concepts Of Operation (CONOPS), in the case of new or upgraded threats or EW systems.
- Research, Development and Engineering in support of new and upgraded EW systems.

OARs focused on EW testing are populated with high fidelity threat simulators in addition to basic range instrumentation. A typical OAR threat simulator is shown in Figure 6-9.

Figure 6-9: Typical Range Threat Simulator – Joint Threat Emitter (JTE) – (© Northrop Grumman Amherst Systems Inc.).

Some OARs also include real threat systems, both own-side/friendly and opponent. Examples are shown in Figure 6-10.

Figure 6-10: Examples of Actual Threat Systems used on OAR – (China Lake Range – Naval Air Warfare Center Weapons Division Photographs).

To be useful for most test conditions, these threat simulators are instrumented to establish a record of EW system effects on the threat. This instrumentation must be carefully planned prior to flight testing commencement 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 (a.k.a. signal sources) are provided to create the high signal density characterising typical operational EW environments. These simulators can also be useful for some airborne integration testing where a low fidelity signal is adequate to stimulate the receiver.

OARs vary considerably in the quantity, quality, and flexibility of their threat simulation and other capabilities. 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.

OARs used for EW T&E have some or all of the features indicated in Table 6-4.

Table 6-4: General Features of OARs Used for EW T&E.

Capability	Features

Range control and instrumentation	• Time space positioning information:
	  • Air Combat Manoeuvring Instrumentation (ACMI) pods
	  • GPS with datalink
	  • Telemetry reception
	  • Range secondary, search/acquisition and tracking/TWS radars
	  • Transponders
	  • Electro-optical (Visual, IR)
	  • Laser range finders (eye-safe)
	• Airspace and exercise/test control capabilities:
	  • Interfaces to C2, air traffic control, weapon systems
	  • Audio and visual recording and display/playback
	  • Real-time 'kill' notification
	• Atmospheric measurement facilities:
	  • Land/maritime – air temperature, humidity, wind, sea state
	  • Visibility (optical, UV, IR)
	• Terrain:
	  • Realism (surface characteristics, foliage, obscuration)
	  • Ability to use chaff, flares and other expendables
	  • Ability to use active RF and EO jamming

Programmable emitter simulators and emulators • Fixed (manned/ unmanned) • Mobile • Relocatable • Open loop • Closed loop (reactive)	• Radar (search, track, surveillance) • Communications (analogue, digital, fixed frequency, spread spectrum) • Visual signature (shape, smoke trail, etc.) • Signatures: IRS, UVS, acoustic signature • IR/UV stimulators, which also help pilots become more familiar with the manoeuvres that will optimise DIRCM/flare deployment and effectiveness • Human-In-The-Loop, automatic and remotely controllable • Missile launch indication
Signature measurement	• RCS (platform, towed/expendable decoys, chaff) • Electro-optical (Visual, IR, UV) • RF emissions (radios/radars, EA, communications, navigation systems) • Acoustic
Databases	• EW Systems • Operational procedures • EW emitter parametrics • Signatures (RCS/IRS/UVS, RF emissions, acoustic) • Terrain (local and target)

6.8.3 OAR Uses

6.8.3.1 Primary Purpose

The primary purpose of OAR EW testing is to evaluate the system under real-world representative environment and operating conditions. Primary tasks are:

- DT&E flying – The final stage of acceptance testing – covers:
  - Verification that EW system performance characterised in earlier test events is representative of performance in the intended operational environment. Results of OAR tests are compared to results obtained in MFs, SILs, HITLs, and ISTFs to arrive at a complete and consistent evaluation of system performance and predicted effectiveness.
  - Final performance verification undertaken prior to customer delivery. This testing not only examines system performance when installed in the airframe, but also looks at safety in terms of, for example, safe separation of flares, chaff and towed decoys.
- OT&E flying – To validate system operational performance/effectiveness at a high level of confidence.
- Gaining an early understanding of operational features such as supportability, utility, and reliability.

In addition to the above, 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. In these roles the OAR facility descriptor is sub-categorised into test ranges and airborne testbeds, which are described in the remainder of Chapter 6.

6.8.3.2 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 the general notion of a HITL facility, see Section 6.6, the equipment available on the OAR frequently meets the tester's 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 yield advantages:

- Duplication of expensive threat simulators at multiple locations is unnecessary.
- Since the same threat hardware is employed in both the HITL and OAR test phases, an important variable is removed.
- An economy of scale is realised; overhead costs are shared between both OAR and HITL tests, and utilisation rates are improved.

6.8.3.3 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. However, such correlation is often difficult as an OAR will only have one instance of a threat that may or may not represent the combat population. As well as simulating multiple instances of emitters, SILs, HITLs and ISTFs also allow excursions in frequency, PRI, etc., not available on an OAR.

If properly structured, flight testing can be used to validate/calibrate ground test facilities and models. EW components, sub-systems, 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 EMI 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 behaviour of the SUT and any threat or victim systems in play. While such an analysis is technically challenging, time consuming, and costly, it usually leads to a consistent evaluation of the EW system.

6.8.3.4 Airborne Testbeds and Flying Laboratories

These flying resources are especially useful in the development of EW and sensor systems. Two sub-categories exist, those which:

- Serve as flying laboratories to carry the SUT, test support personnel, and instrumentation into the test environment.
- Include airframe or pod-mounted systems used to simulate an adversary weapon system, armament, or EW capability.

The flying laboratory has become increasingly important as EW/avionics systems have grown in cost and complexity. It offers an in-flight 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.

Airborne testbeds and laboratories range from small aircraft with pod-mounted components or systems, see Figure 6-11, to large aircraft designed for spread-bench installation and testing of EW and avionics systems. They permit flight testing of components, sub-systems, systems, or functions of EW or avionics suites in early development, often before the availability of prototype or production hardware.

Figure 6-11: Typical Airborne Testbed – (© BAE SYSTEMS 2010, All Rights Reserved).

6.8.3.5 Threat Simulation Testbeds

Threat systems and components may be hosted on range support aircraft to support flight tests and gather data to be used at 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 utilised. In this process a host aircraft carries aloft an actual or simulated threat missile seeker. The pilot follows, to the greatest extent possible, the flight profile commanded by the missile seeker. While very useful, this is a limitation of the capability. It doesn't follow actual missile guidance and closure rates are not realistic, so analysts need to take this into account.

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.

6.8.3.6 Tactics Development and Training

There will always be a need for some flight evaluation of EW systems, especially for development of tactics and training in support of operations and exercises. Ranges like the EW Training Facility at RAF Spadeadam (GBR), Electronic Combat Range at China Lake (USA) and Multi-national Aircrew Electronic Warfare Training Facility (MAEWTF) Polygone (USA/FRA/DEU), and the capabilities of NATO's Joint EW Core Staff, see Figure 6-12, are essential to optimising survivability and mission success probability.

Figure 6-12: NATO JEWCS Training/T&E Capabilities – (NATO JEWCS Photograph).

Some EW OARs can provide the capability for tactics development and training in operationally realistic scenarios. Aircrews can experience a dynamic and complex threat environment, including movable threats, whilst operating with other force components: Time Sensitive Targeting, Close Air Support, Forward Air Control, and Intelligence, Surveillance, Target Acquisition and Reconnaissance.

6.8.4 Benefits and Drawbacks of EW T&E on OARs

Key benefits:

- The full range of tactics and countermeasures against given threats can be explored, including dynamic closed-loop effectiveness testing against threats.
- OARs provide real-world phenomena that cannot be repeated or is difficult to repeat in the laboratory or chamber environment. These include terrain, inter-platform multi-path, chaff dispersion and realistic civilian communications and radar environments.
- OARs can be used to gather data for validating threat simulators and M&S tools and processes.

Drawbacks:

- Flight testing is expensive, especially when compared to chamber and laboratory testing.
- Range threat densities and mixes are usually very limited compared to war, due to the high through life cycle cost of real threats, emulators and simulators.
- Threat scenario flexibility is limited (governed by the range location) and results are not easily repeatable.
- Flight testing is logistically difficult, especially for NATO Nations using out-of country ranges.
- Range time slots for DT&E are usually limited due to great demand by military users for training and OT&E. This underscores the importance of gaining maximum confidence from ground testing and M&S/SE. The drawback is, in fact, usually double when a test fails: the flight has to be repeated after problem investigation and resolution and, as important, the valuable range slot has been denied to another user.

Notwithstanding aspects that can only be adequately tested in flight, chambers and laboratories are much better capabilities from an optimised T&E cost-effectiveness viewpoint than OARs for (especially RF) EW testing as follows:

- Cheaper and logistically easier than flight testing, when overall trials' costs are considered.
- Operationally representative threat densities, mixes and scenarios are achievable, albeit currently with lower simulation fidelity than real threats (noting that chambers can do some SUT tests using real threats when they are made available).
- Scientifically high test repeatability, due to tightly controlled test environment, especially in anechoic chambers.

As T&E capabilities and processes are developed, it is likely that the balance will continue to shift from EW flight testing further in favour of more ground testing and M&S. In this way residual flight testing can be more focused and have a much higher success probability, as many test points will then be confirmatory rather than experimental in nature.

6.8.5 Other EW T&E Resources for OAR Testing Support

Although not strictly flight testing or part of OARs, flight line test sets and similar EW T&E equipment are a very useful T&E resource, especially when performing installed system integration testing on an aircraft. Often, for this type of test, only a limited T&E capability is necessary – a device capable of generating a response in a SUT so that its basic integration with other systems can be evaluated. Figure 6-13 provides some examples of this type of equipment.

JSECT: AN/USM-670 Joint Service Electronic Combat Systems Tester: Platform-independent EW system and cable tester.

(© 2010 AAI Corporation. All rights reserved)

PLM-4: USAF flight line threat generator (a.k.a. 'Squirt box').

(USAF photograph)

Mallina: UV missile launch simulator for Missile Warners.

(© ESL Defence Limited 2009)

ACT: Aviation Crew Trainer, IR MANPADS trainer, with RF emitter optional capability.

(© 2011 Northrop Grumman Amherst Systems Inc.)

Figure 6-13: Examples of Flight Line Testers and Other Equipment for EW T&E.

They are usually limited to confirmatory checks, rather than providing full performance verification, and are designed to increase flight test/trial success probability. A number of them are also used for training and tactics development, e.g., ground-based UV sources for Missile Warner detection and DIRCM/flare dispensing optimisation. Such test sets, dependent upon capability, can also be utilised for system testing but can be limited when compared to, for example, chamber- and laboratory-based threat simulators.

6.9 DISTINGUISHING FACTORS OF TEST FACILITIES

While the primary designation 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 utilisation should be expected for most test activities. Some of the key parameters that distinguish one facility from another are discussed in the following paragraphs.

6.9.1 Number and Fidelity of Players

The total quantity of friendly and adversary players that can be synthesised during testing is important in assessing SUT performance in conditions of varying density and complexity. The ability of EW T&E facilities described in Sections 6.3 through 6.8 to provide numbers and types of platforms and emitters, especially at RF, is varied and is a key factor in determining the technically best and most cost-effective place to conduct a given test. Table 6-5 indicates player fidelity available on each facility type. Moving from 'Simulated' toward 'Real' implies increasing fidelity, complexity and cost; whilst at the same time increasing ease of test and reality of training.

Table 6-5: Player Fidelity vs. Test Facility Type.

PLAYER FIDELITY		TEST FACILITY TYPE					
		M&S	MF	HITL	SIL	ISTF	OAR
REAL: Real, fully functioning assets, e.g., aircraft, ships, land vehicles and SAMs.	SUT	No	Yes	Yes	Yes	Yes	Yes
	Platforms	No	Yes	No	No	Yes	Yes
	Threat Systems	No	No	Yes	No	Yes	Not Usually
EMULATED: Physical and/or digital models providing real stimulus at SUT. May include part-real platforms/threats.	SUT	Yes	N/A	N/A	N/A	N/A	N/A
	Platforms	Yes	N/A	Yes	Yes	No	No
	Threat Systems	Yes	N/A	Yes	Yes	Yes	Yes
SIMULATED: Digital models of players in 'virtual' scenarios. Actual sensor stimulus generated for non-M&S.	SUT	Yes	N/A	N/A	N/A	N/A	N/A
	Platforms	Yes	N/A	Yes	Yes	Yes	Yes
	Threat Systems	Yes	N/A	Yes	Yes	Yes	Yes

Traditionally, in most cases, simulated players were sub-divided into two categories; foreground and background. The foreground players can usually be precisely controlled to follow specific flight paths and have well-defined physical characteristics. Background players were generally of lower fidelity and simply added to the overall scenario density. Nowadays, many-channel RF simulators can produce up to thousands of fully complex emitters at the digital level. Inevitably, the ability to generate these emitters at RF is limited by the number of channels available, the channel pooling capability and the SUT's sensitivity to dropped pulses. This has enabled significantly better representations of operational RF emitter environments than before. Pre-defined scenarios and man-in-the-loop scenarios can be run,

with pre-scripted threat engagements or ones based on weapon system engagement models within the simulator. It is now also possible to include civilian radar emitters, RF jammers and 'third party tracking', where the emitter tracks another platform in the scenario and the SUT rarely or never sees its main beam.

6.9.2 Fidelity of Digital 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 ECM/EA ('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 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.

Section 5 of [4] contains a useful discussion of this important topic under the heading 'Simulation Fidelity – the quest for affordable emulation'. A key question regarding simulation fidelity is 'How good is enough?' for a specific SUT test, since increasing fidelity generally means increasing whole life cost. This thorny question is discussed in a number of references and the nub of the question is depicted in Figure 6-14. [4],[5]

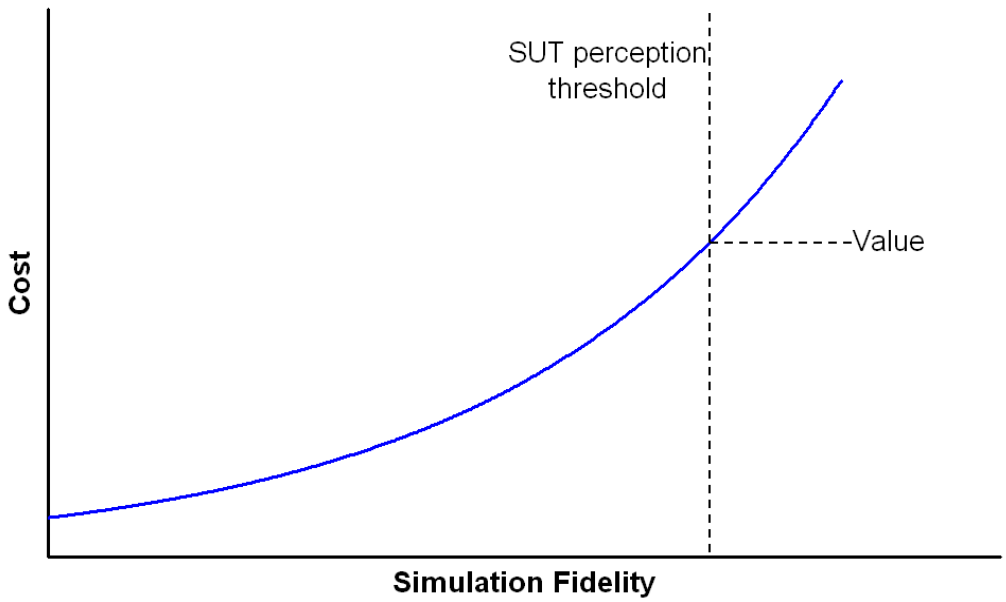

Figure 6-14: Simulation Fidelity – How Good is Enough?

6.9.3 Time, Space and Frequency Resolution and Accuracy

From the test planning process the tester 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 inaccuracies and errors in time, space or frequency (and combinations thereof) on the evaluation of system performance and effectiveness.

6.9.4 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.

RF threat simulators and ECM response measurement and analysis systems, see Figure 6-3, are key test facility equipment. The quantity of RF channels in threat simulators, a significant cost driver, governs their ability to generate complex threat environments. Figure 6-15 reports a survey of the quantity of RF channels per simulator. Chamber installations tend to have simulators with at least eight RF channels.

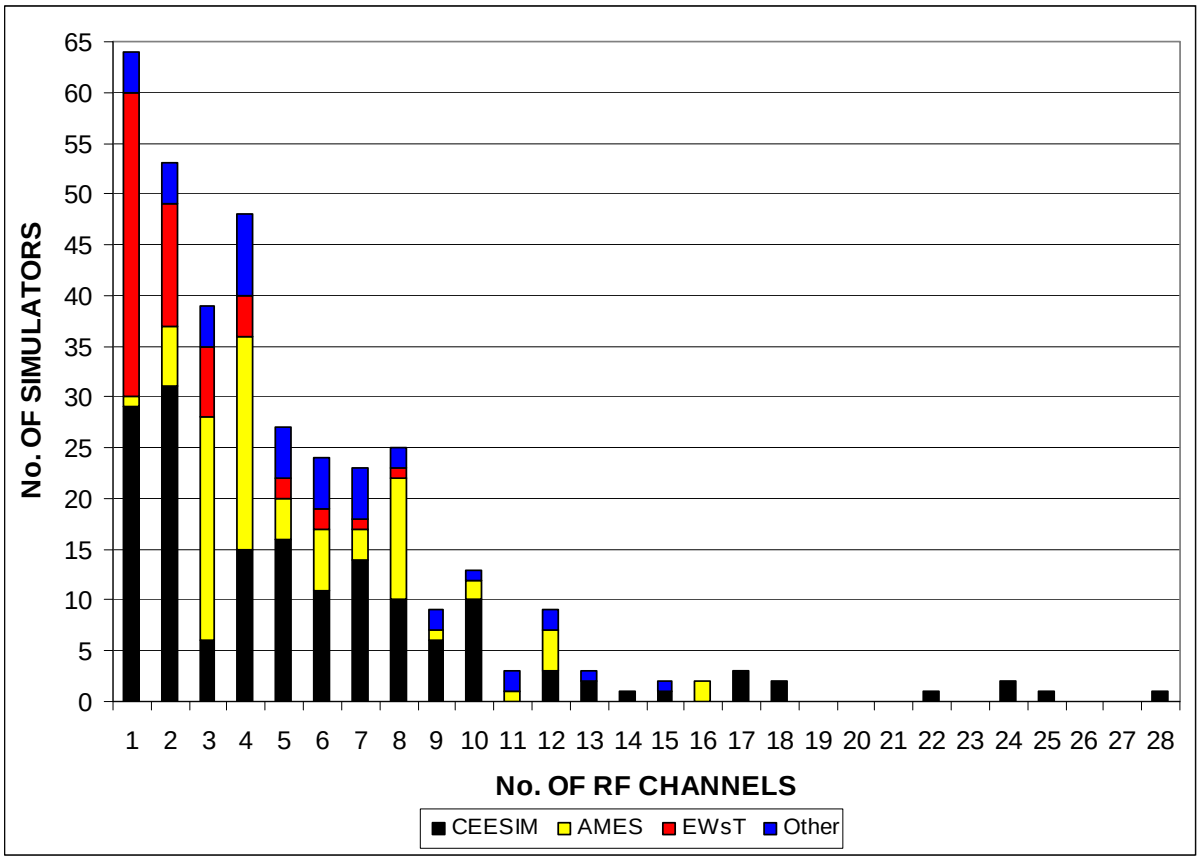

Figure 6-15: Quantity of RF Channels per Simulator – (From [6], with Permission).

Electro-optic/IR/UV scene simulation, by sensor, system or platform irradiation, or by post-sensor 'direct injection' into the SUT, is particularly challenging in the ground test environment. The advent of systems like the Real-time Infrared Scene Simulator (RISS), see Figure 6-16, has provided a step up in laboratory and chamber T&E capability – the ability to provide coordinated multi-spectral threat scenarios. [7] Such capabilities are becoming increasingly important as EW systems move toward full integration, where it may not be possible to adequately ground test the SUT in the traditional way of spectral segment by spectral segment (i.e., Radios/Radars, IR, UV, laser separately).

Figure 6-16: Example of RISS Hardware – (© Northrop Grumman Amherst Systems Inc. 2009).

6.9.5 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 facility and its instrumentation may have on the test environment. The instrumentation must accurately measure and record what the SUT was actually exposed to, not just what was intended.

6.9.6 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. The highest level of RF/EO/IR/UV security control is offered by TEMPEST-grade aircraft-sized anechoic chambers.

6.9.7 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 MFs, and Table 6-3 indicates general features required. Annex A contains specific details of support capabilities offered by available test facilities.

6.10 ELECTROMAGNETIC COMPATIBILITY AND INTERFERENCE

As mentioned earlier in this section, ISTFs are often used to conduct EMC/EMI tests. While these tests are not uniquely associated with EW systems, they are crucial to overall weapons system performance.

Numerous specifications and standards dictate system design characteristics that must be met to minimise EMI and maximise 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 problematic in combat use. The following paragraphs will discuss in some detail some of the types of EMC/EMI tests EW testers should be familiar with.

6.10.1 EMC/EMI Tests

There are four types of EMC/EMI tests: Radiated Susceptibility (RS), Radiated Emissions (RE), Conducted Susceptibility (CS), and Conducted Emissions (CE). During RS testing a test antenna is used to transmit RF at the SUT to see if it is susceptible (whether it can be caused to malfunction or break), whereas in RE testing measurement antennas are used to determine whether RF emanations from the SUT exceed specified levels. RS and RE tests require a shielded room/anechoic chamber. CS and CE tests are usually performed in a shielded room but can be performed in SILs. During CS testing a current probe or similar direct coupling device is used to couple RF current down cabling into the SUT. EM energy is injected to characterise the susceptibility of the SUT to this injected RF current. Similarly, the probe or direct connection can be connected to a receiver or laboratory test equipment to measure cable-borne RF currents from the SUT. Figure 6-17 shows avionic equipment undergoing EMC qualification testing.

Figure 6-17: Typical EMC Testing of EW Equipment –
(© BAE Systems 2003, All Rights Reserved).

During emissions testing all modes of the SUT should be exercised. During susceptibility tests, an end-to-end test in addition to exercising 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 and power 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 equipment and sub-system EMC/EMI testing as early in the programme as possible. Quite often EMC/EMI tests are delayed to the end because problems in other disciplines are still being resolved. The rationale is to wait and do EMC/EMI tests on the system in its final configuration. EMC/EMI tests are expensive, and there are logistic problems in moving the systems and its interfacing equipment to the EMC laboratory. But if EMC/EMI failures are detected early, they can be fixed at relatively low cost and little impact to the system schedule.

6.10.2 Platform-Level EMC Testing

EMC testing at the platform level can be further defined as Intra-system and Inter-system EMC tests. Intra-system EMC tests are used to evaluate the SUT's ability to operate in the presence of other systems installed on the platform. Inter-system tests are used to evaluate the SUT's ability to operate in the presence of external RF emitters representative of the intended operational environment.

6.10.2.1 Intra-System 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. These tests are generally conducted on an open-air test site (a type of MF), anechoic ISTF or hangar, dependent on the test in question. If the SUT exhibits adverse response to the operation of other onboard systems or vice versa, then an EMC issue has been identified. ISTFs and MFs have an important part to play in aiding testers investigate and isolate such problems, and develop and clear solutions. 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 ca. 20 dB. A 6 dB safety margin for non-explosive systems is common.

6.10.2.2 Inter-System EMC Tests

For these tests the SUT performance is monitored while the platform is radiated with RF at power levels and modulations of radar and other RF signals that may be present in the intended operational EM environment. Staircase levels of RF field strengths (power densities) and system performance are usually part of the SUT specification and test programme. Full system performance in the required operational RF environment can be arrived at by a combination of full-threat testing and extrapolation by analysis. An important inter-system EMC test for the EW T&E community concerns formation flying, where each aircraft's radar and RF jamming systems can pose a significant interference hazard to the very sensitive EW and radar receivers on the other platforms in the formation. Figure 6-18 shows a typical MF-based test used to confirm specified performance for formation flying conditions.

Figure 6-18: Typical Platform-Level Inter-System EMC Test –
(© BAE SYSTEMS 2010, All Rights Reserved).

6.11 REFERENCES

[1] UK Defence Industrial Strategy. Defence White Paper, CM 6697, 15 December 2005.

[2] MoD Defence Test and Evaluation Strategy. 22 July 2008.

[3] EW Test and Evaluation Process – Direction and Methodology for EW Testing. Air Force Manual 99-112. 27 March 1995.

[4] Pywell, M. Developments in RF simulator technology – approaching the affordable fidelity limit. The Aerospace Journal, Vol. 111, No. 1123, September 2007.

[5] Anderson, R.B., Bieling, R., Strombo, G., Hunt, D. and Brown, F. Threat correlation to ground test stimulators at the Benefield Anechoic Facility (BAF). US Air Force T&E Days, 6-8 December 2005, Nashville, Tennessee. AIAA 2005-7659.

[6] Pywell, M. and Midgely-Davies, M. Improved Test Capabilities for Cost-effective Performance Evaluation of Airborne Electronic Warfare Systems. The Aeronautical Journal, September 2010, Volume 114, No. 1158, pp. 527-547.

[7] Jacobs, S.E., Palumbo, P.W., Henderson, S.M. and Makar, R. Installation of an IR/UV Stimulation Test System into the CECOM ISTF. Technologies for Synthetic Environments: Hardware-in-the-Loop Testing VIII. Proc. SPIE, Vol. 5092 (2003).

6.12 FURTHER READING

Wallace, Wg. Cdr. P.J., (RAF) Modernizing EW Ranges. Journal of Electronic Defense, Vol. 33, No. 3. March 2010.

Encyclopedia of Aerospace Engineering. Edited by Richard Blockley and Wei Shyy. John Wiley & Sons, Ltd. ISBN: 978-0-470-75440-5, October 2010. Volume 7, Chapter 376: Electronic Warfare and Defensive Aids System Design and Development, by M. Pywell.

Pywell, M., Alonze, P.M., Hurricks, M.E. and Wellings, I.G. The new Enigma – Increased Survivability with Reduced Cost? NATO RTO SCIP Symp. on 'Flight in a Hostile Environment' (1999). Conf. Proc. RTO-MP-47, AC/323(SCI)TP/22.