AUDITORY WARNINGS FOR THE BRITISH RAIL INDUCTIVE LOOP WARNING SYSTEM

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INTRODUCTION

A set of warning sounds has been produced for the Inductive Loop Warning System (ILWS) being developed by British Rail to give advanced warning of approaching trains to track maintenance workers. The manually operated warning system currently employed by BR (referred to as the PeeWee) was reviewed with regard to the guidelines for auditory warning sounds suggested by Patterson [1]. The spectral characteristics were found to be broadly suitable.

The ILWS uses a total of four warning sounds. In order of urgency they are Alarm, Reminder Warning, Qualified Safetone and Safetone. Four new sounds were produced from the original PeeWee sound to preserve the general association between sound and function. This paper reports the stages by which the warning sounds have been designed, the assessment of the PeeWee and its modification.

ANALYSIS OF EXISTING WARNING SOUNDS

Terminology: When describing auditory warnings we use the following three terms:

1. Pulse: An acoustic waveform that carries the distinctive warning sound quality. It is the basic building block of a warning sound and is usually between 100 and 500 ms in duration.
2. Burst: A set of pulses with a distinctive melody and rhythm (between 1 and 3 sec in duration).
3. Warning Sound: A sequence of bursts that indicate a specific warning state.

The Existing Warning Device: The PeeWee sounder emits half-second pulses of a complex wave, and the pitch of the pulses sweeps upwards in frequency from approximately 500 to 1000 Hz. The device has two states -- Alarm and Safetone. The former is signalled by a continuous sequence of half-second pulses, the latter by individual pulses separated by 2-second gaps. The Alarm and Safetone are in regular use and are familiar to track maintenance workers.

The new ILWS will have four states with the addition of a Reminder Warning and Qualified Safetone. British Rail Research (BRR) produced experimental Reminder Warnings and Qualified Safetones to demonstrate the feasibility of adding two extra sounds. These experimental sounds were evaluated alongside the standard sounds, though they have not been used on the railway network and have not been heard by track maintenance gangs. Thus the four existing warnings, in order of urgency are:

Alarm (A): a stream of continuous pulses (Standard PeeWee).

Reminder Warning (RW): repeated bursts of a double and single pulses (Experimental).

Qualified Safetone (QST): repeated bursts of a 3-level pulse cycle (Experimental).

Safetone (ST): a single pulse repeated with 2-sec gaps (Standard PeeWee).

The existing signals were assessed against the requirements of each of these three versions. BRR provided the APU with a PeeWee sounder and a cassette tape recording of a different PeeWee. Specimen warning sounds were generated from both of the above sources.

Overall Sound Levels

The level that the current PeeWee device operates at, when continuously sounding, is approximately 100 dB at a distance of 2 metres from the unit [2]. The level of the experimental Reminder Warning is about 6 dB lower than the Alarm. The Qualified Safetone operates at three different levels. The levels cycle between 0, 6 and 12 dB lower than the Alarm. A level of 100 dB at 2 metres is not only aversive but also potentially damaging if the listener is subjected to prolonged periods of exposure to the sound. Any personnel monitoring the device will, by design of the current system, be exposed for long periods to the PeeWee sounder. Consequently, the new system (as detailed below) reduces the level whenever possible, taking note of the recommended levels. These recommended levels are based upon analyses of the background noise environment [3] and upon Patterson's guidelines [1] for warning sound levels. The fixed, Alarm, level from the PeeWee loudspeaker is from 10 to 35 dB higher than the recommended levels which vary depending on the local background noise.

The level of the experimental Reminder Warning was 6 dB below the level of the Alarm. Also the experimental Qualified Safetone was distinguished from the Safetone in that the level of the former varied while the level of the latter was constant from pulse to pulse. In the construction of warning sounds, it is not advisable to use level as the sole means of distinguishing two warning sounds. When the demands on operator attention are high, changes in level as large as 12 dB may go unnoticed and so level differences should not be used as the sole means of distinguishing warning sounds. Variations in level within a group of pulses can be used as a means of reinforcing distinctiveness where variations in other parameters exist, e.g. spectrum, rhythm, and pitch, but they should not be used as the sole distinction between states.

Temporal Characteristics

For the Alarm sound, the repetition rate of the PeeWee is 2 Hz. The individual pulses have a duration of approximately 500 ms. They have very abrupt, almost instantaneous, onsets but slower offsets of some 50 ms. The Alarm consists of a stream of continuous pulses. There is a disadvantage with continuous warnings in that they inhibit inter-personal communication. Even if there are relatively few occasions when trackside crew need to communicate with each other, the option to do so should still be available. The need to communicate is likely to be the highest when the Alarm is sounding and there is no need for a continuous warning sound. It only makes the warning more aversive.

Equivalent continuous sound level, Leq, is the notional steady A-weighted level that would produce the same A-weighted sound energy over a stated amount of time as the real time-varying sound. Thus the Leq for a given work period will be higher for continuous sounds than for intermittent sounds. So to minimise Leq, one should reduce the total duration of warning sounds, and the sound pulses within the warning wherever possible. Since a reduction of 20% in the duration of a signal reduces the Leq of a signal by only 1 dB and a halving in the duration is necessary to reduce its Leq by 3 dB there is often little to be gained, especially since background noise also contributes to the ambient Leq. However, these reductions in duration will have the advantage of reducing the annoyance caused by the warnings and may give worthwhile extensions to the battery life of portable equipment.

The Reminder Warning has two pulses in immediate succession with a combined duration of 960 ms. After a delay of 500 ms, a single 500 ms pulse is then played. After a further delay of 980 ms, the whole cycle is repeated. The duration of the complete burst, in this case the cycle time of the warning, is 2.94 seconds. The intermittent nature of the Reminder Warning (a double pulse followed by a single pulse) makes it distinctive, and its intermittency permits a brief verbal command between bursts. The lightly syncopated rhythm helps to distinguish it from other competing warnings that might occasionally be found in the working environment, and so broadly speaking, it has a good temporal pattern.

The Qualified Safetone is a variant of the standard PeeWee Safetone. It consists of individual pulses played at the same rate as the those of the Safetone, but differentiated by level; pulses are presented in groups of three in which the second is some 6 dB lower, and the third, 12 to 13 dB lower than the first. This cycle is repeated on a continuous basis, and the total cycle time of this warning is 7.8 seconds. Although the Safetone and Qualified Safetone are temporally distinct from the Alarm and the Reminder Warning, they have the same temporal pattern, and are distinguished solely by differences in sound pressure level. A distracted operator might well miss the change from one state to another. The cycle time is also rather long in that up to 8 seconds is needed to distinguish these two warnings if level information is overlooked. The Safetone consists of single 500 ms pulses with 2.1 seconds silence between each, making a cycle time of 2.6 seconds.

Summary: The duration of the pulses in all of the proposed warnings is longer than necessary. A listener only requires a pulse in the region of 100 ms to perceive the sound quality, and the longer the pulse the lower the level of urgency that can be conveyed by pulse rate. The onsets of the pulses are too abrupt especially for non-urgent warnings; the offsets acceptably slow (around 50 ms). A pulse with a slower onset would be less aversive and less likely to evoke a startle reaction.

Assessment of Spectral Characteristics

The PeeWee emits waves that sweep up in frequency from around 500 to 1000 Hz. Figure 1 shows the spectrum of the APU PeeWee at the start of the sweep when the frequency is low. It can be seen that the sound is broadband and complex, with a concentration of energy in the 400 to 4000 Hz region. Although BRR describe the PeeWee as emitting square waves, it was found on analysis that the waves are far from square. The spectrum of a true square wave contains odd harmonics only. The spectra of samples taken at the start and end of the pulse showed as much energy at the even harmonics at the odd harmonics. The high frequency wave sweeps upwards in frequency from 540 to 1140 Hz, which is slightly more that one octave. The low frequency wave is approximately one semitone lower in frequency throughout the sweep.

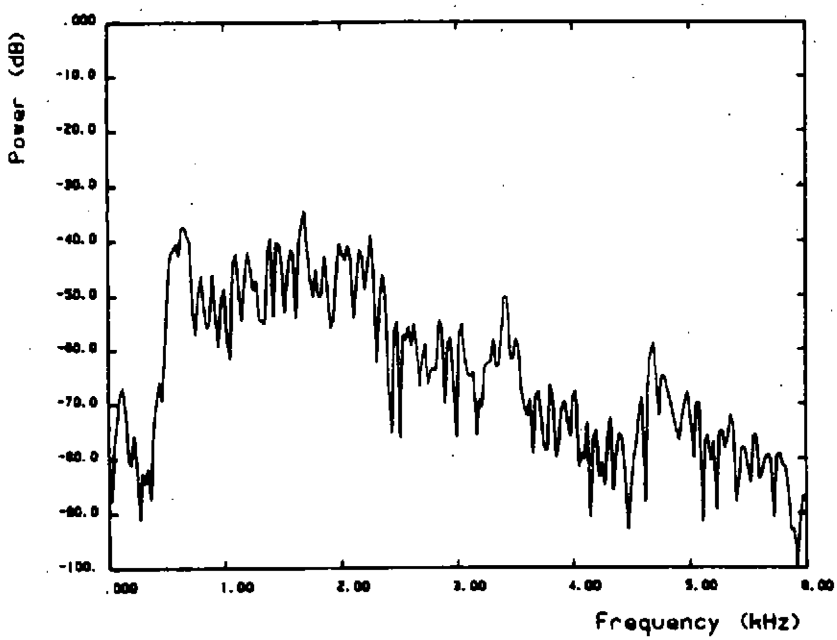

Figure 1. PeeWee Spectrum

In summary, the raucous PeeWee sound is a good attention getter. It has harmonics throughout the spectrum and this, together with the fact that it has a wide frequency sweep, renders it resistant to masking by all but the very loudest, steady-state noises. The discordant nature of the sound is appropriate for a warning which is used to signal danger. A warning used outdoors should be distinct from other warning sounds likely to be encountered. While the PeeWee is reasonably distinct from many other warning sounds such as train horns, car horns, fire bells, and fire sirens, it does bear some similarity to certain ambulance sirens which also employ rising frequency sweeps. The main disadvantages of using the existing sounds in a new system are that a single acoustic building block, the half-second, upward gliding double wave, is used in the construction of all four warnings, and the same pulse is used to signal both danger and safety. Only timing and sound pressure level are used to distinguish the different members of the existing warning set. Modifications to overcome these disadvantages are described in the next section.

MODIFICATION OF THE EXISTING WARNING SOUNDS AND DESIGN OF NEW SOUNDS

The warning set that was ultimately agreed by APU and BRR for the ILWS was developed through a process of refinement over a period of several months. Broadly speaking, APU would generate sets of prototype (or demonstration) sounds and send them to BRR on tape. BRR would then assess the sounds and obtain reactions and comments from a range of BRR personnel. Subsequently, BRR and APU would meet and modify the preferred prototypes. Eventually this iterative process converged on the final set of four warning sounds shown in Figure 3, and approved by the ILWS Project Team. The following subsections present a brief review of that refinement process.

The First Prototype Warning Set

The first set of prototype warnings were primarily intended to demonstrate the variety of sounds that could be generated from the original PeeWee sound, and the distinctive temporal patterns that APU were likely to recommend for the warnings in the ASAD system. The desire of BRR to reduce Leq as much as possible for reasons of safety was taken into account in all of warning sets produced. Each warning sound was designed with the reduction of pulse and burst duration in mind.

The tape consisted of 12 warning sounds (three examples of each of the four states: A, RW, QST and ST). The bursts of pulses that identify the individual warnings are summarised schematically in Figure 2; the abscissa is time, the ordinate is pitch, and with a little practice, the schematics can be read like music. The Qualified Safetone and the Safetone were always built on the single 'square' wave in order to keep the perceived urgency of these warnings down to the appropriate level.

BRR then provided comments and suggestions on these initial prototype warnings. We began the refinement process by assembling a new warning set composed of the Alarm, Reminder, Qualified Safetone and Safetone that obtained the most favourable reaction. The preferred warnings were A1, RW1, QST3 and ST1. Then we used the comments from BRR personnel to improve the warnings. To establish if the warnings were distinguishable in a tunnel working environment BRR had tested each warning in reverberant conditions. This constraint alone resulted in the redesign of some of the warning sounds described below. With regard to Alarms, version A1 was preferred; both A2 and A3 were thought to let the listener down at the end. This was interpreted to mean that they were not sufficiently urgent. For the Reminder Warnings, RW1 was preferred over RW2 and RW3. It was, however, perceived to be too urgent despite the downward pitch contour. Although,

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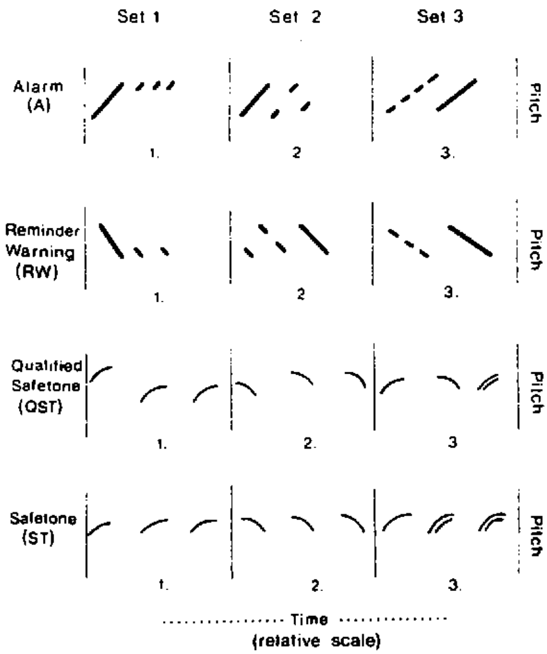

Figure 2. Prototype Auditory Warnings

the Reminder Warning is very important, it was felt that it should be distinguishable from the Alarm in terms of its perceived urgency. With regard to the Qualified Safetone, QST3 was preferred. QST1 was considered to be too close in character to the preferred Safetone (ST1). QST2 was not favoured because the falling pitch contour was not sufficient to distinguish it from ST1, the preferred Safetone. This left QST3 proved to be a good partner for ST1 in reverberant conditions. (The distinction between QST3 and its corresponding Safetone, ST3, had disappeared when BRR had tested them under such conditions). Finally, the Safetone, ST1, was universally preferred. This was almost identical to the original Safetone but with its pulse duration substantially reduced (from 500 to 330 ms).

Warnings A1, RW1, QST3 and ST1 were then modified to produce the second set of prototype warnings. The Alarm was increased in urgency by shortening the silent gaps between the last three pulses; this had the additional effect of making the sound more syncopated and thus more distinctive. The Reminder Warning retained its general downward pitch movement, but an additional short pulse was added at the beginning of the burst to make it more distinct and less urgent then the Alarm. The Qualified Safetone, QST3, had its final "double square-wave" pulse removed from the burst. The Safetone, ST1, was left unchanged for the second prototype set.

The Final and Recommended Set of Auditory Warning Sounds

The second set was presented by the ILWS project team to representatives of all BR regions. Reactions gained from this, plus further comments from BRR who once again tested the sounds in reverberant conditions were used to produce this final set of warning sounds at APU. These are schematically illustrated in Figure 3. The Safetone was considered to be adequate and went forward unmodified. The Qualified Safetone had its second pulse moved (in time) away from the first pulse. In reverberant conditions reproduced by BRR there had been a merging of the first two pulses in a burst of four pulses. The Alarm was felt by BRR to be (initially) insufficiently urgent. The second prototype Alarm, which employed a cycle of three bursts of successively increasing pitch, was reduced to a cycle of two bursts. The remaining bursts still differed in pitch, however, but were perceived by all to be more urgent.

Finally, the Reminder Warning was thought to be too complex in its second version and possibly too close to the Alarm in temporal structure. The direction of the burst was changed so that the general pitch movement was downward. The long downward sweep of the second pulse was further segmented to add further syncopation and distinctiveness. The final two pulses were repeated and tagged on to the end of the burst creating a slight

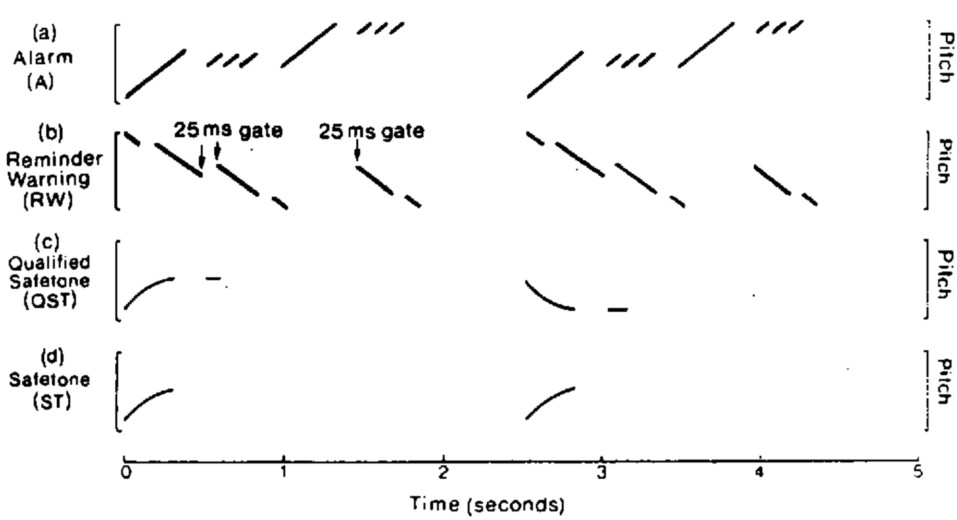

Figure 3. Recommended Warning Set

echo effect. All the warnings in the final recommended set have repetition rates of 2.5 seconds.

DISCRIMINABILITY TRIALS OF THE WARNING SOUNDS

It is important that trackside workers are able to learn the warning sounds and recognise any member of the set without hesitation. Since the recommended set of warning sounds all have similar or identical spectra a confusion test was performed in order to assess the warnings for discriminability. Ten BR trackside maintenance staff from the Cambridge area took part. The experiment was structured as a self-paced learning programme comprising two test sessions spaced one week apart. Subjects were required to identify the four warning sounds after a preliminary learning presentation. All the sounds were presented at the same relative levels as in the final demonstration tape, the Alarm being measured at approximately 86 dB SPL through the headset.

With only four sounds to learn subjects quickly attained perfect performance on a single trial. In order to establish that correct identification on one trial was not a chance occurrence three consecutive perfect trials had to be completed before the learning session was terminated. Audiometry was performed on subjects between learning sessions. This achieved the dual purpose of testing the acuity of each subject's hearing, and providing a suitable gap between learning sessions so that retention could also be tested. Confusion analyses were performed on three learning and two retention trials. The analysis is extremely sensitive but only revealed one confusion with a probability of occurrence of less than 5%. This happened on the second learning session between the Alarm and Reminder Warning but did not occur in any subsequent session. It is very unlikely that track maintenance personnel would confuse any of these warnings.

The recommended final set of prototype warnings (Figure 3) has been approved by British Rail. They are to be incorporated into a prototype warning device and subsequently tested in field trials.

ACKNOWLEDGEMENTS

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AUDITORY WARNINGS FOR FIXED AND ROTARY WING AIRCRAFT

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One of the important requirements for near future and far future aircraft, both fixed wing and helicopters, is that they should be able to extend their operating envelope by flying not only in more extreme weather conditions (North Sea type operations), but also at night or in poor light conditions. Since the human night vision is poor, this requires the pilot to operate outside of his normal visual envelope and this restricted envelope is enhanced through the use of night vision goggles which intensify the available light and provide the information to the pilot's eyes. Whilst this allows the aircraft to fly at night, it also means that the visual workload is considerably increased and under high workload conditions the distribution of attention is increased on the visual side by the aircrew needing to spend more time looking outside of the cockpit and thus having considerably less time to monitor the instruments and normal flying panels inside the cockpit. In the case of visual warning panels, there is an increased risk of missing a warning signal, which, in high urgency warnings, can have serious, and sometimes catastrophic, consequences. In some helicopter situations aircrew must react within two seconds or so if the aircraft is to be saved. For these reasons, and the progresssively increasing need for aircrew to fly "eyes-out", RAE Farnborough undertook a warning signal programme to provide a more scientific base to the provision of auditory warning signals to allow an additional sensory input to the crew along with the normal visual inputs.

The programme took into account the work already under way at MRC/APU Cambridge on civil auditory warnings, some previous civil research at RAE and the work that had been carried out in the USA. The research was carried out by a team from three establishments; MRC/APU Cambridge under Dr Roy Patterson, ISVR University of Southampton with Dr Mike Lower, and RAE Farnborough under the author; with much of the initial work being carried out by APU, the follow on laboratory and computing work being assessed and refined by ISVR and the applicable solutions being tested in aircraft noise simulators and in-flight trials at RAE Farnborough. In all phases of the work, close cooperation and discussions were kept with aircrew at both Farnborough and A&AEE, Boscombe Down, to provide the necessary user input and to ensure that "laboratory only" solutions were not being promulgated.

The initial approach was to provide an attention getting sound (attenson) followed by a voice message, and to follow the civil approach by having a lengthy sequence of attensons and voice message repeats which took into account the chance of pilots missing the initial auditory messages in the sequence when under high stress or high workload. The testing philosophy was that an attenson, being 'unusual' in a normal aircraft communications environment would draw attention to the fact that a problem had arisen and that a voice message, using a female voice, was to follow to pinpoint the particular problem area. It was considered that there was a high probability that a warning speech message alone could go unheeded where there is already considerable amounts of speech (crew communication, radio, weather etc), particularly in the high work-load/stress situation.

The overall warning philosophy was kept as simple as possible, and kept sensibly within the existing principles of visual warning philosophy, and was based upon the requirement that the urgency of warning is the critical parameter, irrespective of the "position" or type of the problem. This led to a four tier category of warnings:

1 Immediate Action (Priority 1): the highest urgency category where immediate action is required to save the aircraft. The response time is considered to be in the order of two seconds.

2 Immediate Awareness (Priority 2): the aircrew should be made immediately aware of the problem, but immediate action is not generally required. An example is an engine fire warning which is very rarely acted upon immediately, aircrew generally checking by other means (smoke, engine instruments etc) before initiating the fire suppression procedures. This category covers the normal red warnings in the visual central warning panels (CWP).

3 Awareness (Priority 3): Aircrew should be made aware of the particular problem, to react in their own time. An example on a helicopter might be an anti-ice system failure warning, where the pilot should be aware in order to take some action which might include a modification of the flight parameters in the longer term. This category in general covers the amber, or yellow, warnings.

4 Information/Status (Priority 4): This is the lowest category and may be used where a change in status of the aircraft or an aircraft system needs to be communicated to the aircrew. Due to its minimal urgency it may be that such audio warnings are not always necessary and that visual warnings, in some cases, may suffice.

Having determined a philosophy which is acceptable to scientists, engineers, aircrew and administrators - no trivial task - there are three major aspects to which a solution is necessary. The attensons must be presented at an acoustic level that has a very high probability of being detected, that the correct urgency is implied and there is minimal risk of confusion between attensons, particularly if the attenson is to be used as an indicator of the category of warning.

The setting of the warning acoustic levels was based upon the research at MRC/APU using Patterson's auditory masking model. The modelling is described in more detail elsewhere, which describes the various phases of work in producing, refining, computer modelling and validating the model by MRC/APU, ISVR and RAE, but the essence of the research is shown in Figures 1 and 2. Figure 1 shows the noise levels at the ear of the aircrew, under the flying helmet or communications head-set - either measured or calculated, and the auditory masked threshold is calculated by the model for the noise spectrum. This level is shown on the diagram. Previous research on psychometric models has shown that once a signal is 15 dB above the auditory threshold, then there is essentially a 100% probability of detection, and this level is shown by the 100% detection level line. Due to the temporal and spectral variability of real-life noise spectra both within and between aircraft types, a 10 dB increase in level was recommended to provide a 10 dB band above the 100% detection but within which detection should be possible in virtually all cases with that particular noise spectrum. Thus it is possible to provide auditory warnings at a calculable level and not rely on providing the highest warning level available to ensure detection. Figure 2 shows an application of the model in providing the required levels of the spectral components of an attenson to ensure the required detectability. The verification of the model was carried out in the RAE Helicopter Noise Simulator and compared the masked auditory threshold of a number of subjects immersed in helicopter noise using a Bekesy technique with the calculated threshold using the model. Figure 3 shows the data mean value comparison whilst Figure 4 shows the two mean values (measured and calculated) and also the individual measured data points superimposed. The model was tested against three types of helicopter noise, Chinook, Sea King and Lynx and a correlation of all data points is shown in Figure 5, correlating measured against calculated values. All 48 pairs of points are plotted and the correlation is across all three helicopters - since the correlation should be independent of noise spectrum. The correlation coefficient is 0.990 ($p \leqslant 0.001$) and the equation of the regression line is $y = 1.013x + 1.073$, with neither the slope nor intercept being significantly different ($p < 0.001$) from the theoretical $y = x$. The standard error of the estimate is calculated at 2.43 dB which gives a 95% confidence limit of 4.76 dB.

Further important aspects of auditory warning attensons are the problems of confusion between attensons, incorrect relative urgencies and the number of attensons that can be readily retained in memory by the pilot.

A number of trials have taken place in the helicopter noise simulator to assess these parameters, and as the complete set of auditory warnings were developed, each set was tested for confusion, urgency and learning at each stage, using computer generated self-paced experiments. The example explained here concerns a final set of warning attensons that were considered to be a fully-tested baseline set for use across all helicopter types.

The experiment used ten attensons, varying from six immediate action attensons, through the remaining priority discrete attensons (immediate awareness and status/information) with the final category being a discrete "low height" attenson intended to inform the pilot when he transgressed a pre-set height on his radio altimeter. Six Priority 1 (Immediate Action) attensons were used since the philosophy of standardisation would require each Priority 1 attenson to be specific to a particular problem area across all helicopters. For example, if rotor droop - a fall off in rotor speed which would rapidly endow the helicopter with the flying characteristics of a brick - required an immediate action, then the attenson used in Gazelle, for example, would also be used for rotor droop in Sea King - or any other helicopter. Thus a pilot could fly any helicopter type and still react to the attenson correctly before hearing the voice message. This does not, of course, apply to the lesser priority warnings, which have a single discrete attenson for each category or priority, but which rely on the voice message to inform the pilot of the particular problem area. The experiments are reported in detail elsewhere, but the cardinal points are shown in Figures 6 to 9.

For the relative urgency research, experienced subjects performed four complete, paired-comparison rank-ordering experiments. When seated in the simulator subjects were asked to choose which of two, consecutively presented, warning signals were considered more urgent. The order of the presentation of the pairs of signals was random and the order of presentation of the signals within each pair was balanced.

For the confusion experiments the subjects, ten RAF aircrew and ten non-aircrew, took part in a four section experiment. Section 1 was performed on the first occasion that the subject was present and, after a briefing and familiarisation, ten warning signals were presented and the subject proceeded to learn all ten, the experiment terminating when all ten had been correctly identified. Section 2 took place one week later and concerned the subject's recollection of the ten signals, being asked to identify a single presentation of each of the ten signals presented in a random sequence with no cue or collaboration. Immediately following Section 2 tests, the Section 3 test was initiated, when the learning experiment of Section 1 was repeated. After a break of some 30 to 45 minutes, during which the subject's hearing was checked using a Bekesy self-recording audiometer, Section 4 was carried out, which was a repeat of Section 2.

From the Section 1 and 3 data both the confusion tables and the mean completion times and error totals were calculated, whilst for the Section 2 and 4 data, the correct response histograms could be calculated.

A typical urgency table is shown in Figure 6 which shows both the ranked urgency of an early experiment ranking 20 signals, and the rankings of ten of the final set of twelve warning attensons.

Generally the experiments show that the signals are internally consistent, that is, the more urgent versions of a signal are always ranked higher than the lesser urgent, with a few minor exceptions. An almost corresponding set of tables in Figure 7 shows the confusion tables carried out on eight of the ten urgency warning attensons, with two additional attensons of the Priority 3 and 4 type added. For the learned attensons in Section 3, for instance, Signal 1 (Fire) is confused once only with each of signals 2, 7 and 9 out of a total of 63 trials, whilst signal 8 (servo) is not confused at all with any other signal, in a total of 62 presentations.

Generally for the confusion experiments there is very little evidence of internal confusions between warning attensons. Even in the data in Section 1, where subjects were learning the signals for the first time, there is only one significant confusion and errors are generally few. In Section 3 of the data there are no significant errors at all and only 22 errors in a total of 641 presentations. The mean errors and completion times, per stage, are shown in Figures 8 and 9, with standard deviations. These data show similar behaviour to previous work. As before there is a marked change in the error rate and in completion times at the sixth and seventh stages, and this is clearly illustrated in the Section 3 data where the data values rise sharply at the seventh stage, but drop back to a continuation of previous trends for succeeding stages, possibly due to a change in strategy adopted by subjects.

From the results of these series of research experiments, a commercial auditory warning system (RACAL AVAD 694) was programmed with a series of attensons and corresponding voice messages - having carefully thought through the detail practical requirements in setting the programming of the electronics with the necessary interleaving priorities, overall priorities, shortening of messages if two Priority 1 messages appear simultaneously, the regrading of the relative priorities on the ground and in the air and the strategies of cancelling or ceasing signals - amongst other decisions - and flown in the RAE Lynx and Sea King. Flight trial assessment of auditory warnings is difficult, in that whilst objective measurements can be made to assess whether signal levels and the spectral contents are correct, the overall question as to whether a pilot detected, recognised and acted in the appropriate manner during flight is probably better answered by subjective questionnaire and observation. The problems in assessment lie mainly in separating personal likes and dislikes of the attensons or systems from whether the system does its job in alerting the aircrew at, and in, the correct timescales and allowing appropriate and correct reactions to be made. Such trials are also complicated by the fact that, in a normal flying career it is hoped that a pilot will never hear or see a warning. Even in a normal operational flight the chances of a warning appearing are small. Hence the appropriate evaluation of an auditory warning system should be carried out with a minimum number of trial warnings per flight - which is generally inefficient in expensive flight time usage. Even in laboratory trials the optimum exposure of a pilot to two, one or no auditory warnings per flight is time consuming in obtaining statistically reliable results. The current in-flight techniques at Farnborough are to train aircrew in the noise simulator and to initially fly airborne sorties using experimenter generated warnings in-flight - but ensuring that any real warnings are correctly perceived and that during the experimental warnings no action is taken to close down the apparently offending system - and subjective opinion and questionnaires are obtained, and then flying the system for real, with a reporting system that enables the experimenter to debrief the pilot in detail after an incident.

Whilst flight trials are under way, and introduction of experimental flights into the RAF and Royal Navy is imminent, more research is in progress at Plymouth Polytechnic Limited by Dr Edworthy evaluating the parameters that convey perceived urgency and also into the use of acoustic sounds to allow trend information to be correctly perceived by aircrew, without the usual alienation effects on the aircrew.

There remains some detail research to complete notably in the areas of attenson-speech sequences and on the relative levels of the voice messages.

The problems with the attenson-speech sequences essentially lie with how long should the sequences continue before the message ends, and how often should the attenson be repeated. The original sequences are shown in Figure 10 and these were flown in the RAE Sea King. Cancellation of a warning sequence was accomplished in one of three ways:

1. At the completion of a predetermined sequence length.
2. By the correction of the fault and subsequent warning system re-set.
3. By manual cancellation under aircrew control either at the instant of pressing the cancel button or at the end of the attenson or voice message in progress when the cancel button was pressed.

Initial aircrew reaction was generally against these long sequences on the basis that the warning had been acquired by the aircrew early in the sequence initiation and that any further messages were superfluous. However, this may well be correct for low workload situations but no research had been carried out under high workload or high stress conditions to determine whether a shortened set of sequences would go unheard due to the levels of workload. Such research is difficult since, even in aircraft simulators, high stress/workload situations are notoriously difficult to reproduce with any fidelity. In the final instance, it is possible to crash a simulator without deleterious effect on the aircrew, in a real aircraft things are somewhat different. By definition, high workload or high stress in an aircraft means higher risk to aircraft safety and thus experimentation is often not acceptable.

After discussion with pilots, it was decided to approach the problem from the other end and provide a set of sequences considered to be the minimum acceptable for UK use, and this set, currently flying in Lynx, is shown in Figure 11. This, however, is a palliative measure and research remains to be carried out on acceptable sequences, lengths and compositions.

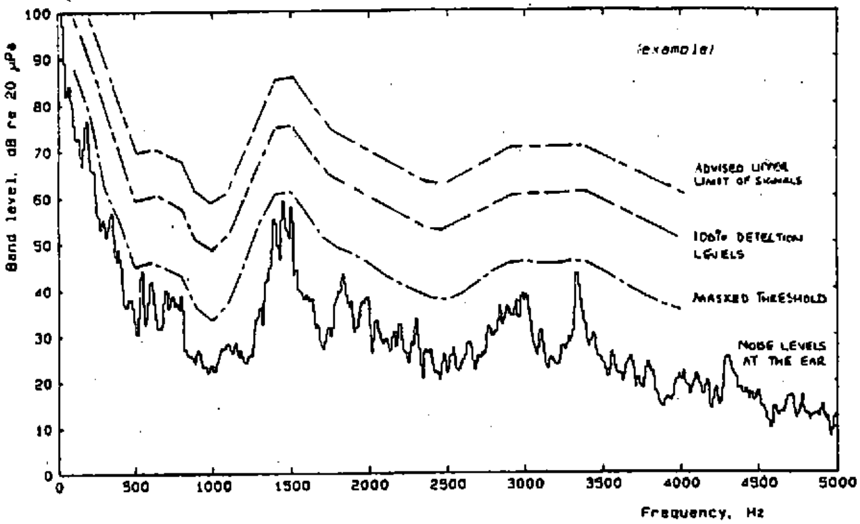
Also, correct levels for the voice messages need to be set in some detail, perhaps from equal loudness assessments of the messages in each set - or from such a measure as time and frequency weighted sound pressure levels. Experimentation in the helicopter noise simulator has determined how the attenson levels must be set when the differences between the three noise conditions experienced in flight are experienced. These conditions comprise:

1. Cabin noise alone experienced through the helmet without any noise transmitted by the aircrew microphone.
2. The same noise, but with pilot's own microphone side-tone noise transmitted and cabin noise transmitted from another aircrew microphone.
3. All of the above plus speech communications at normal levels.

At each condition the level requirements differ and a realistic compromise is required to be made and it is in this level of detail that the correct levels of speech messages are required to be determined.

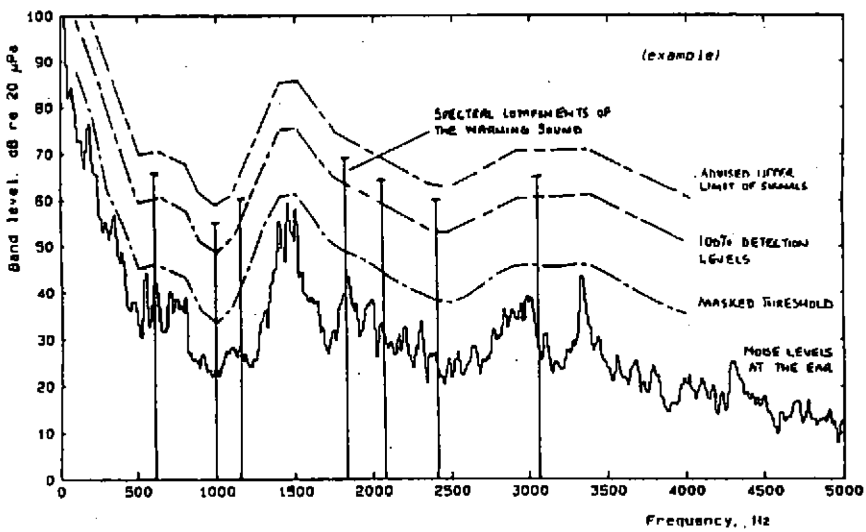
The combination of a sensible, simple and pragmatic philosophy in auditory warnings, the provision of attensons and voice messages at the lowest level, correct perceived urgency and lack of confusion, combined with audio trend information in some situations, all fully integrated with the normal aircraft audio and communications systems and not overloading the pilot's audio channels, should allow the performance envelope of both helicopter and aircrew to be considerably enhanced both in civil and military operations, with no compromise to safety standards.

AUDITORY WARNINGS FOR FIXED AND ROTARY WING AIRCRAFT



Calculated pure-tone threshold and noise at the ear (10Hz res.) in the Chinook.

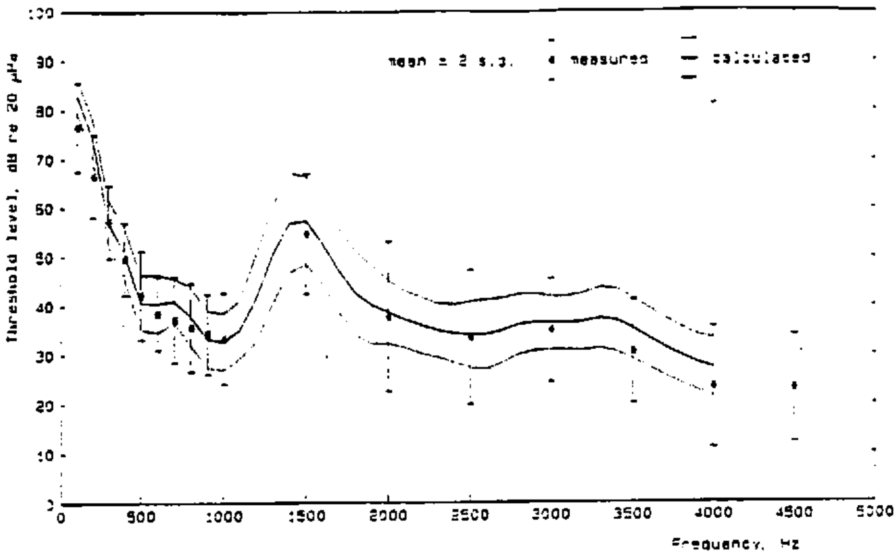
FIG 1: THE AUDITORY MASKING MODEL



Calculated pure-tone threshold and noise at the ear (10Hz res.) in the Chinook.

FIG 2: APPLICATION OF THE MASKING MODEL

AUDITORY WARNINGS FOR FIXED AND ROTARY WING AIRCRAFT



Measured values compared with calculated mean ± 2 s.d.: Chinook noise.

FIG 3: MEASURED VALUES COMPARED WITH CALCULATED MEAN ±2 sd

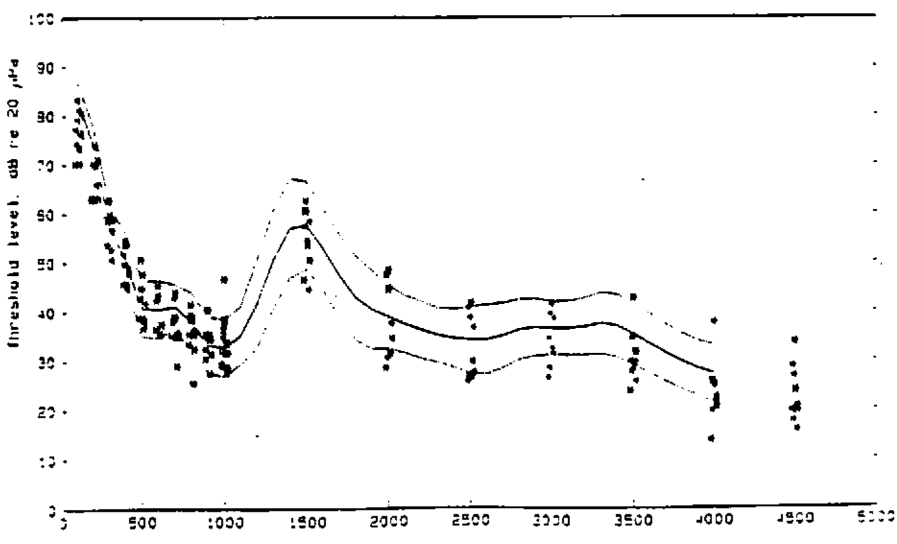


FIG 4: INDIVIDUAL MEASURED VALUES COMPARED WITH CALCULATED MEAN VALUES

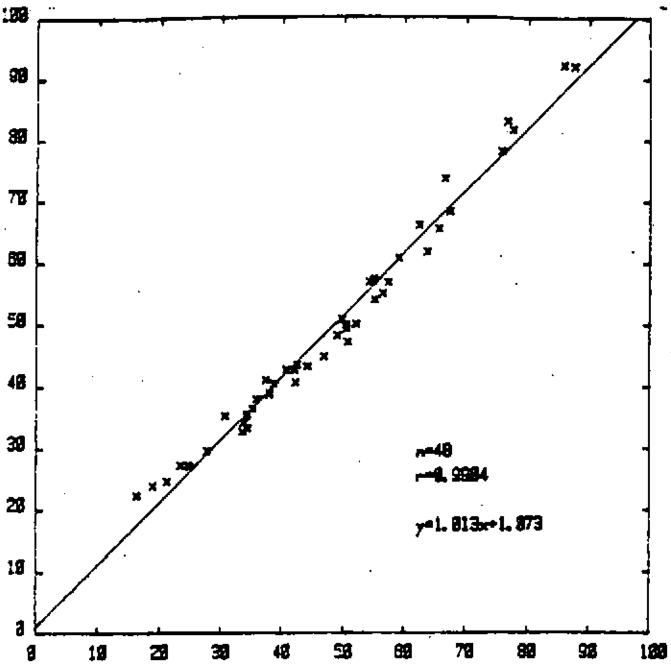


FIG 5: CORRELATION OF MEAN VERSUS CALCULATED VALUES FOR ALL THREE HELICOPTERS (LYNX, CHINOOK, SEA KING)

AUDITORY WARNINGS FOR FIXED AND ROTARY WING AIRCRAFT

Table 2 - SIGNALS IN TRIAL 3 RANKED IN ORDER OF URGENCY

Ranked signals in SECOND set of 20 (over 6 SS) (21-40)

Score SL	Signal	Score CL	Signal	Score 4M	Signal	Score 3M	Signal	Score 5R -	Signal	Score 2B	Signal	Score All	Signal
92.1	33	89.4	33	96.5	30	100.0	25	100.0	30	96.3	34	85.7	30
92.1	30	86.8	40	78.9	40	96.3	33	92.1	32	94.2	25	78.5	33
78.9	27	86.3	29	76.3	29	94.2	32	81.5	29	81.5	30	76.2	29
71.0	29	81.5	35	76.3	24	78.9	39	81.5	37	78.9	32	75.8	32
65.7	31	78.9	30	73.6	32	78.9	35	76.3	40	73.6	39	72.2	35
63.1	39	76.3	37	71.0	33	76.3	30	76.3	24	71.1	40	71.7	40
63.1	37	63.1	32	71.0	25	71.0	40	68.4	35	63.1	33	64.9	27
63.1	32	63.1	25	68.4	35	65.7	24	58.4	25	63.1	31	59.6	35
57.8	25	57.8	34	63.1	24	60.5	37	57.8	27	57.8	24	59.6	24
50.0	26	55.2	38	57.8	37	52.6	34	52.6	39	55.0	37	56.1	34
47.3	40	47.3	27	55.2	38	47.3	32	50.0	31	47.3	39	50.8	31
47.3	35	47.3	24	47.3	39	44.7	31	39.4	29	47.3	27	50.3	17
47.3	24	44.7	31	36.8	31	36.8	37	36.8	34	39.4	36	39.4	39
44.7	22	28.9	28	36.8	37	31.5	36	34.2	35	36.8	35	37.2	38
34.2	28	26.3	29	28.9	29	26.3	28	31.5	38	34.2	22	33.7	27
26.3	38	26.3	26	18.4	26	26.3	23	18.4	26	28.9	28	30.7	26
26.3	34	23.6	22	15.7	36	15.7	29	18.4	22	21.0	29	30.2	22
13.1	36	7.8	21	15.7	21	10.5	21	10.5	21	21.0	31	12.7	21
10.5	21	5.2	36	13.1	22	2.6	36	5.2	23	10.5	23	6.5	36
5.2	23	2.6	23	7.8	23	2.6	33	0.0	36	2.6	36	5.7	23

FIG 6: EXAMPLE OF EXPERIMENTAL URGENCY TABLE

CONFIDENCE TABLES FOR SECTIONS 1 AND 2
(SIGNIFICANT ENTRIES UNDERLINED)

Responses for Section 1

SIGNAL PRESENTATION	1	2	3	4	5	6	7	8	9	10	TOTAL
1 FIRE	90	1	2	1	1	0	1	0	1	0	97
2 ELECTRICS	4	89	0	1	0	0	4	0	0	0	98
3 INFORMATION	2	2	94	2	0	1	0	1	0	0	100
4 LOW HEIGHT	1	1	0	91	1	0	2	1	0	0	97
5 THREAT	0	1	0	9	87	2	1	2	2	2	98
6 UNDER CARRIAGE	0	0	0	0	0	97	1	1	0	2	102
7 FUEL	2	2	1	9	4	2	73	1	4	2	102
8 SERVO	2	2	0	1	4	1	2	79	2	2	96
9 ROTOR	0	0	0	1	1	4	4	0	85	2	102
10 GEARBOX	2	1	1	0	5	2	1	2	5	88	108
	102	97	98	98	103	109	96	85	103	107	

Responses for Section 2

SIGNAL PRESENTATION	1	2	3	4	5	6	7	8	9	10	TOTAL
1 FIRE	60	1	0	0	0	1	1	0	1	0	62
2 ELECTRICS	1	58	0	0	0	0	0	1	1	0	67
3 INFORMATION	0	2	56	0	0	1	0	0	1	0	58
4 LOW HEIGHT	0	0	1	60	0	0	0	0	0	0	60
5 THREAT	0	0	0	0	58	1	0	1	1	0	59
6 UNDER CARRIAGE	0	0	0	1	0	67	0	0	1	0	68
7 FUEL	1	1	0	0	0	0	64	0	2	2	68
8 SERVO	1	1	0	0	0	1	0	62	1	1	62
9 ROTOR	0	0	0	0	1	1	1	0	57	2	61
10 GEARBOX	0	1	0	0	1	0	4	0	1	62	69
	61	59	56	60	59	68	73	62	62	67	

FIG 7: CONFIDENCE TABLES

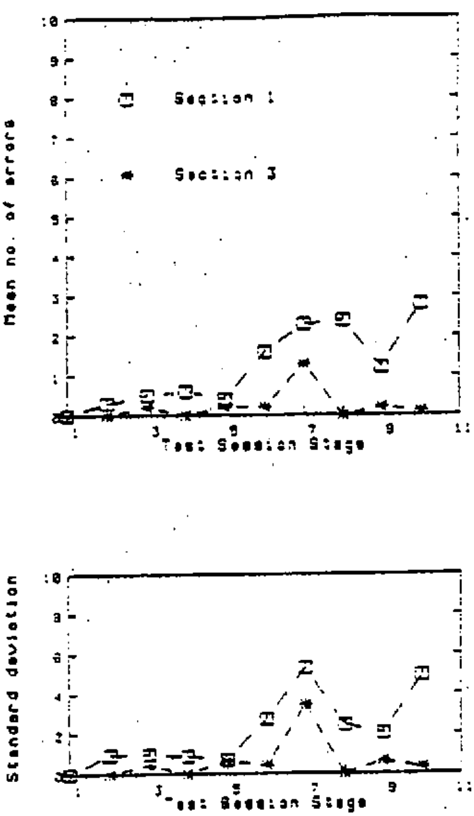


FIG 8: MEAN RESPONSE ERRORS

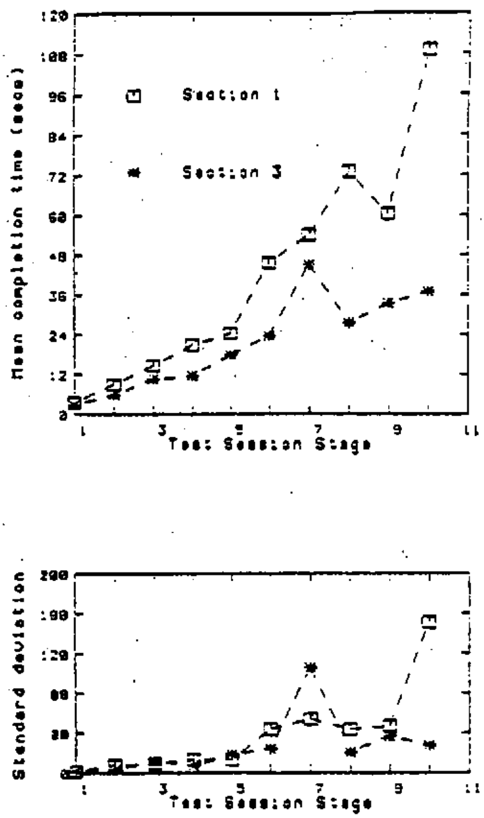
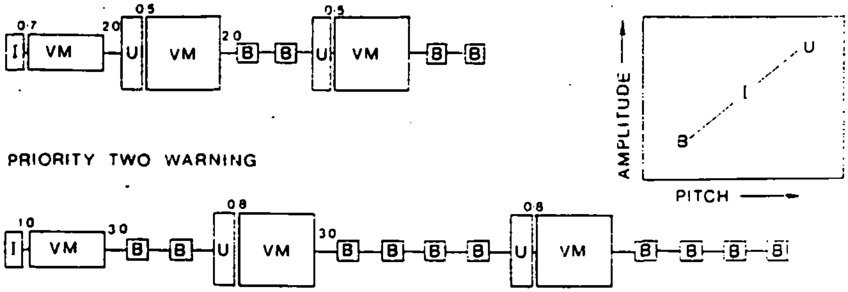


FIG 9: MEAN COMPLETION TIMES

AUDITORY WARNINGS FOR FIXED AND ROTARY WING AIRCRAFT



10: AN EXAMPLE OF SOME EARLY EXPERIMENTAL LONG MESSAGE SEQUENCES

Category	Condition	Attenson	Voice Message	Duty Cycle	Reset
1 Immediate Action	a. Engine Failure	RAE P1A	Engine Fail	P1A – VM	Automatic Cancel Condition Corrected
	b. Rotor Underspeed	RAE P1B	Rotor, Rotor	P1B – VM – VM	Automatic Cancel Condition Corrected
2 Immediate Awareness	a. Engine/APU Fire	RAE P2A	Fire Warning	P2A – VM	Depress MWC Condition Corrected
	b. All Other Red Captions	RAE P2A	Warning		
3 Awareness	All "Caution for Pilots Information" Captions	RAE P3A	Caution	P3A – VM	Depress MCC Condition Corrected
4 Status/ Information	150 ft	RAE P4A Where necessary	One Fifty Feet	P4A – VM	Nil
- Low Height	Low Height Warning (set by pilot on RADALT bug)	RAE LH1A	Low Height or Check Height	(continuous repeat)	Manual Cancel on Controls Condition Cleared (ie above set low height altitude)

FIG 11: EXAMPLES OF SHORTENED MESSAGE SEQUENCES

Proceedings of the Institute of Acoustics

THE PERCEIVED URGENCY OF AUDITORY WARNINGS

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Advanced auditory warning design using digital computers allows the design of warnings that are less startling, less aversive and more discriminable than traditional warnings such as horns, bells and sirens. The designer has a large number of sound parameters at his or her disposal during the design process, which allows a certain degree of matching between the subjective and/or behavioural response to the warning sound and the situation being signalled. Matching may take place along a number of dimensions, and one important dimension is that of perceived urgency. By such a process, high priority situations can be signalled by warnings of high urgency and low priority situations by warnings of low urgency, with appropriate gradations between them. The relative urgency of an auditory warning can be determined by manipulating the spectral, temporal and melodic qualities of the warning, especially if it is of the multipulse burst type (1). This paper provides an experimental database concerning the subjective ratings and rankings of the perceived urgency of many of the spectral, temporal and melodic parameters that can be used in auditory warning design. The results may be applied systematically and reliably to the design of future auditory warnings systems. The results are potentially applicable to warnings designed for any situation or environment although the work was carried out with particular reference to the high-workload environment of the helicopter cockpit.

In each experiment two or more sound parameters were combined in order to generate a set of stimuli which subjects ranked from most to least urgent. The design of the experiments implemented a multiple ranks technique, from which paired comparisons data can be obtained, proposed by Gulliksen and Tucker (2). The use of this technique allows the experimenter to address the following issues (amongst others):

a. The nature of the effect of individual sound parameters on perceived urgency.

b. The interactions between parameters tested in the same experiment.

c. The consistency of the rankings both within and between subjects.

The results of the experiments were used to generate a set of auditory warnings where the rank ordering of their urgencies was predicted prior to experimentation. The results were also used to make recommendations and guidelines for future auditory warning design and modification of existing warning systems. (3)

General method and treatment of results

Subjects Twelve to sixteen subjects participated in each experiment. They consisted of male and female members of the psychology department subject pool of Polytechnic South West.

Apparatus The stimuli were generated by a Tandon PCA20 microcomputer linked to a Cambridge Electronic Design 1401 digital interface and 1701 filters with a cut-off of 4kHz. They were played through an amplifier and speakers. The experimental design was controlled by a BBC Model B microcomputer linked to the Tandon microcomputer via a serial line.

Stimuli In all of the experiments short bursts of sound lasting approximately two seconds were heard. They were of the multi-pulse burst style recommended by Patterson (1). Pulses were 150 - 200 ms in length with a defined spectrum and amplitude envelope. The pulses possessed many harmonics, the precise number depending on the fundamental frequency of the pulse. In most experiments a 3 x 2 stimulus design was used. Six stimuli were generated from three levels of one parameter (e.g. speed - fast: moderate: slow) and two levels of another (e.g. fundamental frequency - high : low). A seventh stimulus, chosen by the experimenters, was added necessarily to enable the experimental design to run successfully (2).

Procedure After some training on the task, subjects heard the stimuli in sets of three. They were required to rank order them from highest to lowest urgency. A Youden square design was used so that, over seven trials, each stimulus was compared with every other stimulus. Subjects then heard each stimulus in a random order and were required to rate its urgency on a scale from Ø to 1ØØ. Thus both ranking and rating data were obtained for each stimulus.

Treatment of data The rank ordering from most to least urgent stimulus was obtained in each experiment. A corrected form of Kendall's W (W') was obtained for each subject and for the group as a whole. The higher the value of W', the more consistent the subjects and hence the more reliable and useful the parameters in manipulating the urgency of auditory warnings. The rankings and the ratings were correlated and, where significant, analysis of variance was carried out on the rating data in order to clarify main effects and interactions implicit in the ranking data.

The experiments are described briefly below. They are divided into three sections. In the first, pulse parameters are considered (e.g. harmonic content, amplitude envelope etc). In the second, burst (melodic) parameters are considered (e.g. speed,

Experiment	Parameters (levels)	Description of parameters and levels
1	Amplitude envelope (3)	Slow offset: regular: slow onset Slow offset = 20ms rise time, followed by fall for rest of pulse. Slow onset = 20ms fall time, preceded by rise for rest of pulse. Regular = 20ms rise and fall time.
2	Harmonic series (2)	Regular : 10% irregular Regular = all harmonics integer multiples of fundamental. 10% irregular = some harmonics +/-10% integer multiple of fundamental.
	Fundamental Frequency (2)	200Hz : 350Hz
3	Harmonic series (3)	Random: 10% irregular: 50% irregular Random = random selection of harmonics 10% irregular as in Experiment 2 50% irregular = some harmonics +/-50% integer value
	Delayed harmonics (2)	Present: absent Present = some harmonics play only for the second half of each pulse Absent = all harmonics play for duration of pulse

Table 1: Description of stimuli, Experimental Series One

rhythm, pitch range etc). In the third, the findings are applied to the design of complete, multi-parameter auditory warnings.

Experimental series One: Pulse parameters Warnings of both the advanced type (1) and of the more traditional type often possess many spectral characteristics which together determine their perceived urgency. Among the most important parameters are likely to be the fundamental frequency, the amplitude envelope and the harmonic series (e.g. the relationship between the fundamental frequency and the other components). The loudness level of a warning also affects its perceived urgency but unfortunately this also affects the aversiveness of a warning which may lead to inappropriate use in the working situation (e.g. the operator turning off the warning). Since advanced auditory warnings are intended to be non-aversive, the manipulation of parameters other than loudness are used to create the range of urgencies desired, as these experients show.

Three experiments were carried out on spectral parameters. Those tested in Experiment 1 were amplitude envelope and the regularity of the harmonic series using a set of stimuli with a fixed fundamental of 150 Hz. Experiment 2 investigated these same two parameters, using a fixed fumdamental of 530 Hz. In Experiment 3, fundamental frequency, regularity of harmonic series and delayed harmonics (a 'trick' possible with synthetic warnings which can affect the quality of a pulse) were combined in a larger experiment where four stimuli were rank ordered in each trial. The experimental stimuli were six-pulse bursts consisting of a repeated pulse. The pulse possessed a full set of harmonics up to the 4 kHz cut-off. The burst lasted approximately two seconds.

Table 1 shows the details of the stimuli used in Experiments 1 to 3.

All three experiments produced highly significant values of W' meaning that subjects were consistent. All the parameters produced significant effects, meaning that they all affect perceived urgency and are therefore potentially usable in auditory warning design. The results are summarised in Table 2. Where a / symbol occurs, the difference between those two levels of a parameter were found to be negligible.

Discussion All the parameters tested produced clear effects on perceived urgency. In addition, subjects agreed well about the direction of these effects. Thus different levels of fundamental frequency, amplitude envelope, harmonic series and delayed harmonics could be used to generate the pulses for sets of warnings varying in their degree of urgency. Some parameters have stronger and more consistent effects than others, however. In these experiments, fundamental frequency produced the strongest effect whilst delayed harmonics produced the weakest effect. The latter parameter might therefore be used when attempting to generate warnings of approximately the same urgency within a complete

Experiment	W'	Main Effects	Direction of effect (Most urgent ≫ least urgent)
1	.696**	Amplitude envelope	Slow onset/standard ≫ slow offset
		Harmonic series	10% irregular ≫ regular
2	.615**	Amplitude envelope	Standard ≫ slow onset ≫ slow offset
		Harmonic series	10% irregular ≫ regular
3	.503**	Fundamental frequency	350Hz ≫ 200Hz
		Harmonic series	Random ≫ 10% irregular ≫ 50% irregular
		Delayed harmonics	Absent ≫ present

Table 2 : Summary of results, Experimental Series One

**p<.001

warning set, because the presence of delayed harmonics makes a sound distinctive rather than urgent or non-urgent. The same is true of some of the other levels of parameters, and further details and recommendations can be found elsewhere (3).

Experimental series Two: Burst parameters

A burst is a small unit of sound lasting approximately 2 seconds, and usually consists of several pulses. The pulses can be played at different fundamental frequencies and with different time intervals between pulses in order to create a sound very similar to an atonal melody with a rhythm. A whole range of temporal and melodic (musical) parameters are available for use, some of which are likely to have strong and consistent effects on perceived urgency and some of which are likely to have weaker effects.

The second experimental series explored some of these parameters in six experiments (Experiments 4 to 9). Table 3 shows the details of the stimuli for each experiment.

Every experiment produced clear and consistent effects for the parameters tested, as well as highly significant values of W' (.701 .796, .561, .353, .619 and .354 for Experiments 4 to 9 respectively) Some experiments produced more consistent responses overall, as can be inferred from the range of values of W' obtained.

For the sake of clarity, the results from these six experiments are summarised in two tables. The first (Table 4) summarises the effects for temporal parameters (speed, rhythm, number of units,

Experiment	Parameters (levels)	Description of parameters and levels
4	Speed (3)	Slow : moderate : fast Slow = approx 1.5 pulses/sec Moderate = approx 3 pulses/sec Fast = approx 6 pulses/sec
	Rhythm (2)	Regular : irregular Regular = all pulses equally spaced Irregular = syncopated
5	Fundamental Frequency (3)	Low : moderate:high Low = 200Hz. Moderate = 420Hz High = 880 Hz
	Speed (2)	Fast : moderate As in Experiment 4
6	Number of units (3)	1 unit : 2 units : 4 units 1 unit = 4-pulse burst 2 units = 2 4-pulse bursts 4 units = 4 4-pulse bursts
	Speed (2)	Fast : moderate As in Experiment 4
7	Pitch range (3)	Small : middle : large Small = 3 semitones Middle = 6 semitones Large = 9 semitones
	Pitch Contour (2)	Down/up : Random Down/up = bidirectional pitch pattern Random = multidirectional pitch pattern
8	Speed Change (3)	Slowing down : regular: speeding up
	Number of Units (2)	1 unit : 2 units As in Experiment 6
9	Musical structure (3)	Resolved : unresolved : atonal Resolved = diatonic, with V-I harmony Unresolved = diatonic, with I-V harmony Atonal = random sequence of pulses
	Pitch range	Small : Large As in Experiment 7

Table 3 : Description of stimuli, experimental series two

speed change) and the second (Table 5) summarises the effects for melodic parameters (fundamental frequency, pitch range, pitch contour and musical structure).

Parameter	Direction of Effect
Speed	Fast ⇒ Moderate ⇒ slow
Rhythm	Regular ⇒ Irregular
Number of Units	4 units ⇒ 2 units ⇒ 1 unit
Speed Change	Speeding up/Regular ⇒ Slowing down

Table 4: Summary of results for temporal parameters, experimental series Two

Parameter	Direction of Effect
Fundamental frequency	High ⇒ Moderate ⇒ Low
Pitch range	Large ⇒ Middle / Small
Pitch contour	Random ⇒ Down/Up
Musical structure	Atonal ⇒ Unresolved ⇒ Resolved

Table 5: Summary of results for melodic parameters, experimental series Two

Discussion The consistency of response varied from experiment to experiment. This suggests that some parameters are more important in terms of their effects on perceived urgency than others. In general, those parameters affecting the temporal qualities of the stimulus produced the most consistent effects on perceived urgency. Melodic parameters,apart from fundamental frequency, produced rather less consistent effects although significant results were produced throughout the experimental series. Thus the manipulation of the temporal aspects of a warning sound (and its fundamental frequency) are likely to bring about the most significant changes in perceived urgency, whilst melodic parameters could be used in order to generate distinctions between warnings of otherwise equal urgency. The application of these parameters to warning design are discussed at length in another report (3).

Experimental series Three: Producing auditory warnings

In this series of experiments, complete auditory warnings were generated and tested. The aim of these experiments was to apply the findings of the earlier experiments to the design of complete auditory warnings, varying along many spectral and temporal parameters, to predict their perceived urgency, and to test them empirically. A set of 13 pulses and 13 bursts were generated where Pulse 1 was constructed in such a way as to make it the most urgent and Pulse 13 the least urgent. The same principle was applied to the design of Bursts 1 to 13. Pulse 1 consisted of a 600Hz fundamental, a standard envelope and a random harmonic series where Pulse 13 consisted of a 100Hz fundamental, a slow offset envelope and a regular harmonic series (Table 2). Burst 1 consisted of 6 2-pulse units, a 150ms average inter-pulse time, a regular rhythm and a random pitch contour whereas Pulse 13 consisted of a single 4-pulse unit, an irregular rhythm that slowed down towards the end, an average inter-pulse time of 550ms and a unidirectional downward pitch contour (Tables 4 and 5). In the first experiment (Experiment 10), Pulse 1 was combined with Burst 1, Pulse 2 with Burst 2 and so on to produce a set of warnings. It was predicted that subjects would rate the urgencies of the warning set in such a way as to make the Pulse 1 - Burst 1 combination the most urgent and the Pulse 13 - Burst 13 combination the least urgent, with appropriate rankings between the two extremes. The warnings were heard in groups of 4, which subjects were required to rank order from most to least urgent as in Experiment 3.

A between-subjects W' of .920 was obtained for this experiment, which is highly significant ($F = 148.618$, df = 11,154, $p < .0001$) All subjects were very consistent and were very confident in their rankings. The overall rank ordering produced a correlation of .929 with the predicted order, which is highly significant. A perfect correlation would have been achieved but for the displacement of one pulse-burst combination which was ranked two places lower in the experimental ranking relative to the predicted ranking, with the consequent displacement of the two combinations just below this.

This experiment demonstrates how the experimental results can be applied reliably and successfully to the design of auditory warnings, and is therefore a practical validation of the experimental results. The final two experiments explored the relative strengths of pulse and burst parameters by using the same set of stimuli but combining urgent pulses with non-urgent bursts (e.g Pulse 1 with Burst 13) and vice versa, and asking subjects to rate the urgencies of the resulting warning sounds. The results indicate that burst parameters, particularly temporal parameters, have a much stronger influence on perceived urgency than pulse parameters.

This work is supported by MoD(P.E) A.Rad 13, London

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(1) Patterson, R.D. (1982) Guidelines for Auditory Warnings Systems in Civil Aircraft CAA paper 82017

(2) Gulliksen, H & Tucker, L.R. (1959) A General Procedure for Obtaining Paired Comparisons from Multiple Rank Orders

(3) Edworthy J, Loxley, S, Geelhoed, E & Dennis, I (1988) An Experimental Investigation into the Effects of Spectral, Temporal and Musical Parameters on the Perceived Urgency of Auditory Warnings. Report on MoD (P.E.) Project number SLS42B/205.