Chapter 9 – LEARNING FROM EXPERIENCE

9.1 INTRODUCTION

This chapter gives examples of problems encountered during T&E of EW and related avionics systems over more than three decades. For each problem a root cause analysis enabled identification of one or more learning points. With the benefit of experience, most problems that were noted are now avoidable. The EW T&E practitioner wastes less time, effort and money by anticipating and avoiding past problems. This improved efficiency is essential to the T&E process, particularly in an uncertain economic environment.

9.2 BACKGROUND AND OTHER SOURCES OF LESSONS LEARNED

Berkowitz, in his paper *EW Testing Lessons Learned*, summarised points with which the authors of this updated AGARDograph fully concur:

> 'Electronic Warfare testing provides many challenges and is fraught with dangerous problems. Fortunately, many problems can be anticipated and avoided. [The] secret to EW testing is "Plan, Plan, Plan ..." Yet despite the best laid plans, there will be problems ... that is guaranteed. However, with foresight and planning, at least they won't be the same old familiar problems.' [1]

This chapter, in common with similar 'lessons learned' publications, actually gives 'lessons identified' – better described as 'learning points' – rather than 'lessons learned'. A lesson cannot accurately be described as 'learned' until the required action is taken to prevent the problem's recurrence. This subtle distinction is important to note; unfortunately, experience has shown that it is difficult to achieve lessons learned.

Against this background, this chapter aims to provide novice, experienced and expert EW T&E engineers and programme managers with problem recurrence prevention knowledge to help minimise cost, time, effort and risk on future EW trials on all types of T&E facilities. This knowledge has been gleaned from many contributors, who together have hundreds of years of T&E experience on a multitude of EW systems, on many platform types, and in a number of NATO Nations.

The examples that follow have been collected directly from test engineers in the field. They provide useful insight to the types of failures or anomalies that have been frequently experienced in the course of testing. While some examples are very specific and might seem too unique to be of any help, they are presented here to illustrate the broad range of problems that may occur.

Further examples of learning points are contained in Berkowitz's *EW Testing Lessons Learned* and Stadler's *Test and Evaluation Lessons Learned from the Field.* Although these examples are not repeated in this chapter, they contain much useful information for the EW programme manager, test planner and test engineer alike, and their study is recommended. [1],[2]

Readers are invited to add to this knowledge base, for inclusion in this Handbook's next update, by contributing EW T&E lessons learned. Contact information can be found on Page xxvii.

9.3 LEARNING POINTS IDENTIFIED

The following notes apply to the lessons and learning points identified in this chapter.

- All lessons identified in this chapter are offered by the contributors without prejudice, liability or commitment. They are provided in good faith to help reduce the time, cost and risk of EW T&E across NATO and its partner Nations.

- The learning points:
  - Are presented in no particular order or priority.
  - Supplement the commentary within Chapter 6 on the strengths and limitations of various types of T&E facilities.
  - Have had most references to specific programmes, projects, platforms, equipment and persons removed.
- The problems and learning points resulted from T&E at various stages of the SUT life cycle, from R&D through D&D to DT&E/OT&E and in-service use. They have resulted from T&E of EW equipment in isolation, from sub-system (Defensive Aids Suite) integration activities, and from systems integration activities and platform-level T&E on the ground and in flight.
- Most lessons, although originating from air platform EW T&E, are considered equally applicable to EW T&E for land and sea platforms.
- Many learning points identified yield suggestions to the EW SUT and air platform specifiers and designers on how to ensure repetition of the problem is prevented.

Table 9-1: Lessons Learned – An Aid to Problem Recurrence Prevention.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Know the expected results	During planning for tests, you should identify the expected test results so any differences are readily recognised and, if necessary, more data can be taken. Generally, it is too late after tests are conducted and data are analysed 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 laboratory, so critical laboratory test time and/or assets are not wasted. An example is given below. 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 in-band signal which was saturating the spectrum analyser. 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. Whilst applicable to most avionics T&E, this risk of wasted time and effort is especially so for EW systems, in particular for RWR/ESM-to jammer tests, where the final test result is often not known until post-test analysis has been completed. A problem discovered then often means a full re-run of the test and analysis.	Test time and effort can be wasted if the tester does not have a good idea of what the test result should be. Two items are particularly helpful in reducing T&E time, cost and risk: • Pre-test prediction of acceptable results. • Use of Quick Look-See features in test equipment, e.g., QLS in the Northrop Grumman Amherst Systems' ECM Signal Measurement System. This allows problems to be picked up at the time of the test, enabling further and/or investigative measurements to be quickly taken.
Know and understand Interface Control Documents	The root cause of a number of problems encountered during EW T&E have been attributed ICDs. Problem recurrence could be prevented if the following clarifications were added to ICDs: • Tolerances on leading/trailing edges and widths of digital pulses, especially on blanker (suppression management) systems. • Precise specification of connector type, shell orientation and pins/sockets for equipment and aircraft connector. • Precise identification marking on aircraft connectors/cables and equipment boxes.	Test engineers need not only to have an intimate knowledge of the specification of the EW SUT(s) they are about to test, but also they need to know and understand the ICD(s) that govern the interconnectivity between the SUT(s) and other avionic and other equipment to which it connects.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Know and understand Interface Control Documents (cont'd)	• Expansion/clarification to prevent problems that cannot be attributed to either ICD or specifications. • Formal review of ICDs are required whenever equipments are modified. Unplanned investigation and solution costs and time delays have been incurred where this has not been done. • Although it has been suggested that equipment specifications be refined to include a better definition of the on-board and external RF environment, there is a case to include this in ICDs. That is, treat the airframe and surrounding atmosphere as an 'interface' between RF transmitters and receivers.	

Aircraft ground trials problems resolved by use of anechoic chamber facilities	Most problems encountered on aircraft ground test on outside test sites can be prevented or mitigated by running those trials in the weather- and electromagnetically secure environment within anechoic chamber test facilities. Generic problems encountered that can benefit in this way include:
	• RF pollution/interference/security clearance for transmissions, with severe restrictions on the use of frequency agility and 'war' modes: severely limits scope, time and location of tests.
	• Weather limitations: Between technical (design and operation), natural (weather, environment and limited number of daylight hours) and logistical requirements (need for opening radome, bays and canopy) during such trials, a general observation by Trials Managers has been made that outdoor EW trials in winter should be avoided if possible. Investigations by one PSI have shown that over 15% of aircraft EW ground test programme time was typically lost to weather alone.
	• Reflections, especially from wet ground and nearby metalwork on radars/radios/ECM/RWR/ESM trials:
	  • Microwave and millimetre wave propagation is dependent on atmospheric conditions.
	  • Multi-path effects and the very low grazing angles used with respect to the ground lead to distortion of results and a wholly unrealistic external environment around the aircraft, in many cases leading to problems seen on the ground but not repeatable in flight et vice versa.
		• Avoid executing aircraft ground trials on open air test sites during the winter months, to optimise test programme schedule, risk and cost.
		• Use anechoic chamber test facilities in preference to outside test sites for aircraft EW ground trials. This will aid minimise time and risk, and maximise the scope of tests possible.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Aircraft ground trials problems resolved by use of anechoic chamber facilities (cont'd)	• Furthermore, the uncontrolled nature of these reflective surfaces makes repeatability of test results almost impossible to attain. This is seen as the dominant factor in the overall poor quality of EW test results other than those in anechoic chambers and has led to the need for much repeat on-aircraft test work. • In many EW receiver cases much test effort has been wasted as a result of using an uncontrolled RF environment. Only an anechoic chamber can provide a suitably controlled environment.	
EW flight trials problems	A number of generic EW T&E problems have been noted during flight trials, some of which are similar to those noted in this table regarding ground trials: • Weather: The impact on trials duration is generally worse that that noted above on ground trials. • Limited number of EW test ranges, and the limited RF emitter scenarios that can be generated (see also Chapter 6). • Logistical difficulties and cost of using airborne EW targets. • Security clearance for use of sensitive ECM/radar modes. • Poor instrumentation of EW systems. • Poorly documented and communicated Rules of Engagement for the operation of ground-based and airborne threat simulators during the test mission. One of the most common reasons for failing to meet test objectives.	• Wherever possible, move EW DT&E/ OT&E work from flight to ground test, in anechoic chamber ISTFs, laboratories and via the use of suitably validated M&S. • To minimise cost and time, limit EW flight test to those areas that can only be cleared by flight test.
Test engineer experience	A prior study showed the importance of having capable, experienced test engineers with a good appreciation of the 'real world' that the EW SUT is required and designed to work in. There is also a clear need for a 'wide-eyed' approach to rig testing. Here emphasis needs to be placed, within financial constraints, on examining system performance against the 'real world', rather than merely testing word for word against the requirements of the equipment specification. The benefits of using such engineers with that approach was seen by comparing the EW problem-finding ratio SIL-to-flight test for one platform variant vs. that of a different variant of the same	Use experienced RF and EW test engineers if a minimum risk, cost and duration rig and aircraft trials are required.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Test engineer experience (cont'd)	platform. The SIL with the experienced RF and EW engineers found four times as many problems than the lesser experienced team on the second SIL, resulting in many less problems being left to be found during flight trials. The study also showed that there is a definite requirement for feed-forward of SIL test expertise to aircraft ground and flight test, in the form of systems 'specialists' who move with the SUT through its development life cycle. Failure to do this resulted in a large number of problems being re-found, re-investigated and re-raised as problem reports during the aircraft ground and flight test phases.	
Importance of formally reporting problems	Formal system/avionic problem reports are part of a closed-loop process that ensures problem fixes or adequate and acceptable explanations result. Unfortunately, these reports have not always been raised during EW/avionic trials on rigs, during aircraft ground test and flight test. Sometimes this has allowed real problem to get past DT&E and OT&E only to be then be reported from operational use by the air force(s) concerned. Some have even had adverse operational impact. The reasons for this are varied, with some examples here: • Test engineers do not recognise there is actually a problem present. This is most usually caused by either unfamiliarity with the SUT and its specification (see separate 'Know your SUT' lesson) or inexperience or a combination of these. • The problem is 'covered' in the test report for the trial concerned, but has then lain dormant and un-progressed for a considerable period of time or not followed up at all. • Reluctance to report problems from aircraft ground and flight test for fear of slowing, lengthening or having to stop the trial. • The view of some engineers that if a problem cannot be repeated it is therefore not a problem – see separate lesson learned on this topic. • Test engineer enthusiasm to "get on with testing".	• Always raise system/avionic problems when something does not or does not appear to operate correctly. It will never get fixed if you don't report it! • Even if the SUT meets its specification, if – as a professional engineer – you believe there is a problem that will adversely affect its successful operation by the end user, then raise a problem report. • In this way there can be a reasoned examination of whether the specification itself may have shortfalls or ambiguities – a common occurrence. • At best you will have prevented a problem being passed to the platform's operational phase and optimised the time and cost of fixing it; at worst you will have spent a relatively small amount of time getting clarification of what the SUT should and should not do.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
RF threat simulation capability and use	Many problems encountered during T&E of EW receiver systems (RWR/ESM/ECM) have been traced to inadequacy of, or problems with the use of RF threat simulators. Points of note are: • Test engineers should check that emitter data programmed into the threat simulator is compatible with that programmed into Mission Data in the EW SUT. Much time has been wasted due to data/database errors and differences between these or between one or both of these and the parameters of the real threat emitter. • To maximise the potential for conducting as much of RF EW system testing on sub-system and systems integration rigs rather than on aircraft, a fairly substantial RF threat simulation capability is required. The 'rule of thumb' 1.0 Mega-Pulses Per Second capability, whilst adequate for testing some RWR systems, is considered less than adequate for modern ESM. • Unless the threat simulator has intra-pulse high fidelity modulation (pulse shaping) capability, the test engineer should remember that simulators generate signals that can have considerable differences to the real-world emitters they are simulating. Consequently, EW SUTs may react differently in the rig/chamber environment to how they will on an open air range against a real threat emitter. • Emitter and scenario construction and validation prior to use in T&E is complex and can be prone to human error. Appropriately thorough checking is essential to prevent problems. The use of emitter validation tools such as the Northrop Grumman Amherst Systems Inc. Environment Graphical Analysis (EGA) tool can help the test engineer visualise what is happening in the scenario with time and does not tie up the threat simulator whilst the emitter and scenario construction and validation takes place. Such tools also allow the T&E engineer to double check that the test scenario being constructed can actually be catered for by the digital and RF resources of the threat simulator. Without this level of care in the construction and use of threat simulators it can be very difficult to see, investigate and resolve a problem. Indeed, it is wise, when using complex RF scenarios, to examine both the SUT and the test set-up when a problem is first encountered.	T&E engineers need to understand the capabilities and limitations of the RF and other threat simulators they use. These are highly specialised items of test equipment and specialist advice should be sought as necessary.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
On-board and external RF environment	Some of the more subtle, problematic and operationally serious problems encountered concern the performance of RF EW systems when exposed to the on-board and/or external RF environments, including the formation flying case. This item can be broken down into two aspects: • EMC of the EW systems themselves: To assure problem-free operation the EMC specification of the EW equipment must adequately cover the operational air RF environment the platform has to operate in. This is not always adequately covered by standard EMC qualification tests and unexpected problems have been experienced during aircraft ground and flight test. • The performance of RWR/ESM/ECM systems in the presence of a given external RF environment: In this case, receiver front-end overload has been seen on a number of occasions. How this manifests itself and the immediate and subsequent warnings to aircrew of system performance degradation have been the subject of a number of problem reports.	• Develop an accurate definition of the operational air RF environment the SUT has to operate in. This needs to include formation flying aircraft RF emitters, the on-board RF environment, reflections of own emitters from the ground and other aircraft, surface/sea emitters and other airborne RF sources. • Use M&S tools to develop robust predictions of this environment where measured power density profiles are not available. • Provide the RF EW equipment supplier with an accurate picture of the total air RF environment.
RF inter-operability, antenna coupling and RF compatibility	Confusion about the specific meaning of the terms ‘RF Interoperability’ and ‘RF compatibility’ in aircraft EW ground trials has led to duplication of on-aircraft test work under the guise of first EW performance verification, and then EMC clearance of platform. Whilst the definitions vary across Nations and their agencies, a common view is: • **Interoperability tests** involve the EW systems’ antennas with the receivers and the rest of the RF EW system connected. It addresses how RWR/ESM/ECM equipments perform when subjected to the actual RF environment generated by one or a combination of other transmitters on the host aircraft. Encompassed in this is demonstration of adequate RF suppression management to ensure that RWR/ESM/ECM systems can perform their respective tasks adequately. • **Antenna coupling**, which has by far been one of the biggest problem areas during EW systems integration on military air platforms, is a function of the transmit/receive antennas, their installation, the airframe and the RF power density generated by each transmitting antenna.	Ensure an all-party understanding exists of these terms at the outset and thus tailor test programme to minimise duplication.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
RF inter-operability, antenna coupling and RF compatibility (cont'd)	It involves the determination of installed antenna polar diagrams and the quantification of energy coupling between antennas or groups of antennas anywhere on the aircraft. This coupling is to be determined for all stores configurations to be used, especially where large reflective surfaces are added, e.g., external fuel tanks. The coupling can be measured by connecting a suitable RF signal generator/amplifier to the transmitting antenna and a spectrum analyser to the receiving antenna. Antenna coupling is essentially an EMC test and numerous examples have been seen over the years. Antenna coupling power measurements can be used by EW/radar/radio equipment manufacturers to optimise receiver performance and suppression management strategies. • **RF Compatibility Matrix demonstration** is an EMC test and comprises the operation of each aircraft transmitter singly and in combination, whilst monitoring for any interference caused to the aircraft's receivers.	
RF inter-operability of installed radar and RWR	When carrying out flight testing shortly before a new RWR capability was due to be cleared for operational use, it was found that when the FCR was in certain frequency agile modes, the RWR intermittently displayed false threats at around 7 o'clock. The Government Customer had placed 3 separate contracts for the systems involved: • Government Furnished Equipment (GFE) contract for the radar from a system supplier. • GFE contract for the RWR from a different division of the same system supplier. • System installation by the fighter aircraft company. For "need to know" reasons, the engineers in the aircraft company and in the RWR division had not been given the details of certain FCR modes. When the problem was pinpointed to the interaction between the FCR and the RWR, the Customer was frustrated that none of the 3 companies/divisions involved would accept liability (i.e., pay for) fixing the problem, despite high level pressure from the Customer. Owing to operational urgency, the RWR was accepted for entry to service with a known problem that took a considerable amount of time and effort (commercial and engineering) to fix retrospectively.	• Ensure that someone has clear contractual responsibility for platform system integration, including RF Interoperability. • Ensure that the engineers involved in designing and testing the RF Interoperability of the installed systems are recognised as having a "need to know" for the detailed transmit characteristics of all of the radar modes to be used operationally. • Conduct installed RF interoperability testing of classified modes in an anechoic chamber as early as practical in the project.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Ensure EW SUT serviceability prior to test commencement	Always run a complete I-level repair test on the SUT (including sensitivity and power levels) before it is tested on an aircraft, and repeat the diagnostic after taking aircraft data. If a SUT fails part of the second I-level test, it may explain why that SUT failed aircraft tests. For example, an RWR missed identifying emitters in a certain quadrant during an operational test. After repeating an I-level test, it was later determined that a hardware failure had occurred and there was not a design deficiency with the RWR.	Use appropriate processes to ensure that the SUT is fully serviceable prior to commencement of testing.
Where are the problems in an EW equipment likely to be?	It is rare that a completely new EW or other technology is introduced to a platform. Consequently, in general terms, another test engineer, somewhere in the world has already 'walked the path' that you are about to walk when designing an EW SUT or planning and conducting T&E on that EW SUT on a particular platform. Despite this, international experience has shown that many engineers, of all disciplines, have appeared to think that they were the first to design, install, integrate, rig-test, aircraft ground/flight test an equipment of a particular genre, e.g., a radar, a flare/chaff dispensing system, a RWR. SUT designs and test plans have been generated from scratch and few, if any lessons have been learned. In this way many problems and inefficiencies have been re-encountered project after project, within and across Nations. It is beneficial and relatively easy to investigate what problems have been encountered on prior projects introducing or upgrading EW systems on platforms. These problems comprise problems with the SUT itself and T&E problems. For example, understanding where problems are most likely exist on a new towed RF decoy by investigating where problems occurred on prior TRDs, and with the T&E of those TRDs enables: • Problem prevention (by SUT/platform design or modification); and • Tailoring, focusing and optimising of T&E philosophy and methodology, procedure and facilities.	Focus the T&E plan by: • Investigating what problems were experienced by others when testing an EW equipment of the type and/or genre you are about to test. • Wherever possible, talk face-to-face with the designers and testers of the prior systems. • If accessible, use prior problem reports on a given EW equipment type to indicate where problems might be. • At the start of a new project, a run-through of all previous problem reports (closed or otherwise) for EW equipment of a similar genre is highly likely to save considerable time and effort in the overall T&E programme.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Verification via 'read across'	Function and performance verification of a project's deliverables was managed via Specification Verification Matrices, which used the generic verification evidence classes: Inspection, Analysis, Test and Demonstration. This project benefited greatly from realising the opportunity of read across of relevant verification evidence from prior projects, reducing both overall project cost and risk. Some read across was defined/assumed at project outset and more was identified and realised via the risk and opportunity management process. Two issues were encountered that, with hindsight, could have been prevented: • Some verification evidence from a prior project was found to have been incomplete and/or incorrect. This project's Factory Acceptance Test process and procedure trapped these few issues. • Adequacy of prior project testing for read across: On one major deliverable it was assumed that the recent prior project had adequately checked out their almost identical deliverable. This proved not to be the case and significantly more testing and problem investigation was required than anticipated, adding considerable risk and duration to this project.	• Minimise project cost and schedule via identification of maximum read across of verification evidence at project outset. • Ensure all read across evidence is appropriately reviewed prior to use, especially items in the 'Test' and 'Analyses' verification categories. • Continually watch out for further read across opportunities, as it is generally easy to realise the cost / time / risk benefits.
Don't forget multi-path!	During the development phase of a RWR it was thoroughly tested using an open-loop radar environment simulator in a HITL laboratory. The RWR utilised 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 optimised. 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.	• Create ground and inter-platform multi-path representative of the planned flight trajectory during SIL/HITL testing by coupling a sample of the signal with the anticipated delay and reflection/diffraction loss. Adding random amplitude and phase modulations increases the fidelity of the multi-path simulation. • Be mindful that, especially for aircraft ground tests, RF energy reflections around the aircraft itself can substantially change test results when compared to anechoic chamber and SIL/HITL trials.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Don't forget multi-path! (cont'd)	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.	• The aircraft's stores configuration, including fuel tanks, weapons, jammer pods, etc., significantly alters the number of reflective surfaces involved. Reflection/ diffraction in some cases is further complicated by the non-metallic materials some stores are made from. • Computation Electromagnetic Modelling can help predict test results and investigate any problems encountered. CEM can also assist in clearing EW SUT performance against different stores configurations – aircraft test programme durations and budgets usually prohibit EW SUT testing for every stores and aircraft configuration.
M&S credibility and fitness for purpose	Problems encountered are discussed in Chapter 7, Section 7.8.7.	See Section 7.8.7.
The high value of video recording during aircraft and rig trials	The lack of suitable video recording of EW system and other displays during rig and aircraft ground/ flight trials has hampered many trials over the years and made investigation of some of the trickiest problems encountered difficult and time-consuming. Video recording is a well-established diagnostic tool. Where it has been available and been used, it has helped test engineers quickly home in on the root cause of problems and has aided the identification of solution options.	Always consider the use of video recording of key aircraft displays during EW ground and flight trials.

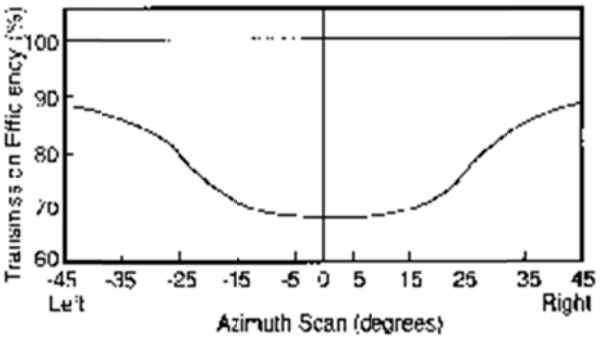
TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Simulation vs. Stimulation of RF EW SUTs	The simulation/stimulation issue is important to EW, radio and radar systems. The [Platform A] EW SIL experience has shown that most of the RF interface problems that could have been found on the rig using the techniques and test equipment available in fact were found. The bulk of this work was done by low power irradiation of receiver antennas, with a lesser amount of direct, cable-connected transmitter to receiver injection of RF signals. Although some investigation was conducted into direct signal injection at Intermediate Frequencies it was decided that the End-to-End concept should apply – i.e., test the system out as it would be in the aircraft. This investigation has shown that the end-to-end concept is robust for EW systems, with some confidence that many of the RF interface problems would have got through to aircraft had it not been for this approach. There has been a marked reluctance to consider the use of SILs in this area, probably stemming from an incomplete understanding of the power of the rigs as investigative and diagnostic tools for RF problems. For example, the [Platform C] radar-RWR interoperability problem entailed extensive aircraft ground/flight trials for some three years. Although it is accepted that airframe effects could only have been examined on aircraft, it is believed that most of the optimisation of RF 'windows' in the RWR could have been carried out using a real radar on the [Platform C] SIL. Thus it is concluded that much time and effort could have been saved in this area.	Use real RF systems on SILs and in anechoic chambers to: • Minimise RF interface problems getting to aircraft trials. • Cost-effectively investigate and diagnose RF interface problems.
Bypassing a platform's SIL causes problems	As a result of deliberately bypassing tests on a platform's SIL, problems that could have been discovered on that SIL have subsequently been discovered during EW on-aircraft trials, resulting in a higher cost-to-find and cost-to-fix. In three cases this occurred on the EW systems of [Platforms A and B]: ECM, blanker (RF suppression management unit) and CMDS. The reasons are varied why this problematic short-cut was taken in each case. Some aspects include: • SUT cleared for aircraft on the basis of tests with the manufacturer's test set only. • Prior testing, done years before on a much earlier variant of same platform type, was done by "trial and error". In retrospect the trials manager concerned described the earlier results as "totally wrong". • Failure to recognise that SILs have a powerful role to play in RF system testing.	New or upgraded EW equipments, or those previously fitted to other platforms/variants, should not be introduced to an aircraft type without going through normal system integration tests in the SIL for that type.

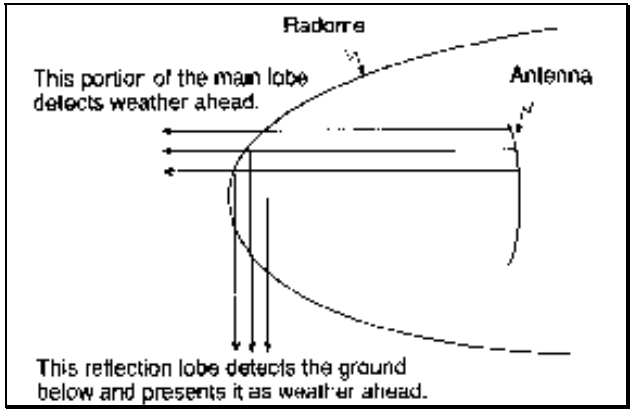
TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Set time limits on troubleshooting	When a problem is encountered during part of a test, set a prudent amount of time to investigate, then continue the original test procedure because if the initial problem cannot be readily understood, subsequent 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 labelled '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.	To maximise test timescale success probability, especially on aircraft ground trials: • Set a limited time for investigation of a problem after encountering it, prior to returning to execute the next test in the planned sequence. A rule of thumb is up to 4 hours. • Conduct further investigation of problems discovered during a test sequence once the entire planned sequence has been completed.
Understand timing relationships, measurements, and uncertainty	Data analysts must understand what is being measured as well as the precision and accuracy of the measurement. Response time is a common measure of performance in EW RF receiver testing and makes a good example. The response time calculation requires the analyst to know the initial time, i.e., when the radar began to transmit and the time when the event of interest occurred, e.g., the RWR displayed the related symbol. The OAR post-mission test data will include the "ON" times for the subject radar. Analysts must understand exactly what this means. Radars are instrumented in a number of ways. Three common methods and their associated shortcomings are: • **Switch Position** – the instrumentation records the time when the switch is engaged. Instrumenting the switch position tells the analyst when the operator commanded the transmitter to turn on, it does not represent the time that the transmitter actually began radiating. This is a potential error source, since there will be a time difference between the time that the switch was engaged and the time that the transmitter began radiating. This time difference will vary by system and can even vary within a system, for example, a transmitter that is warmed up may come up to full power more quickly than a cold one.	It is critical that data analysts understand what is being measured, how the MOPs are specifically defined, how accurately the data will allow the MOPs to be calculated, and how these relate to the specified system requirements.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Understand timing relationships, measurements, and uncertainty (cont'd)	• **Data Bus Message** – modern radars and simulators employ software controlled elements and can record when the message commanding the transmitter to engage was sent on the data bus. In this case the initial time will be after the operator commanded the transmitter to turn on. There will be a lag until the command is sent on the data bus. As is the case of instrumenting the switch position, the instrumentation system only records the time that the transmitter was commanded to radiate. • **Radio Frequency Transmitted Signal Power Level** – a RF detector measures the signal output power level at the transmit antenna. When the signal level exceeds a predetermined threshold the instrumentation records the time of the event. This method can at times actually induce an unusual anomaly: a negative response time, i.e., the SUT receiver detects the RF signal before the instrumentation system records that the radar is transmitting. This can occur because the transmitted power ramps up in amplitude and takes additional time to exceed the reporting threshold. This is most likely to occur when SUT receiver is fast and very sensitive and the radar has a relatively long ramp up time. Each of these methods can introduce errors and measurement uncertainty.	
Record SUT details and test configuration	Record serial equipment being tested along with the time and date of test. It is amazing how quickly measurement data becomes worthless when a question arises later and the exact test configuration cannot be ascertained or recreated. Although simple, obvious and begging the question "Why is this even in a lessons learned list?", international experience has shown this to be an intermittently recurrent and fully preventable problem for over 30 years.	• All test engineers need to be very disciplined in this regard and treat their test configuration like that for an academic research trial. • All necessary data must be recorded to enable a third party, at some later date, to exactly replicate the test and its results.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Monitor the power line during tests	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 SUT specification, full SUT 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 monitoring equipment works. A disturbance analyser was flown in a military aircraft to try to determine why the on-board 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 analyser 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 analyser had an overheating problem and we were back to square one on identifying the aircraft problem.	• Monitor power lines in the laboratory and during aircraft trials, as voltage interrupts and transients, and spurious and harmonic signals have been the root cause of a number of problems with EW and other avionic equipments. • Be ever mindful that test equipment can be as problematic as the SUT under test. Never discount T&E equipment, especially if containing software, as a SUT problem contributor until you are doubly sure this is true.
Effects of component response time	A number of problems have been experienced whose root cause was the apparently innocuous change of an internal component's response time. Three examples are provided: • 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 refuelling 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. • 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. • An aircraft's new blanker box worked less well than its predecessor. 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.	Always suspect a changed component if timing problems appear on an upgraded SUT and platform installation that previously worked correctly with the earlier version of SUT.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Determination of test point limits	As part of acceptance testing a 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 ms. The system continued to operate properly through the short microsecond dropout of power. Its operation ceased during the 10 ms dropout of power but it automatically recovered when power was reapplied. The system never recovered after a 1 ms 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.	• Test points should be selected carefully and, where possible, should be chosen to probe the correct operation of a particular element of function or performance. • Avoid selecting 'maximum and minimum only', as experience shows this often hides problems that emerge later.
Radomes – characterisation and post-repair testing	Radomes are used on aircraft nose radars, jammers, RWR/ESM antennas and other RF transmitting/ receiving antennnas. Various problems affect their use and effectiveness, most of which impact all types of radomes, and some – such as described below – are particular to nose radar radomes. A nose radar 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, whilst 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	• Radomes should be fully characterised after damage repair. • 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.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Radomes – characterisation and post-repair testing (cont'd)	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: Transmission Efficiency.** As can be seen, the area directly ahead has a worse 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.	

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Radomes – characterisation and post-repair testing (cont'd)	 **Figure 9-2: Radome Ground Return.** Note: Figures and background material contributed by Ben MacKenzie, Director, Technology and Engineering, Norton Performance Plastics Corp., Ravenna, Ohio.	
Look at data cross-over 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 cross-over region are similar, if not 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 cross-over region, the spectrum analyser 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 to get valid measurements.	Sub-banding of tests, for a variety of reasons, is commonly required to fully cover a particular SUT performance measure. In this case ensure that data is measured to enable verification that data elements in adjacent sub-bands are identical (within measurement error) or fully and satisfactorily explainable.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Don't make assumptions when reporting problems	The system/avionic problem report is the primary method of getting SUT problems fixed. To aid speedy resolution without the need for subsequent investigations, it is important that the test engineer provide as comprehensive and complete a record of the problem, with supporting evidence, as is possible. The report should also be accurate – two examples follow where an incorrectly made assumption hindered rather than helped resolution of the problem: • When a RFCM 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 RFCM system was in the receive mode. The witness assumed that since the transmit light was on, the RFCCM system was transmitting. The RFCM 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.	• Ensure system/avionic problem reports are accurate, precise, comprehensive and complete. In general, the better the problem report, the quicker the solution. • Provision of photos, figures and other evidence that might help the equipment/ software supplier to pinpoint the problem's root cause is strongly recommended. • Don't make assumptions – double check the facts.
On-aircraft RF coupling (interference) may not be symmetrical	Symmetry of RF coupling, based on a simple view of transmit and receive antennas' placement on an aircraft, is often and reasonably used to justify clearance of a full performance envelope based on extrapolation of a sub-set of physical measurements on that aircraft. For example if RWR antennas are identically mounted at the top extremities of both wings, then coupling from an in-band RF transmitting antenna on the top centre of the fuselage to any of the RWR antennas will be very similar, if not identical. There are cases, unfortunately, where this RF coupling is asymmetric to a greater or lesser degree. For example RF coupling, which may cause interference, from the radar 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	• Symmetry of on-aircraft RF coupling paths should not be assumed, especially when attempting to justify a reduced T&E programme based on that symmetry. • Antenna pattern modelling should be used to predict the level of symmetry likely to occur on a given platform, which should then be validated by a limited set of measurements.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
On-aircraft RF coupling (interference) may not be symmetrical (cont'd)	attenuation to the backlobe of the radar 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.	
EW man-machine interface	Sub-optimal MMI is a common theme running through many of the problems previously seen during EW T&E. In some cases there has been scathing criticism by aircrew and engineer alike concerning EW display presentation, usefulness and confusion caused when trying to use it 'in anger'. The execution of MMI assessments early in the design life-cycle, as is more often the case nowadays, helps prevent this type of problem reaching the aircraft, where it is more costly and time-consuming to fix.	Engage EW T&E engineers and aircrew in MMI assessments during the design phase, to minimise problems at the rig and aircraft test phase.
How to know if the problem is the avionics system or the platform	When a SUT passes Intermediate-level (I-level) tests, then fails in an aircraft, and fails a repeat I-level test, suspect aircraft wiring if this sequence occurred 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 re-passes I-level tests, suspect aircraft wiring, physical or environmental considerations: • In one case, a keying connector wasn't connected 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, test preparation instructions were changed to include testing with one end slightly elevated if a sloshing fluid noise is heard during handling.	• If a serviceable EW SUT is fitted to an aircraft for the first time and it fails, immediately suspect and investigate the aircraft wiring. • Unless unavoidable, **do not** fit a replacement SUT until the faulty original unit has been investigated and the aircraft and its wiring cleared of involvement in causing the fault. • If a serviceable SUT is off-aircraft re-confirmed as still being serviceable after failing on the aircraft, initially suspect broken wires or incorrect, faulty or mis-connected connectors.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Try to arrange measurements so measurement errors are obvious	The test engineer can help him/herself by designing tests that include an element of 'self-checking'. Two examples are given here: • 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 analyser when lower power measurements were made at the lower frequencies, it was necessary to use a Low Pass Filter (LPF) to attenuate the strong in-band 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 analyser. During the second test an external 10 dB attenuator was attached to the analyser. Therefore, if the analyser'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.	Where possible, design tests that enable the test engineer to quickly identify if measurement errors are present.
SUT instrumentation and data recording	Even if you have done a very good job under the T&E period with a lot of defined test cards, there will always be situations during flight test operations that the SUT does not behave in a correct way and which was not defined in test cards and perhaps situations that are difficult to recreate. To make it possible to analyse that type of problem it is necessary to have a recording system running all the time.	It is very important to have a very "powerful" internal recording system dedicated for EW purposes in every military aircraft, especially those going in harm's way.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Airframers need to know what the avionics contractor is thinking	The following examples, although really design and ICD issues, are typical of the more subtle installation problems that can get through to aircraft to be found by the astute test engineer: • 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 cut-out to leave the switch alone. The jammer contractor didn't realise it until one technical representative 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.	• Before testing on SIL/HITL rigs and on aircraft, engineers should become familiar with the SUT specification and relevant ICDs. • Attention should be paid to the operation of on-aircraft, free-space RF feedback loops as used on many RWR/ESM/ECM systems. These should be replicated or simulation on SIL/HITL rigs. • These rigs should include the same number and type of interlocks and switches as are installed on the aircraft. Test procedures should correctly cover their operation. • Particular attention should be paid to the function and operation of 'Weight-on-Wheels' ('Aircraft-on-Ground') switches, problems with which has been at the root of many past EW SUT and T&E problems.
Multiple reporting of EW/Avionic problems	An investigation of DAS T&E rig and aircraft ground/flight trials during a many-year development programme on each of two platform types showed that – with the benefit of hindsight – many more system/avionic problem reports had been raised than was necessary. This resulted in the two programmes being longer and more costly than they could have been. This experience is known anecdotally to be generic across the EW T&E community, although process and procedure enhancements in recent years have improved the situation. The reason for duplicated problem reports fell into three categories, those:	To minimise the risk and number of repeat or duplicate problem reports on a programme: • Always adopt an Integrated Test and Evaluation Approach. • Where the same or similar variant of EW equipment is fitted on one or more platforms/variants and is to be fitted to another, always screen open and closed

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Multiple reporting of EW/Avionic problems (cont'd)	• Initially raised on SIL/HITL facilities that were re-investigated and re-raised on aircraft ground and/or flight trials. Sometimes the exact same problem is raised at the rig, aircraft ground test and flight test, with the latter two duplicate reports adding nothing to the original one. • Raised on EW equipment on one platform type then re-raised on the same or very similar equipment fitted on another platform type at a later date. • Which are different facets of the same problem. • The single root cause identified is inadequate visibility to ALL involved departments/agencies of the existence and latest status of problem reports.	problem reports that were raised on the earlier platform/variant.
Use and limitation of video recording during aircraft RF EW trials	Much EW T&E work in the last two decades has been in the area of relatively high power on-board transmitters interfering with sensitive on-board receivers. Measurement of interference has often been subjective, i.e., by aircrew/engineer comment on displays and/or post-trial analysis of video recordings of EW and other RF equipment displays. Whilst video recording is a powerful development tool and has been used on SILs for many years with great success, it has had a number of shortcomings when considered in the on-aircraft EW context. These are: • Subjective and qualitative, rather than quantitative measurement of results of jamming and/or RF interference. • Often poor quality video, caused by the use of cockpit mounted TV camera(s) rather than direct recording of display surface video signals. • Substantial time and effort overhead in post-trial analysis, including the necessity to use experienced EW engineering effort.	Use direct video recording of display surfaces for T&E investigations of jamming and other interference on on-board EW and other radar frequency receivers.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Conformance to Specification vs. 'Fit for Purpose'	The primary emphasis of Industry T&E engineers in earlier times was to confirm that the platform and EW SUTs met the functional and performance requirements defined in their contract specifications – the basis of being paid by their defence ministry and armed forces customers. This led to some problems encountered on rig and aircraft trials being declared as 'Meets the specification, this is not a problem.' There is now a wider recognition that *Fit For Purpose* does not mean, as was historically the case, *Meets the specification*. The combination of specifications, ICDs, and an associated '*Capability and Limitations*' document provides a clear view of what is and, as important, what is not being provided under a contract. This enables proactive and early resolution of any items that might not be acceptable to the customer. Customer and military end-user agreement to this latter document provides a consistent, all-stakeholder definition of *Fit For Purpose*. In addition there is an implicit understanding that the SUT needs to be free of serious 'bugs' at the point of delivery to service and during its operational life. This adds a dimension to the above – to approximately quote an American systems engineer "Proving conformance to specification does not prove the absence of faults". It has been observed over many years that a substantial element of the overall T&E effort on EW and other avionic systems has been spent on finding and fixing software/ hardware bugs rather than on merely demonstrating conformance to specification.	• Produce at contract outset a Capability and Limitations document for a given EW SUT or DAS, agreed by all stakeholders. Update as appropriate during the contract. • Use this document in conjunction with SUT specifications and ICDs to guide and optimise the scope, duration and cost of the EW T&E Plan.
Tape recordings can help pinpoint audio interference	When audio interference was heard on an aircraft internal communication set, 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 analyser with the 'max hold' function selected. By comparing the two spectrum analyser presentations, the frequency of the interference was calculated, which then enabled engineers to determine the specific circuits causing the interference.	As with video recordings, see other lessons learned, high quality audio recordings can be very useful when investigating on-aircraft interference.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Unexplained EW SUT effects during testing	During rig and aircraft ground and flight trials sensitive EW receivers have, on a number of occasions, suffered from display freezes, software re-starts and stoppages, and/or inaccurate/ambiguous fault indications. Many have, upon investigation been either 'unexplained', 'unrepeatable', 'not understood' or considered (usually by the equipment supplier) as 'unrepresentative test'. Some have been traced to sensitivity to supply voltage transients when other, high current aircraft equipments are turned on or between off, standby and on modes, i.e., an EMC/EMI problem. Others are thought to fall into a category of 'catching' the EW computing hardware/software at some time-critical point in its processing cycle. This type of problem is generic to computer systems and can be extremely difficult to repeat, fully diagnose and solve. Despite this, it is thought from the circumstantial evidence gathered over the years that many may, in the final analysis, have been caused by noise/voltage transients on signal or earth lines either within the EW system or at the interface with the aircraft supplies.	To aid replication, investigation and resolution of any such problems: • Use video recording during tests. • Monitor power lines into and out of the EW receiver system's own power supply unit.
'Subjective' investigation of RF coupling problems	Much EW T&E work in the last two decades has been in the area of relatively high power on-board transmitters interfering with sensitive on-board receivers. Investigations of such problems, especially when involving ECM systems, have been lengthy, some have been inconclusive, and a number have been very cost-ineffective – resulting in little or no improvement. This resulted from one of more of these reasons: • No modelling of ECM to RF antenna/receiver coupling, which would immediately identify the type of interference (in-band transmitters affecting in-band receivers, or out-of-band interference). • No in-depth assessment of the problem and its causes, or review of equipment design to establish if potential solutions were capable of offering required level of improvement. • A minimum of antenna coupling measurements, necessary to confirm those predictions. • Subjective assessment of interference seen ("better than before" – even if it is still considered unacceptable). • Limited quantitative measurements of victim SUT-received interference power/frequency.	To minimise technical risk and RF interoperability test timescales: • Prior to aircraft tests use M&S (Computational EM) to establish whether there is likely to be any inter-system interference. • Confirm correct RF interoperability via whole aircraft tests in an anechoic chamber ISTF. • Conduct a minimum of on-aircraft investigations when/if unexpected interference is encountered. Then go back to the M&S models to investigate the problem and potential solutions prior to returning to the aircraft for further testing.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
'Subjective' investigation of RF coupling problems (cont'd)	• Somewhat un-scientific approach to possible solutions: stick a bit of RAM here, then there; swap ECM from one wing to the other; RAM paint application.	
The utility of 'Confirmatory' testing	Prior investigations have shown that in most cases each successive stage of tests, (Supplier CoC, Platform Supplier Acceptance Test, SIL Pre-Integration/Integration, aircraft ground test and flight test), is broadly a sub-set of the earlier one, but with much repeat test work being conducted. If this situation is inspected logically from a cost effectiveness point of view, no test should be repeated unless it either demonstrates an aspect of conformance to specification or is specifically requested by the Customer in the contract. This request, if it is present at all, is likely to be more of a Public Relations exercise – giving him 'confidence' – rather than a technical necessity.	• Screen existing test plans and procedures to remove redundant and costly 'confirmatory' tests. Avoid their use in future plans and procedures. • In this way the SUT supplier's tests should be the most technically exhaustive followed, in decreasing order of duration and complexity by avionic rig, aircraft ground and aircraft flight testing.
Problems with RF connectors	Two primary problems have been experienced repeatedly over the years and across a wide variety of platforms: • Aircraft RF cables, when connected to EW equipments, have not always been torqued up correctly. In some cases they have only been connected 'finger tight'. For correct EW SUT performance it is essential that all RF connectors are correctly torqued up. Failure to do so can lead to degraded performance – sometimes not bad enough for the SUT's BIT system to detect but bad enough to adversely affect overall threat direction finding, detection and identification performance. Sometimes the BIT will indicate a faulty LRU when, if fact, there is no problem with the LRU. This can lead to lost test time, nugatory investigation and the availability impact of LRU 'No Fault Found'.	• When connecting aircraft RF cables to EW black boxes always correctly torque up RF connectors to assure performance and prevent problems. • Double check RF cable connections to EW RF receiver LRUs/LRIs on SIL/HITL avionic rigs and aircraft. • Check for the RF cable swapping problem on RWR/ESM installations by conducting a simple, walk-around quadrant check using a RF signal source.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Problems with RF connectors (cont'd)	• Aircraft RF cables to RWR/ESM antennas and/or receivers being accidentally swapped over due to lack of connector keying or difficulty seeing connector idents on the LRU when installed in the aircraft. An often result of this is that emitters in two quadrants appear in the opposite quadrants. This kind of mis-connection can be trapped by a walk-round test of the aircraft using a hand-held RF emitter simulator.	
Use of SIL and HITL facilities for EMC testing and investigations	Generally, the aircraft is the only real place where full system EMC can be confirmed. The risk of EMI and other EMC-related problems is minimised by robust design practice and EMC qualification of individual LRUs/LRIs. Historically, avionics rigs with SIL and HITL facilities were not designed or suitable for EMC testing. Nowadays many modern avionic rigs use aircraft grade cable with representative lengths, they utilise aircraft screening/earthing/bonding schemes, and have 'cockpits' with aircraft equipment laid out as they are in the aircraft. Whilst predominantly designed this way from an integrated avionic system testing standpoint, this has made them more electromagnetically representative of the aircraft. Some limited, system-level EMC risk reduction work can be conducted on the SUT on such rigs. Pulsed and CW RF Bulk Current Injection tests have been shown to have good correlation with on-aircraft test results. This can aid early identification of problems, prior to aircraft use, and provides an off-aircraft investigative tool for EW and other avionic EMC/EMI problems.	Consider the use of avionic rigs in SIL/HITL facilities for EMC/EMI testing and investigations.
'Parallel' SIL and aircraft flight testing	A few examples of 'parallel' testing have been seen. This is where a software and/or hardware update or new package is delivered to the SIL and aircraft at the same time. A bare minimum switch-on clearance test is conducted then the aircraft ground/flight trials are allowed to proceed in parallel with full SIL integration/assessment activities. Whilst this approach can theoretically be used in an attempt to save time or recover development programmes experience shows this to be a high risk, poor payback option in practice. All that happens is the problems, some of which are major, which should have been found on the rig, are instead first found in flight with a much higher cost and timescale penalty. In one case a two-aircraft flight trial and associated post-trial investigations were totally wasted.	• Ensure optimal use of SIL (sub-systems and avionics integration) facilities by following the Integrated Test and Evaluation and Acceptance process. • Do not take the risk of jumping straight to flight test without passing EW and other avionics through the SIL process.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
'Un-repeatable' test problems	There are occasions where a problem has been seen once during EW rig and aircraft trials with the SUT and/or with test equipment being used in the T&E process, but which cannot at that time be repeated. In the past some have either: • Chosen to ignore the occurrence ("It's not repeatable, so cannot be a problem."); • Attempted to repeat the problem a small number of times as part of the ongoing trial, after which it is declared not to be a problem; or • Decided not to record/progress any definitive action to reproduce it beyond that briefly conducted during the ongoing trial. Some such problems have only re-surfaced again once the platform has been in operational use for some time. Some of these have had unacceptably adverse operational impact and a significant amount of time and effort has then had to be expended 'hunting gremlins' – usually with some success. Some problems have been repeatable and on more than one occasion the problem has been repeated, but only when an out of the ordinary (but allowable) sequence of keyboard or other 'button' pushes has been effected. A phrase often encountered over the years when sharing experiences on such problems with other users of the SUT and/or platform and/or test facility/equipment is "We've seen that!" – accompanied with the information that they also haven't formally recorded the problem either, for the same reasons as above.	• Record all problems seen during trials using the system/avionic problem reporting process, then move any un-repeatable problem to a 'Watch List' if not re-encountered within a reasonable period of time. • Ensure all relevant stakeholders in the platform and SUT (as appropriate) are aware that there is a risk of such problems recurring at some point during the SUT's operational life. • Optimise problem early fix potential by sharing such information with the manufacturer of the test equipment, SUT or platform.
Investigate test response when SUT is not connected	A test result may not be what you expect when a system is not connected. For example, while evaluating the effectiveness of I-level tests of a jammer on a piece of Ground Support Equipment (GSE), the tests were run on the GSE without the jammer connected. 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.	• Be mindful that test equipment is not perfect. This includes GSE, COTS (e.g., spectrum analysers) and other Special-To-Type Equipment. • Some can, under certain conditions, provide indications or give measurements that incorrectly suggest a 'Pass'. • Familiarity with the test equipment is the best defence against this type of problem.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Commonality of test tools and training	• Cases have been encountered where different sites/divisions of the same company have obtained different results from testing due to the use of different measurement equipment and/or procedures and/or training. • This is especially relevant when considering RF EW tests conducted at different sites, divisions, agencies and companies, where different RF threat simulators and other emitter generation equipment has been used.	• At the T&E planning stage, ensure appropriate levels of test tools and training commonality across the test engineering stakeholders irrespective of their agency. • If adequate commonality cannot be determined at that point, factor in how the differences will be taken into account during the T&E process.
Microwave testing problems	A number of typical problems have been encountered during microwave testing at various levels, from EW component, box and system testing in the laboratory, via SIL/HITL to aircraft testing in ISTF and in support of flight test and trials. Learning points for a few are presented at right.	• Always use isolators in any microwave test set-up, to minimise risk of damage to un-protected components. • Always take a transmission and reception measurement before starting to test: this will provide the tester with the current equipment set-up losses which can be taken into account. • Ensure that component, sub-system and system tolerance coning is correctly carried out prior to commencement of practical T&E. • Always check that the antenna under test is on boresight before commencing initial radiation pattern measurements. The non-use of a simple VSWR meter to obtain this is common practice and lends itself to poor results being gained.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Microwave testing problems (cont'd)		• Check that antenna radiation patterns do not show signs of bifurcation on the main lobe: there are times when such a feature is so small that it is easily overlooked. It is at this point that judgement needs to be made as to whether reposition, or continue testing.
Basic test set-up	The use of basic test set-ups is good practice. Too often have engineers used previous test set-ups only to find at a crucial point that their results are invalid because a small but important item of test equipment was missing.	• Have a basic test configuration thought out and always return the equipment to this state following the completion of a phase of testing. • Have basic test set-ups detailed in block diagram format and available to non-RF engineers. This enables seconded personnel to set-up equipment by themselves. It was then checked by engineers familiar with RF before test commencement.
Test equipment calibration	Test equipment being found out of calibration at the start or during a test phase remains a problem that is intermittently encountered. Another facet is when an item goes out of calibration just after the originally planned test completion date – but is now a problem as the aircraft trial has been extended.	• Ensure all required test equipment for a given test phase will be inside calibration for the duration of the trial. • Ensure sufficient schedule reserve on the calibration past the planned completion of the test phase. If this is not possible, arrange loan or hire of a replacement equipment to minimise risk to the test programme.

TOPIC AREA	PROBLEM, ROOT CAUSE AND COMMENT	LEARNING POINT
Adequacy of ‘problem’ and ‘equipment failure’ time	Invariably test and/or SUT failures are encountered during T&E programmes. Problems are also usually encountered during the testing, which require investigation – some at the time and more at a later point during or at the end of the tests. Often the planned programme schedule does not allow sufficient time to cater adequately for these realities of T&E.	• Plan testing thoroughly: build in problem investigation time and equipment failure time. • Plan which test elements have priority 1, 2 and 3, should such problems and failures occur during a given test phase. Agree this with the customer before beginning. Have a mid-test meeting to discuss progress and problems. Hold an end-of-test wash-up meeting.
Airframe harmonic effects	The energy radiated by higher order harmonics of a high power transmitter on an aircraft interfered 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 minimise 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 initial 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.	• Transmit and receive antenna function and placement is best optimised using Computational Electromagnetic Modelling (CEM). • This includes maximising isolation between in-band and harmonically related antenna pairs, and maximising coverage (polar patterns) in required directions. • CEM is beneficial when introducing or re-locating antennas. • CEM’s benefit is multiplied when dealing with antennas on airframes made of dissimilar materials, e.g., Carbon Fibre Composites, titanium and aluminium.

9.4 REFERENCES

[1] Berkowitz, P.H., "EW Testing Lessons Learned", Track: SOS/DST 16 June 1998. Report: A302553. Internet: http://dodreports.com/pdf/ada355203.pdf. Last accessed: 12 October 2011.

[2] Stadler, K.M., "Test and Evaluation Lessons Learned from the Field", Defense Acquisition Journal, September 2007, pp. 396-408. Internet: http://www.dau.mil/pubscats/PubsCats/ARJ45_Stadler.pdf. Last accessed 12 October 2011.

9.5 FURTHER READING

Conference Proceedings for the annual U.S.A.F. T&E Days, organised by the American Institute of Aeronautics and Astronautics. Internet: http://www.aiaa.org/content.cfm?pageid=320 Last accessed 25 November 2011.