Active Noise Reduction, Sea King Trials – The Real Story

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Abstract
The UK MoD sponsored a development programme to investigate the use of Active Noise Reduction in Military Aircraft. QinetiQ, Helmet Integrated Systems Limited and Acoustics Management and Communication Consultants (AMCC) undertook to design, develop, manufacture and test an analogue based Active Noise Reduction System.
Development and manufacturing issues arose which impacted design constraints, but finally yielded a qualified system, which was taken to trial at RNAS Culdrose in the Sea King AEW2.
In terms of introducing ANR into service, a major component of the programme has been the conducting of noise surveys where the aircraft noise environment and aircrew at-ear noise levels were investigated.
The use of ANR presents advantages over the standard flight helmet including the improved detection of speech and non-speech signals, a reduction in fatigue and stress levels and improved speech intelligibility.
Trials have continued in the Sea Kings HC4, HU5 and HAS6 and now the Sea Harrier FA2 and T8.
This paper seeks to discuss the development and manufacturing issues that arose and present findings of the trials conducted and review the effectiveness of ANR 'in-service.

Introduction
QinetiQ were tasked with providing technical advice and support regarding the use of ANR systems in the Sea King AEW2 noise environment.
QinetiQ sought partners in completing this task. AMCC were employed as consultants with a remit to undertake the electro-acoustic design and development. HISL were to support the development and manufacturing phase with QinetiQ operating the management and test brief.
As part of this tasking, a number of laboratory assessments and flight trials were conducted culminating in a survey of the production ANR system currently being flown by 849NAS at RNAS Culdrose.
The production ANR system was introduced to the first squadron aircrew during July 1999 with the noise survey being conducted during April 2000, the delay allowing the aircrew to build up a familiarity with the system.
The pre-production versions of the ANR system have been tested across a number of aircraft over many years. A production version is now available as a Commercial-Off-The-Shelf item.
The UK MoD currently operate two models of aircrew helmet in its rotary wing fleet the Mk4A4 and Mk4B4L, see figure 1. Critical to the introduction of an ANR system

into service was an assessment of these two products. There should be no changes to the base helmet qualification and any attendant fitting procedures. This was to include a review of the helmet size range as it was considered unacceptable for the ANR system to have an effect on the current helmet sizing.

Figure 1 Mk4A4 & Mk4B4L

In terms of introducing ANR into service, a major component of the programme has been the conducting of noise surveys where the aircraft noise environment and aircrew at-ear noise levels have been investigated. These surveys were conducted both with and without ANR systems to enable an assessment of the performance, and related benefits, provided by ANR. For, as well as a reduction in hearing damage risk, the use of ANR presents other advantages over the standard flight helmet. These can include the improved detection of speech and non-speech signals, a reduction in fatigue and stress levels, improved speech intelligibility. During these early surveys, various models of demonstrator and pre-production ANR systems were flown, powered by battery boxes, and the findings led to the limited introduction into service of ANR with the Sea King AEW fleet.

The most recent survey, conducted during 2000, involved the production ANR system powered directly from the aircraft. This noise survey was conducted to determine whether use of the production ANR system in operational service leads to the benefits predicted during previous flight trials. For this reason the survey was conducted approximately 4 months after all of the squadron had been equipped with the system in order that experience of operation be accumulated. In fact a number of the squadron had been flying with ANR for almost a year.

2. The Active Noise Reduction system

2.1 Operation

The principle of ANR, in brief, is that noise at the ear is monitored using a miniature microphone, the signal is then inverted and fed back in anti-phase producing destructive interference and hence noise cancellation. Figure 2 shows the system comprising a negative feedback loop, incorporating an acoustic path between the telephone and microphone. The incoming speech signal is pre-amplified to compensate for the operation of the noise reduction system and the electronic circuits have been miniaturised to fit into a helmet earshell.

The ANR system monitored during the survey was the production standard system currently in service with the Sea King AEW fleet. The downlead is split into a standard ‘mic/tel’ lead (with UK NATO jack) and the ANR power lead. Power for the system is obtained direct from the 28V aircraft supply.

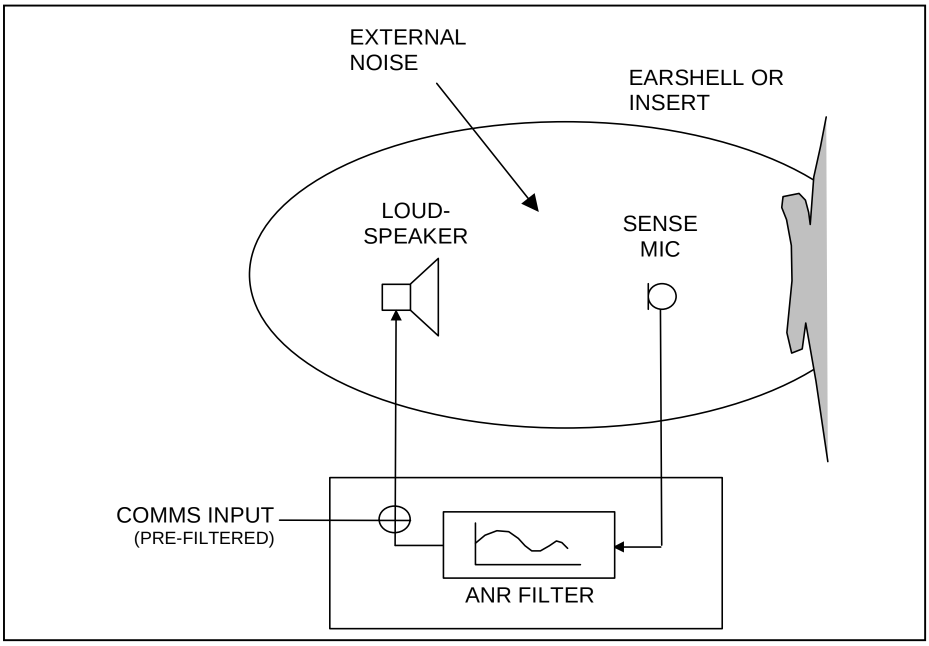


Figure 2 ANR Block Diagram

2.2 Prototype, Development and Pre-Production Phases

Given the remit on helmet selection, the standard ear capsule used in the Mk 4 series aircrew helmet was selected as the baseline for the ANR development program. HISL were tasked with prototyping hardware to retain the ANR circuitry. Using a 3D Cad package, suitable mouldings were designed and fabricated to allow initial bench assessments of the ANR performance. Prototype electronic systems were 'bread-boarded' and tested at the QinetiQ laboratories, see figure 3.

Figure 3 ANR Hardware

The MoD project office undertook to modify the trials aircraft to supply a 28 volt d.c. power supply. It was decided to keep the current UK communications interface plug. A second plug was fitted to provide the d.c. power. This resulted in a twin plug downlead for the helmet and a corresponding aircraft modification.

A bench power supply was later provided due to initial fitting problems associated with the ANR headset. One unsatisfactory feature of ANR systems is their predisposition to oscillate if a correct seal is not maintained between the headset and the wearer. The Mk 4 series helmets utilise a toggle arrangement which provides the lateral clamping force of the headset to the wearers head.

When fitting an ANR system this was initially done with the ANR deactivated. Once the ANR system was activated in the aircraft a number of helmets required refitting due to oscillation of the ANR.

The bench power supply was employed as a change to the fitting sequence to allow the ANR to be energised. Hence the headset sealing adjustment was optimised before reaching the aircraft. It also was used to confirm ANR operation in the ready room prior to flight.

3.0 Qualification Test Program

As part of the flight clearance program an environmental and EMC test program was conducted.
EMC testing to MIL-STD-461/462D, RCTA/DO-160D/EUROCAE ED14/D and DEF Stan 59-41Pt3 Supplements Issue 5 was undertaken. Failures during this round of testing resulted in AMCC designing modifications to the electronics and a subsequent retest program. In addition the original design of helmet downlead was rejected. This comprised two separate leads terminating in two jack connectors, one as the communications interface and the second for power. A custom lead, which had a single downlead and splits into the two jack connectors, was adopted. Certification was obtained on the retest and production units released for flight.

3.1 Flight Trial Issues

During the flight trial program two users reported a problem with irritation of the pinna. A review was conducted of the materials selected for the interior of the headset and in particular the facing cloth. Although this did not show any dermatological problems it was found that inclusion of the electronics and associated padding in the ear capsule increased the pressure on the pinna compared to a standard earcapsule. The two users in question were sensitive to this increase in pressure. No further investigations into these effects were possible at the time and the users appeared to become accustomed to the increased pressure.

4. Production ANR noise survey

4.1 Noise measurement

To assess the effect on noise levels at the ear when using ANR, noise dosemeter measurements and noise recordings were conducted. In order to provide a statistically large sample, data was collected on all sorties flown during the trial week. All standard crew positions were monitored and the data used to determine the individual aircrew hearing damage risk.

4.2 Questionnaires

To obtain subjective data on the performance of the system, questionnaires were issued to the aircrew subjects. These helped to identify the man machine integration aspects of using ANR - information that cannot be obtained from the noise measurements. The questionnaires were issued in sufficient time for completion and returned to the trials team by the end of the trial week.

5. Noise Measurement

5.1 Recording equipment

To measure noise dose two miniature microphones were used, one positioned on the inside of the earshell to monitor noise at the ear and one placed on the epaulette of the flying coverall to monitor cockpit/cabin noise. The signals from the microphones were A-weighted, to compensate for the filtering performed by the human ear, before being logged in the dosemeter.
A noise recording system was also used for measuring both noise levels at the ear and cockpit/cabin noise. A microphone was positioned inside the earshell of the helmet. The output from the microphone was fed via the microphone input of a control box to a digital recorder. A remote control switch mounted on the control box enabled the

recording to be started at the correct time. Recordings of cockpit/cabin noise were obtained at the same time by using a second miniature microphone taped externally on the helmet.

5.2 Analysis

5.2.1 Noise dosemeters

On completion of the sortie a software programme performed statistical analysis on the data to produce values for the L_{Aeq} , the A-weighted Equivalent Continuous Sound Level. The L_{Aeq} is the sound level which if maintained for the same duration as the fluctuating sound in question, would cause the same acoustic energy to be received by the listener.

5.2.2 Noise recordings at the ear

All recordings were downloaded into dosemeters to enable the calculation of L_{Aeq} 's and the display of time pressure histories, allowing compatibility with the noise dosemeter results. Relevant portions of the recording were also analysed using 1/3 octave or narrowband analysis to help characterise the noise environment in terms of sound pressure level and frequency content.

5.2.3 Cockpit/cabin noise

As for the noise at ear recordings relevant portions of the cockpit/cabin noise recording were also analysed using 1/3 octave or narrowband analysis to help characterise the noise environment in terms of sound pressure level and frequency content.

6. Results

6.1 Noise levels at the ear

A typical time pressure history, obtained from dosemeter measurements, is shown in Figure 4. Both the cabin noise (upper trace) and noise at ear (lower trace) have been superimposed onto the same axes showing how noise levels vary throughout the sortie.

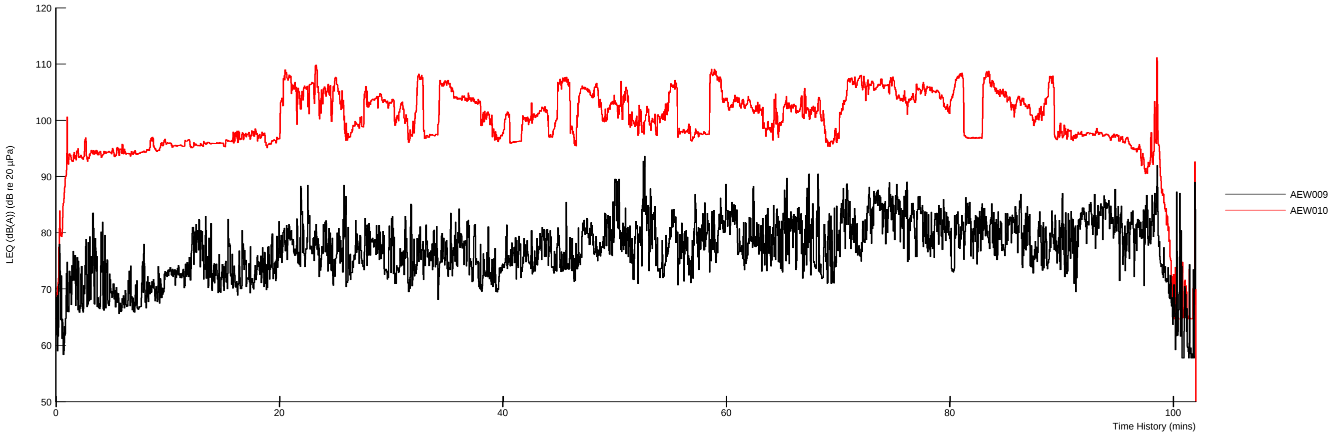


Figure 4 Typical Time Pressure History

For each crew position the mean L_{Aeq} (and associated standard deviation) was calculated and compared to data obtained during the previous noise survey of Sea King AEW2 aircrew conducted with the standard (non-ANR) helmet. The reduction in noise levels at the ear, by using ANR, was found to be of the order of 8dB(A) for aircrew in the cockpit and 10dB(A) for aircrew in the cabin.
To determine whether they are statistically significant, two-tailed Students t-tests were conducted on the data with the results shown in figure 5

Location	5% significance level	t value obtained	Significant difference?
Pilot	2.1	5.4	Yes
Observer	2.0	5.6	Yes

Figure 5 Two Tailed Students t-Test

From the t-test results it can be seen that the difference in means is significant; based on the data collected, the use of ANR does significantly lower the noise levels at the ear.

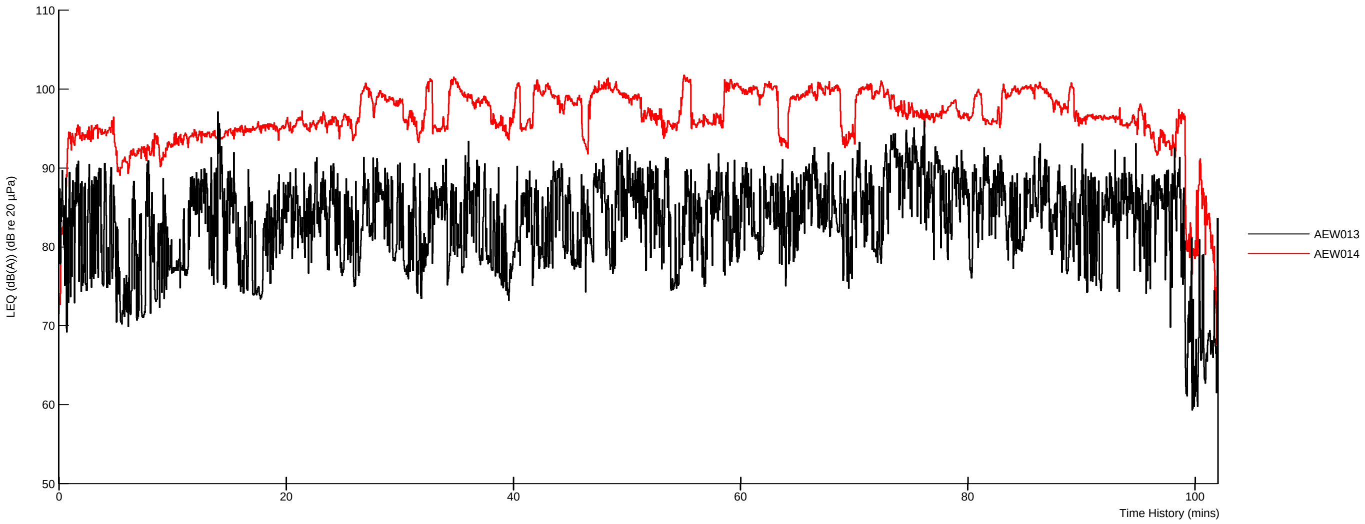
6.2 Helmet attenuation

By using the time pressure histories, a measure of the attenuation provided by each helmet can be calculated. The cockpit/cabin noise trace is reduced until it is aligned with the bottom of the trace for noise at ear. This is because, without communications, the noise at ear is driven by the attenuated cockpit noise. Hence, the amount of reduction is a measure of the attenuation provided by the helmet. Figure 6 provides the overall mean attenuation figure for each helmet.

Overall Mean Attenuation (Standard Deviation) dB(A)	
Standard helmet	**ANR helmet**
19 (3.6)	28 (3.0)

Figure 6 Overall Noise Attenuation Comparison

Figure 7 shows this difference graphically; the upper graph being a standard helmet and the lower graph an ANR helmet. The difference between the upper and lower traces in each graph giving an indication of the helmet attenuation.



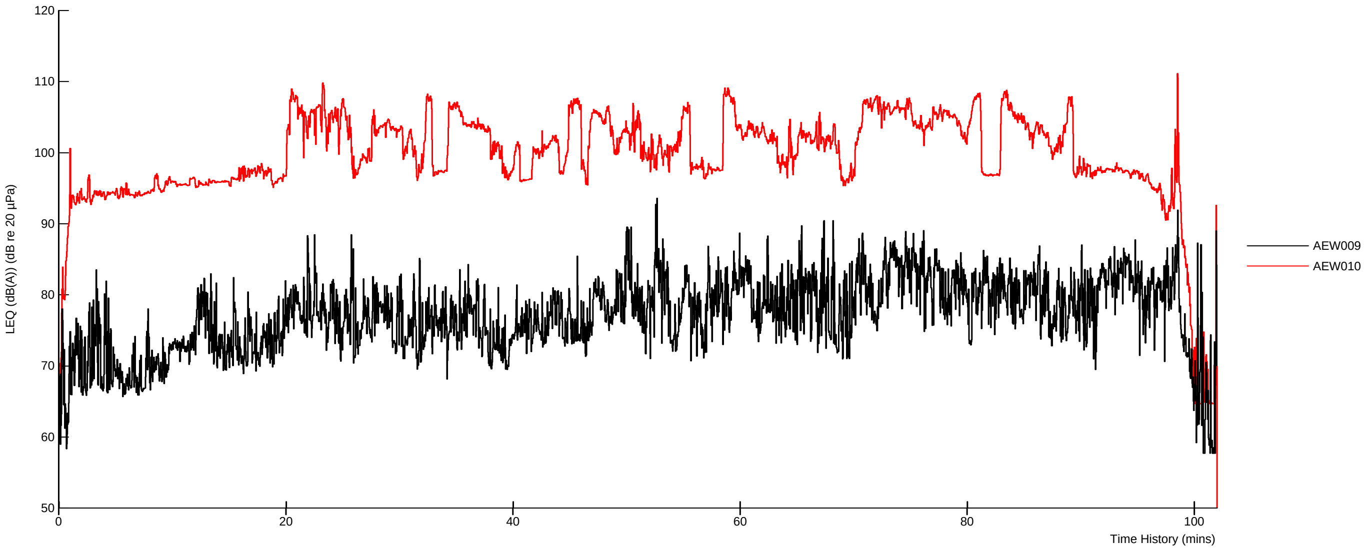


Figure 7 Time Pressure Histories Indicating Helmet Attenuation

6.3 Aircrew questionnaires and subject debriefing

The aircrew subjects (10 pilots, 6 observers) had flown with the ANR system for between 20 and 100 hours, with the system on for at least 95% of the time. The Ground-Engineer had flown with the system for 4 hours. Below is a summary of the main responses.

1)	Does ANR reduce noise at the ear?	100%	Yes
2)	What is the degree of reduction?	90%	High
		10%	Medium
		0%	Low
3)	Were cockpit/cabin noise levels fatiguing with previous (non-ANR) helmet?	67%	Yes
		33%	No
4)	If yes does ANR reduce fatigue?	100%	Yes
5)	Were cockpit/cabin noise levels stressful with previous (non-ANR) helmet?	67%	Yes
		33%	No
6)	If yes does ANR reduce stress levels?	83%	Yes
		17%	No
7)	Is the ANR system acceptable for an operational Environment?	90%	Acceptable
		10%	Undecided
		0%	Unacceptable

Specific points raised within the questionnaires and during post-flight debriefing are detailed below along with general comments. Where relevant, italicised authors comments follow. Many of these have been expanded on within section 7.

(i) Use of the ANR helmet with ANR disconnected is perceived as undesirable with attenuation provided being lower than that for a standard Mk4 series flight helmet. *[Helmet attenuation is slightly poorer with the ANR system disconnected. However this is seen as an emergency mode of operation as all sorties are to be conducted with ANR on]*.

(ii) "ANR has changed all of the noise cues. This appears to have good and bad points but in reality it is just a change of mindset. You hear as much with ANR in terms of essential noise cues".

(iii) "Twice, excessive head movement caused high pitched squeal". *[There were a number of comments related to this. It is a fitting issue and has, since the end of the survey, been identified as a problem with the foam insert within the earshell. A slightly deeper foam has now been issued which should cure the problem]*.

(iv) The failure of the systems whilst operating away from SE support was identified as a possible problem.

(v) “Great systems”.

(vi) “Initially ANR takes some getting used to. Lots of otherwise masked audio cues now heard”.

(vii) “In one a/c when flight idle stops / fuel crossfeed valve, are selected there is electrical interference on the pilots system”.

(viii) “ANR fitted casual flight helmets will need to be available (at air stations and on carriers) in order to prevent people flying in an ANR a/c with a non-ANR helmet”. *[The ‘sharing’ of comms boxes is acceptable provided both crew have ANR. If one crew member does not have ANR then problems will occur due to a mis-match in radio and i/c volumes; the crew member with ANR will, in general, have the volumes set too low for a crew member without ANR]*.

(ix) “The earpieces tend to click on and off until flight is stabilised past launch”. *[It is thought this is a problem with that one particular ANR system as no similar comments were noted]*.

(x) “Due to aircrew *being* used to ANR, any crew member with ANR off notices reduced volume of aircrew i/c”. *[As in (viii) above]*.

(xi) “Despite teething problems the overall improvement in health and safety outweighs the slight disadvantages highlighted herein”.

(xii) “Without a doubt the reduction in stress and fatigue commensurate with ANR will undoubtedly increase crew performance and positively affect the outcome of operational and non-operational effectiveness and improve flight safety”.

(xiii) “When using an intercom position without volume control speech is a little too loud for prolonged use. (Pilot instructor connection)”. *[This is a particular problem for any ground engineers who are asked to fly and connect to a radio box with fixed gain volume. The reduction in environmental noise at the ear leads to a need to reduce the radio and i/c level]*.

7. Discussion and Conclusions

The primary requirement in introducing ANR to Sea King AEW2 aircrew was to lower the noise levels at the ear, thereby reducing the aircrew hearing damage risk. Hence, the bulk of the work conducted during the programme has concentrated on direct measurement of noise at ear levels and it is these that will be discussed in detail now. However, the other benefits of ANR - improved detection of speech and non-speech signals, a reduction in fatigue and stress levels, improved speech intelligibility.

The acoustic measurements obtained during the production ANR survey do show a statistically significant reduction in mean noise levels at the ear for all aircrew. For pilots the reduction is 8.3dB(A) whilst the corresponding reduction for the observers is 9.7dB(A). Reductions of this order were, on the basis of laboratory assessments, predicted for ANR but until now they have never been realised during flight trials. The reason for this is quite simply that a reduction in the environmental noise reaching the ear should lead to the aircrew being able to reduce the output levels of their radios by a comparable amount. However, setting the volume knob to a lower position than ‘normal’ requires a conscious effort on the part of the aircrew. This effort is part of a ‘learning curve’ associated with ANR that requires the aircrew gaining confidence in using the system. Earlier ANR surveys, such as the one conducted during 1996, involved a small number of subjects flying with the system for a limited number of sorties. Although those aircrew subjects did appreciate that ANR reduced noise levels at the ear, they did not fly with the system over a sufficiently long period of time to fully appreciate the levels they could reduce their radios by. So, although reductions of 3.6dB(A) and 6.6dB(A) were measured, for the pilots and observers respectively, it has to be noted that quick ‘look-see’ surveys of ANR do not give a full indication of the effectiveness of ANR systems in reducing noise at ear. It is only when aircrew have flown with the system over a long period of time and have gained confidence with it’s use, as was the case during this latest survey, that the true reduction becomes apparent.

A related problem is that of aircrew sharing communications boxes. If both are wearing ANR helmets then no real compatibility problems should be encountered as the helmets will have the same ‘baseline’ noise attenuation. However, if one aircrew subject wears an ANR helmet and another is wearing a standard helmet then the sharing of a communications box should be avoided. Depending on whoever ‘controls’ the volume level, the one with ANR will find the levels too high or the one with the standard helmet will find them too low. This is due to the difference in baseline attenuation and the following guidelines should be followed.

Flight helmets worn	Share communications box?
Both ANR	Yes
Both standard	Yes
One ANR and one standard	No

The overall measured attenuation provided by the ANR helmet, in Sea King noise, was 28dB(A) as compared to 19dB(A) for the standard helmet. This shows how effective the ANR helmet is in reducing noise levels with the benefit being seen in the frequencies up to 1.25kHz. Interestingly, the mean reduction in noise levels at the ear was around 9dB(A), further showing that the aircrew had reduced their communications levels by a comparable amount to the actual reduction in environmental (cockpit and cabin) noise.

Questionnaires completed during the course of the survey and verbal de-briefing of the aircrew do indicate that the benefits of ANR identified during previous surveys are present during operational use. Direct questions show that two-thirds of aircrew find noise levels with the standard helmet fatiguing and stressful and that, out of these, all found ANR helped reduced fatigue levels and 83% found that ANR helped reduce stress levels. Comments were also obtained highlighting the fact that communications levels could be reduced and that lots of otherwise masked audio cues could now be heard. This in fact was disconcerting to begin with as the use of ANR creates a ‘modified’ noise environment whereby instead of reducing all frequencies linearly it reduces the frequencies below 1kHz in a non-linear manner. This is all part of the learning curve with the important point being that not only are all expected noise cues still present but now additional ones can be heard. Also, the reduction in communication levels enables the achievement of a ‘better listening environment’ which helps with the clarity and detection of incoming radio calls.

With the ANR systems being operated during the survey a number of fitting issues became apparent with comments reflected in the questionnaires. A small number of aircrew found that the system ‘squealed’ whenever they turned their heads and that although this could, in most cases, be cured by a re-fit of the helmet some did have lingering problems. These problems were investigated during and after the survey and it was determined that the foam insert within the earshell was not of sufficient depth to enable a good fit. Increasing the depth of the foam should solve this problem.

In conclusion, the surveys conducted on the Sea King AEW fleet have identified the noise problem inherent within Sea King AEW2 operations and fully investigated the use of ANR as a solution. With ANR fitted flight helmets the following benefits have been obtained:

(i) The noise levels at the ear have been significantly reduced with a corresponding reduction in aircrew hearing damage risk.
(ii) The listening environment has been improved with better clarity and detection of incoming radio calls.
(iii) A reduction in fatigue and stress levels for most aircrew.

The success of this programme should act as an example to the users of other marks of Sea King, and military aircraft in general, that ANR does work in service and that significant benefits are to be obtained.

Acknowledgements

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Mark joined the Aircrew Protection section of the Royal Aircraft Establishment (now QinetiQ) in 1986 working on specialist aircrew clothing and facilities, aircrew helmets and helmet mounted devices. His work at this time involved a number of field and aircraft trials and these have formed a large part of his work since. In 1991 he moved into the Acoustics and Vibration section where he has been involved in many aspects of the teams work including research into hearing protection (both passive and active), audio warnings, spatial localisation and communications.

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Simon joined Helmets Ltd in 1979 and during this time has specialised in the design and development aspects of protective headwear. He has been responsible for a number of significant development programmes including the F22 helmet system and now the JSF Helmet Mounted Display System. His involvement in Active Noise Reduction system started in 1982.