

NINETEENTH EUROPEAN ROTORCRAFT FORUM

Paper N° F3

**EH101 - THE IMPLEMENTATION OF AN
EMC PHILOSOPHY TO MEET MODERN
CLEARANCE REQUIREMENTS**

by

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September 14-16, 1993
CERNOBBIO, (Como)
ITALY

**ASSOCIAZIONE INDUSTRIE AEROSPAZIALI
ASSOCIAZIONE ITALIANA DI AERONAUTICA ED ASTRONAUTICA**

EH101 - THE IMPLEMENTATION OF AN EMC PHILOSOPHY TO MEET MODERN CLEARANCE REQUIREMENTS

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1. Abstract

This paper relates the development of the EH101 helicopter with regards to achieving a high degree of immunity to internal and external electromagnetic interference. The development is taken from the initial requirements, through the development and definition of the aircraft and standards, to the testing and results obtained. Although the EH101 has been designed to be resistant to lightning effects, this lies outside the scope of the paper.

A brief description of the helicopter is given, together with the requirements placed upon the aircraft and its systems by both the military customers (the UK and Italian Ministries of Defence) and the Civil Authorities.

The response to the requirements is then discussed, specifically detailing the EMC control and management techniques and the design philosophies adopted by Westland Helicopters and Agusta. The methods covered will include cable classification, routing and screening and the use of backshells.

A description of the techniques used to demonstrate compliance with both military and civil requirements is given. The paper goes into considerable depth on the test techniques used for the civil certification programme and on the effects of the stringent requirements to be met.

2. Introduction

The EH101 design started in the early 1980's with the aim of producing a safe, reliable and cost-effective medium-lift helicopter. The aircraft was aimed at both military and civil markets with a wide range of roles being envisaged.

The design introduced a large degree of electronic systems to ease flight-crew workload and, in the military versions, to provide an effective combat system. In addition, to reduce the aircraft weight, composite materials were used on portions of the airframe. When these two factors were combined with the more severe external electromagnetic environment, the implementation of an EMC control programme was (and is) a necessity.

The bulk of the programme discussed below is concerned with the military variants. However, the EMC installation techniques and test methods were carried across to the civil variant with good effect.

The test results obtained so far, demonstrate that the EMC has been controlled on the EH101 with the EMC requirements being met with a significant safety margin. This clearance achievement has proved the EMC management and design techniques implemented.

3. EMC Requirements

The EMC requirements for the EH101 both cover a wider frequency range and require the demonstration of conformance at higher levels than for earlier aircraft. These new aspects reflect

- the greater use of electronics in flight safety critical functions and
- the increase in the use of the frequency spectrum outside the standard communication bands.

Previously, aircraft testing has concentrated almost exclusively on the radio frequency range, namely 2 to 400MHz, with the exception of high-powered radar-frequency testing. Even where this radar-frequency testing was performed, it only covered certain spot-frequencies. While the military requirements imposed on the EH101 have not altered the frequency range, the external environment requirement has increased significantly.

With regards to the certification of the civil variant, the EUROCAE environment has extended the frequency range down to 10kHz and up to 18GHz. In addition, the overall test levels required have risen significantly, in places the increase being several orders in magnitude. This EUROCAE environment is shown graphically below:

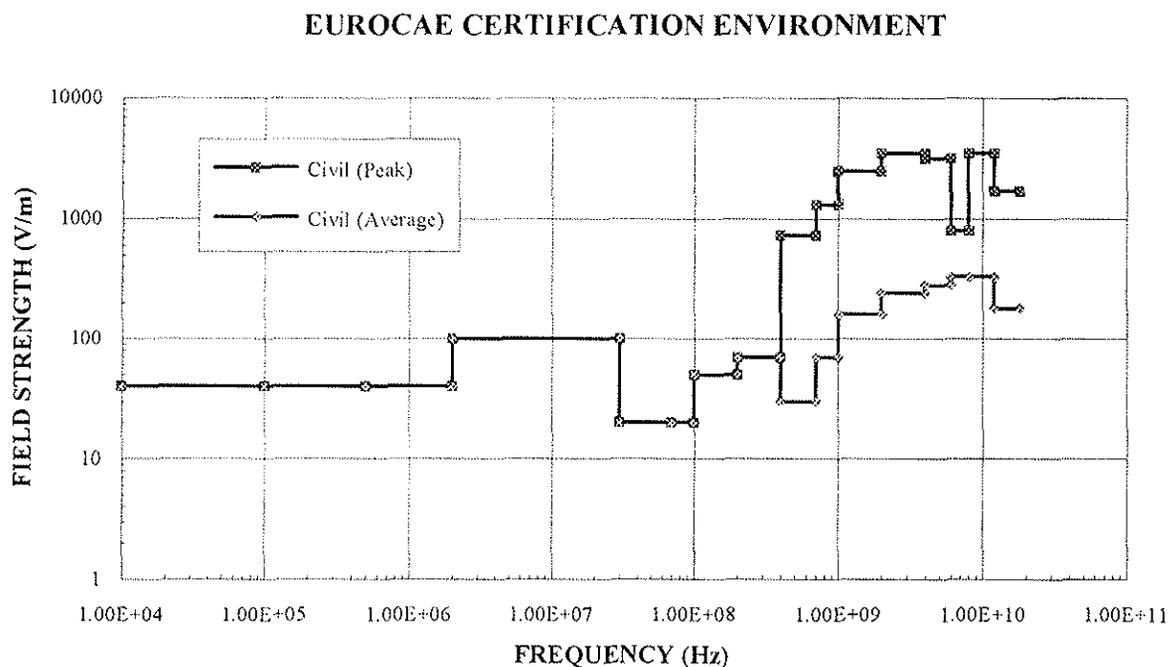


Figure 1

4. EMC Control & Management Techniques

From the outset of the EH101 development, it was realised that good communication was required to ensure that standards were met. This communication had to be established between WHL, Agusta and the customers and between WHL, Agusta and the sub-contractors. The EMC Management procedure created is based upon the recommendations of MIL-E-6051. The discussion that follows covers the military versions of the EH101, while the Civil Certification procedure is outlined afterwards.

Two Boards were set up for the military programme; the EMC Management Board and the EMC Control Board. The former provides a discussion forum between the International Project Team (IPT), WHL and Agusta, while the latter draws together EMC officials from the UK and Italy and EMC Managers and Controllers from WHL and Agusta.

4.1. EMC Management Board

The principle aim of the Management Board is to monitor the activities of WHL and Agusta with respect to EMC on the EH101. A secondary aim is to provide a focal point for the exchange of information on EMC matters between the companies and the defence ministries. It is responsible for;

- considering and approving the overall EMC strategy for the EH101,
- monitoring the EMC Control Board,
- acting as a discussion forum between EHI, WHL & Agusta and the government furnished sub-contractors.

4.2. EMC Control Board

The EMC Control Board operates at a lower level to ensure intra-system and environmental EMC. To provide a link between the two Boards, both the Control Board Chairmen and the Italian & UK EMC Officials are represented on both Boards.

The aims of the Control Board are to;

- define the EMC requirements for the airframe and to ensure that these requirements are met.
- ensure that suitable EMC programmes are implemented for equipment,
- monitor the progress of sub-contractors with respect to EMC, and
- plan rig and system testing, assess the results and recommend any modifications that may be necessary.

4.3. Civil Authority Liaison

The Civil Authorities (CAA and RAI) have had a high degree of involvement at all stages of the civil certification process. Particular attention has been paid to the production of and adherence to the EMC philosophy documents and to the quality of the test methods used to demonstrate the clearance.

4.4. Sub-Contractor Management

In order to ensure EMC on the EH101 in the most cost-effective manner, it was essential that the sub-contractors designed for EMC at the earliest stages in the development process.

To allow the assessment of the activities of sub-contractors, emphasis was placed on formal documentation. Two documents, the EMC Control Plan and the EMC Test Plan formed the basis for a continuous evaluation of the suppliers' design effort.

Liaison during equipment development was found to be a major contribution to the attainment of overall EMC for the helicopter system. In order to realise the optimum communication, each sub-contractor was required to appoint an EMC Engineer, who would assume responsibility for compliance with the EMC Control Plan submitted by the sub-contractor.

In addition, in order to maintain control down the "tree", the sub-contractor was required to ensure a satisfactory EMC management structure and control over their own sub-contractors.

The successful imposition of these requirements upon sub-contractors has resulted in an equipment fit on the aircraft that meets the EMC requirements.

4.5. Equipment EMC Qualification Testing

At the time of the initial specifications for the EH101, the military standards were in a state of change. The tests defined in MIL-STD-461 were not sufficiently exhaustive and new test techniques were being developed by UK EMC specialists. As WHL needed to impose these new test requirements on the sub-contractors, a compilation of test requirements was developed using both techniques in MIL-STD-461 and new methods (for example Bulk Current Injection). In addition, the test levels set reflected the severe external environment and the position of the equipment within the aircraft.

By insisting that the qualification tests in these standards are met, it was possible to be confident that the systems installed on the aircraft would function as required in the external electromagnetic environment. This confidence has been borne out through the test results obtained.

5. EMC Installation Design Philosophy

In order to maintain a high level of immunity from external and internal interference, the design of the installed systems was of critical importance. The primary areas of concern can be summarised as:

- Cable Classification & Routing
- Equipment Location
- Screening & Screen Termination

5.1. Cable Classification

Experience has shown that a large proportion of EMC problems in aircraft systems result from interference coupling between cables and then being conducted into equipment. By categorising cables and routing them appropriately, the degree of coupling, and hence interference, is reduced. Obviously, the choice of routes and groupings is often limited by the aircraft structure itself. However, applying the guide-lines developed has resulted in high-integrity installations in the EH101.

All cables on the EH101 were classified at the design stage to define the system configuration during installation. The groupings are roughly as follows:

- **S** - Cables transmitting low-level signals which are prone to interference and are therefore screened. Efforts were made to keep the number of cables in this group to a minimum to save weight on the aircraft.
- **F** - Antenna feeders, which are themselves divided into sub-classifications of transmitters, receivers and transceivers.
- **A** - Armament cables associated with the release of external stores or the initiation of Electro-explosive devices (EED's).
- **G** - General cables not included in the above groups. This includes distribution and general purpose wiring.

The minimum separation between and (where necessary) within classifications was specified. In the event that the minimum distances could not be maintained, priority was assigned to certain classifications. For example, where S, F and G type could not be separated, priority would be allocated to the antenna feeder (F) class.

5.2. Cable Routing

In addition to the cable classification and separation discussed above, attention has been paid to the overall route of the cables. In order to reduce the coupling between the external environment and the aircraft looms, cables were routed to make optimum use of the

screening effect of metal structure within the airframe. Obviously, routes that lie near non-conductive parts of the aircraft skin have been avoided wherever possible. Where such panels cannot be avoided, metalisation has been applied to increase the shielding effect. A prime example of this is area aft of the cockpit.

5.3. Equipment Location

In addition to cable routing, careful selection of equipment locations in the aircraft was used to improve the EMC of the aircraft. The EH101 design makes use of avionics cabinets for many of the safety critical systems. These cabinets, being constructed of metal, provide a further level of screening between the external environment and the equipment.

5.4. Equipment Box EMI Resistance

Considerable emphasis was placed upon the use of the equipment boxes to provide resistance to electromagnetic interference - a hard-box policy. The principle aim of this policy was to reduce the reliance on external (cable) screening to protect electronic circuits from interference conducted on the system's cables. This resulted in a reduction in weight and a significant improvement in maintenance procedures.

The measures taken to attain the goal include:

- Filtering of signal and power cables to counteract conducted interference.
- Ensuring that the box provided protection against radiated interference (a high-frequency problem.)

5.5. Cable Screening Techniques

With the WHL philosophy on cable classification and grouping, there were two fundamental options for screening the cables in looms. The first consisted of enveloping the entire bundle in an overall screen, while the second involved screening individual cables, twisted-pairs etcetera.

The relative merits of the two options are tabulated below:

Screen Type	Advantages
Overall	<ul style="list-style-type: none"> • Marginally simpler termination to backshell (see §5.6 below).
Individual	<ul style="list-style-type: none"> • Yields screening between different cables within the loom. • Allows cables to enter/exit the loom at any point. • Provides good access to cables for maintenance. • In testing on a Lynx system, the individual screened loom gave a higher resistance to interference¹. • Easier construction of the cable bundle itself.

¹ The tests on the Lynx system involved the assessment of two cable bundles. The first used overall screens with some wires triple-screened. The alternative cable, developed by WHL, utilised individually screened wires and twisted wire pairs. The characteristics of the two assemblies are summarised in the following table:

- | | |
|-------------------|---|
| • Function | No detectable difference between the two assemblies. |
| • EMC | WHL slightly better in BCI and radiated emissions qualification testing.
No impact on the intalled system in on-aircraft BCI testing.
Screening effectiveness was not the susceptibility parameter of the system. |
| • Reliability | No problems encountered but long-term problems expected with the overall screened version due to its high rigidity. |
| • Maintainability | WHL cable demonstrated significant advantages in service. |
| • Cost | The WHL assembly was considerably less expensive to produce; approximately 15 hours assembly time and 4 hours installation time saved. |

On the basis of the above, the philosophy adopted for the EH101 was that individual screens would be used, especially with the development of improved backshell systems.

It should be noted that power supply wires to equipment were not screened as it was not practical to screen the whole of the generation and distribution system. Without this complete screening, interference would be able to couple onto the generation and distribution systems downstream of the wire's screen, hence negating this screen.

5.6. Screen Termination

The method used to terminate the cable screens determines the effectiveness of the screen itself. The use of the wrong screen termination technique can degrade the screening effect such that the cable might as well be unscreened. Obviously, the aim of the termination is to provide a low-impedance path for the currents induced on the screen to reach the ground plane of the aircraft over the widest frequency range possible.

Two screen termination techniques are commonly used:

- The Pig-Tail consists of leading the screen away from the central cables and attaching it directly or indirectly to the ground plane.
- The Backshell technique involves connecting the cable screen to a metal (or conductive) shell which is itself connected to the ground plane.

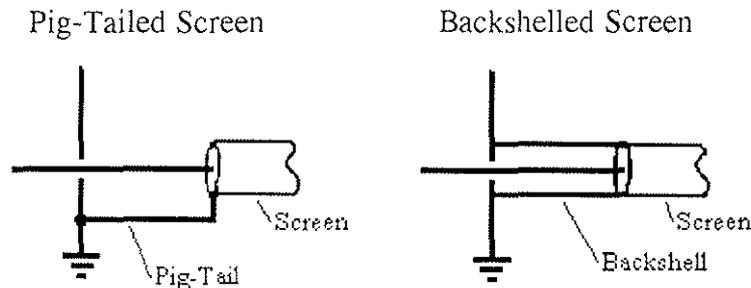


Figure 2

The difference between the two methods that is immediately apparent from figure 2 above is the disruption of the screen in the pig-tailed approach. The backshell keeps the signal cables running within a screened enclosure at all times.

The pig-tail technique would appear to offer an acceptable method for terminating the screens, but problems are encountered at higher frequencies (see figure 3). As can be seen from the plot, the pig-tail screening effectiveness falls away to the levels of an unterminated screen due to its high impedance to r.f. energy. The frequency at which this occurs is dependent upon the length of the pig-tail - the longer the tail, the lower the frequency². As a result, the pig-tail method was rejected for the EH101 in favour of backshells.

It should be noted with some concern however, that some sub-contractors are still unaware of how pig-tailing screens can degrade the EMC of their equipment installation.

• Weight The WHL designed cable weighed **6kg** less than the overall screen version, reducing the loom weight from 10.8 to 4 kg.

² In some instances, the nature of the structure of the pig-tail construction can lead to pig-tail lengths of 60cm in looms with numerous cables.

Comparison between Backshell and Pig-Tail Screen Terminations

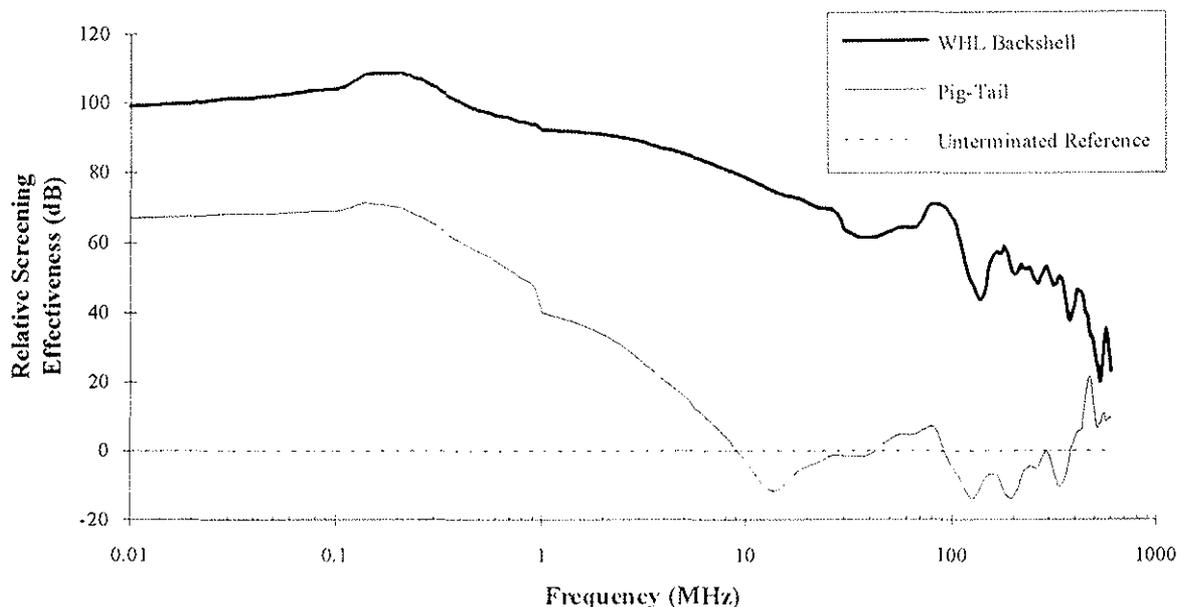


Figure 3

WHL's policy of using individual screens on the cables in a bundle, rather than an overall screen presented a problem for the screen termination. While it is relatively easy to terminate an overall screen, being able to make sufficient electrical contact for high-frequency conductance on a bundle of individually screen cables is (initially) harder.

Therefore, WHL designed a new backshell which offered ease and consistency of installation, low weight³ and ease of maintenance. The following table compares the WHL design with other backshells on the market:

	WHL	Type 1	Type 2	Type 3	Type 4	Type 5
Angled Versions	Adaptor	No	Separate	Adaptor & Separate	Separate	Separate
Special Tools	No	Yes	No	No	No	Yes
Weight (SS19)	18g	37g	51g	33g	66g	45g

Considerable investigation was done into the techniques for the EH101 programme. The traditional method of measuring the screening effectiveness of a screen termination (using a triaxial or quadraxial jig) only determines the braid-to-backshell termination. It does not give an indication of how the backshell will perform when in its installed configuration nor allow itself to be adapted to test bundles of individually screen cables.

A test method was developed to compare the screening effectiveness of different termination methods when used on a common cable bundle. This involved injecting a current onto the screens of the cable assembly. The screen current (in dBµA) and the voltage induced across a pair of cables (in dBµV) were measured with the difference between the two being recorded

³ A weight saving of 11kg has been achieved compared to the development standard aircraft which used other backshells.

as the transfer impedance (dBΩ). It should be noted that this is not a true impedance but can be used to provide a comparison between different screen terminations. The graph below shows that the WHL backshell provides screening effectiveness values (generated from the recorded transfer impedances) that are comparable with other manufacturers' items.

Comparison between Backshell Screening Effectiveness

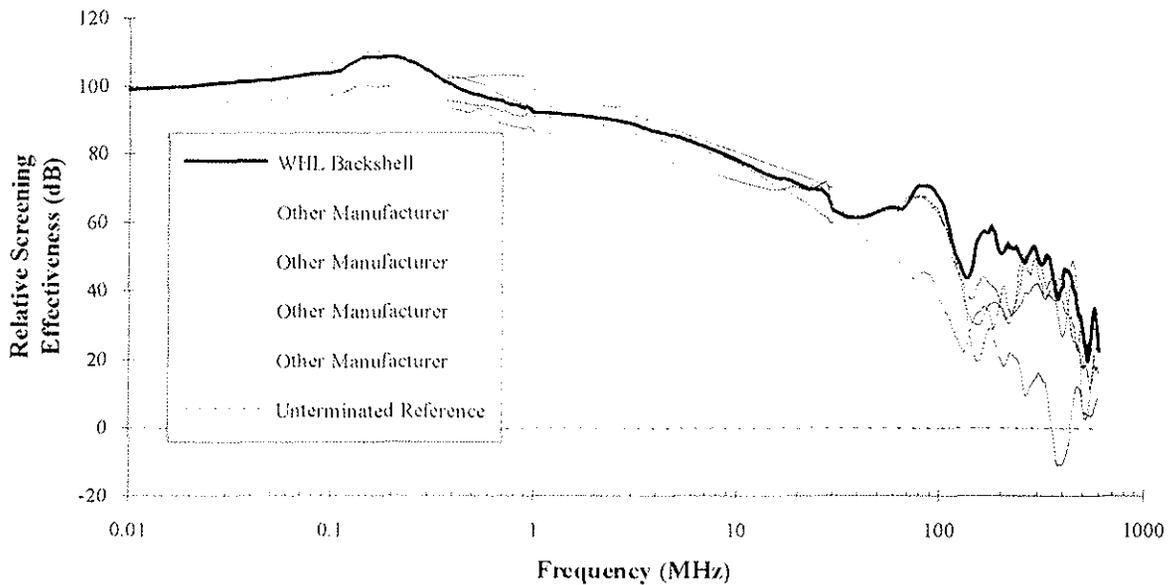


Figure 4

6. Test Techniques

Faced with the new frequency ranges and higher test levels, it became evident that some existing test methods would need to be revised and new ones would be required. The approach to demonstrate clearance was divided into three bands covering the required frequency spectrum. The methods used to test the aircraft systems within these bands are listed in the table below:

Frequency Band	10kHz ↓ 2MHz	2MHz ↓ 400MHz	400MHz ↓ 18GHz
Coupling/Ingress Assessment	EM Modelling & Low Level Direct Drive	Low Level Sweep	Airframe Attenuation
Equipment Testing	Bulk Current Injection	Bulk Current Injection	Radiated Susceptibility
Radio Assessment		On-Boards (Bulk Current Monitoring)	

With the large amount of testing required for the EH101 EMC Clearance, the use of computers to control tests and to allow analysis of data was needed. Therefore, an integrated suite of test control and data acquisition software was developed. In addition, a

database for the data acquired was produced to allow automatic processing of results and overnight data plotting.

6.1. Low Frequency Modelling

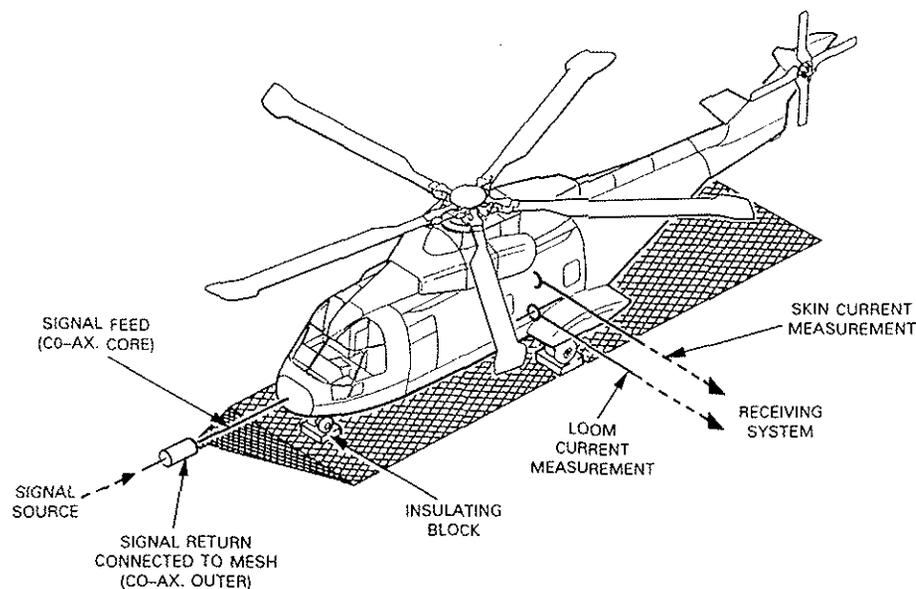
The first part of the low frequency assessment of the EH101 was the calculation of the skin currents that would be induced upon the helicopter in a field of 1V/m. An electromagnetic model of the EH101 was developed using an internal graphic interface WISDOM with data derived from NASTRAN models and aerodynamic models. The model was solved using NEC which utilises a method of moments algorithm. NEC is ideal for solving problems where an external far-field is to be applied to a structure.

Due to the extremely long wavelength (150m at 2MHz), the helicopter can be considered as being electrically small (even minute at 10kHz with a 30km wavelength). With this borne in mind, the model can be relatively crude. The resultant model follows the contours of the airframe, but several assumptions were made:

- The aircraft was considered to be entirely metallic.
- Items such as windows and the undercarriage sponsons were excluded due to their minimal impact on the current flow.
- Various models were used to assess the inclusion of engine firewalls, rotors and the tail section. It was determined that all of these had minimal impact upon the skin currents predicted.

6.2. Low Level Direct Drive (LLDD)

In order to determine the relationship between the skin and loom currents on the aircraft, LLDD is performed on an un-powered aircraft in the hangar. The technique consists of placing the airframe over a wire mesh (with the conductive tyres insulated from the mesh) and connecting the signal feed and return to the airframe and wire mesh respectively.



With a swept-frequency c.w. signal applied to the aircraft, the skin currents and loom currents are measured with the surface- and loom-current probes.

6.3. Low Level Swept Frequency - Current Measurement (LLSF)

LLSF is an established technique used to establish the degree of coupling between the external radio-frequency (r.f.) field and the aircraft looms. The test procedure consists of:

- Irradiating the aircraft over three frequency bands HF, VHF and UHF to cover the frequency range from 2 to 400MHz.
- At each frequency band, using two wave polarisations, vertical and horizontal.
- For each polarisation, the aircraft was illuminated from four orientations, nose, starboard-side, tail and port-side.

The field is generated by feeding an amplified tracking generator output into four antennas in turn. The transmitting antenna is selected by an internally developed and built high-power-handling and low-VSWR switch with the current measurements being relayed to the test equipment by fibre optic link (FOL).

Having irradiated the aircraft over the required frequency band for all orientation/polarisation combinations, the results for each connector are processed to produce a maximum profile. This profile is then used to generate the loom currents required for the BCI testing.

6.4. Bulk Current Injection (BCI)

BCI testing was performed on the systems installed on the aircraft to determine the equipment's susceptibility profile. The test levels used were defined in terms of the loom currents, which were themselves derived from the EM Modelling/LLDD and LLSF results.

For the BCI tests, r.f. energy is coupled directly onto the aircraft loom using an injection probe. Both the forward power into the injection probe and the resultant loom current are measured. At each test frequency, the injection power is slowly brought up from a low level until either the target current is met or the safety levels are exceeded.

When testing complex systems care was taken to cycle the equipment through all available modes of operation during the initial tests. If and when confidence was gained that the operation mode had no effect on the failure level, subsequent tests on the equipment item were only performed on one mode. Additionally, the modulation applied to the signal was altered at points of susceptibility to determine the worst-case modulation frequencies.

6.5. Airframe Attenuation

The first stage of testing above 400MHz involves determining the attenuation of the external electromagnetic environment by the airframe. The aircraft is illuminated from four orthogonal directions and the field strength at various locations on the aircraft is measured. The attenuation factors are then calculated by comparing these field strengths with the free-space calibration measurement.

6.6. Radiated Susceptibility

These tests have not been performed at the time of writing. Radiated susceptibility testing is used to determine the failure level of the aircraft equipment at frequencies above 400MHz. The equipment has been tested for radiated susceptibility as part of the equipment qualification testing. The test levels used for these tests reflected the installation location on the aircraft and the severity of the external environment.

At these frequencies (above 400MHz), the coupling problem is highly localised around the equipment box with cable-conducted interference becoming less significant in favour of radiated interference penetrating the equipment box itself. As a result of this highly local effect, the qualification test results from the laboratory are reasonably representative of the aircraft installation. In addition, the EH101 has been exposed to a high-frequency and

power environment at spot frequencies without showing any system degradation. WHL are confident that the equipment will pass the radiated susceptibility test as a result.

6.7. On-Boards - Bulk Current Monitoring (BCM)

The BCM test provides a method of determining the current levels induced on the aircraft system wiring due to the use of the on-board transmitters, covering the range between 2MHz and 400MHz.

The traditional method involves transmitting on each of the aircraft radios at a series of frequencies across the working range of the radio. The current level on the aircraft looms is measured at each of these frequencies. This method, however, is slow due to

- the relative complexity of the communications system on the EH101 which is not designed for this use and
- the amplifier rest time required after each transmission (approximately double the transmission period) and limits on the transmission duration itself.

For example, on a Lynx helicopter, BCM testing took 4-5 days of testing for approximately 20 connectors. As a result, a new test method was sought to allow rapid testing of the 100+ connectors on the EH101 as the implied test time was unacceptable.

Several problems were encountered during the analysis of the test technique which centred around the use of tuned antennae on the aircraft. It was necessary to develop two methods for circumventing these:

- Where the antenna tuning unit is integral with the radio amplifier, an independent automatic tuning unit is introduced.
- If the antenna tuning unit is separate from the amplifier, the aircraft a.t.u. is directly controlled by the test control computer.

Using these methods permitted the careful use of an EMC amplifier to power the antenna which, in turn, converted the technique to a swept-frequency method.

7. Summary

The successful design, development and testing of the EH101 helicopter and its systems has produced an aircraft that meets the electromagnetic requirements of the customers and certification authorities. The EH101 programme has shown that the following are essential components of complex system developments:

- Designing with consideration of EMI from the outset.
- Controlling sub-contractors and insisting on standards being met.
- Qualification tests on equipment to relevant levels.
- Classifying and routing cables.
- Implementing a hard-box policy for equipment.
- Screening cables where necessary and ensuring that the screens are effectively terminated.