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THE DESIGN AND PRODUCTION OF AUDITORY WARNINGS FOR HELICOPTERS
1: THE SEA KING

by

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APPENDICES D AND E CONTAIN INFORMATION WHICH IS COMMERCIAL IN CONFIDENCE AND HAVE BEEN OMITTED FROM THIS COPY

Preface

This interim report has been issued in support of work completed to October 1986. Since work is continuing any ideas and information contained within may be subject to revision based on experience in trials and discussions with aircrew.

CONTENTS

CONTENTS (contd)

0.0 SUMMARY

A set of auditory warning sounds has been designed and produced for the Sea King helicopter. The warnings were made in accordance with the guidelines of CAA Paper 82017 extended to apply to helicopter use.

The warnings, which indicate airworthiness problems and radio-altimeter function, have been tailored to the specific Sea King noise environment but are designed to be easily re-tailored for any military or civil helicopter. The warnings have been tested for ease of discrimination in a Helicopter Noise Simulator.

The criteria and principles involved in the design are outlined, the methods of production and testing are described and the parameters of the finished warnings are given.

The finished sounds have been supplied as a high-quality digital PCM tape recording.

1.0 INTRODUCTION

This report describes the production of auditory warnings for the Sea King helicopter. The task was undertaken jointly by ISVR, Southampton and the MRC Applied Psychology Unit, Cambridge with, and on behalf of the Royal Aircraft Establishment (Flight Systems, FS(F)4, Human Engineering Divn.), Farnborough. The project was funded by D Air Radio under MOD(PE) Contract No. A94B/3593.

The warnings have been evaluated for ease of recognition and discrimination by RAE in a simulator and are now awaiting in-flight trials. For completeness, the simulator trials are also described in this report. A definitive set of approved auditory warnings will be prepared for other UK military helicopters, after the Sea King flight trials.

The auditory warnings were made using the guidelines given by Patterson in CAA Paper 82017 [1]. These guidelines were prepared for civil airliners but have been extended in this project to meet the different requirements of helicopters.

Warning sounds produced to these guidelines have carefully chosen sound levels and ergonomic temporal and spectral characteristics. As a result each warning should be readily audible but not so loud as to disrupt thought and concentration. Each will have a distinctive and memorable rhythm conveying an appropriate degree of urgency with the minimum of disruption to speech communication. The spread of spectral components will make for a distinctive sound as well as providing a high degree of redundancy for detecting the sound under varying conditions. The overall effect is that a crew member will not be bombarded with sound and the sounds he hears will be easily identified. Unlike some conventional warnings these new warnings should not cause pilots unnecessary additional stress during a critical phase of a flight.

The frequencies and levels of the component sounds have been tailored to the specific noise environment in which they will be heard. In the case of the Sea King and all military helicopters, all the warning sounds will be presented through the communications telephones in the crew's flying helmets. The frequency response of the telephones, the noise at the ear passing directly through the helmet and the noise at the ear from the communication system have all been taken into account - complications not normally addressed in producing warnings for civil aircraft.

It must therefore be emphasized that the warnings produced have been designed specifically for use in the Sea King, with Mk4 helmets and Mk4 telephones. These warnings may not be suitable without modification for use in other helicopters or in fixed-wing aircraft, nor will they be suitable for presentation through telephones which have a frequency response substantially different from that of the Mk4 telephones.

2.0 THE NEED FOR AUDITORY WARNINGS IN HELICOPTERS

Auditory warnings for helicopters fall into two categories which may loosely be termed "airworthiness" and "operational". The most immediate need is for airworthiness warnings. All the warnings produced for the Sea King, except one, fall into this category.

2.1 Airworthiness warnings

Airworthiness warnings are concerned with the helicopter itself or with the safe flying of the helicopter. Warnings of an engine failure, a fire, a gearbox or hydraulic problem are all examples. Airworthiness warnings in general are equally applicable to military and civil helicopters.

At present airworthiness auditory warnings are not routinely installed in UK military helicopters. If a fault occurs the pilot is usually alerted by a light on a central warning panel (CWP). Until now visual warnings have been accepted as adequate. However, night vision goggles (NVG) are now being introduced into service. These image intensifying goggles enable the pilot to fly low and fast in very dim light, but they do restrict the pilot's field of view and may obscure the central warning panel [2]. In addition when flying low the pilot's work load is high and he must concentrate mostly on the landscape outside. He is more likely to miss a warning light under these conditions. Thus there is an immediate need for auditory warnings to supplement the visual warnings. The auditory warnings once provided will nevertheless be used all the time whether the goggles are worn or not.

2.2 Operational warnings

Operational warnings are those which are concerned with the military operations in which the helicopter may be used. Warnings in this category include electronic warfare (EW), enemy radar, infrared or laser detection and various threat warnings.

Operational auditory warnings are already used in some military helicopters but tend to be sounds generated on an ad hoc basis and many may be amenable to improvement. These warnings are outside the scope of the current project but cannot be ignored. Any new airworthiness warning sound must not be confused with any of the existing operational sounds.

2.3 Radio-altimeter (Radalt) sounds

Radalt sounds come within the scope of this project, though since the sounds required do not fall into either of the above categories and in many ways constitute a special case they will be addressed more fully in a separate report and merely outlined here. The radalt is used differently in military and civil helicopter operations.

In military helicopters the radio altimeter is an aid to low, fast flying. It allows the pilot to set a datum height and will continuously inform the pilot if he is at that height or higher or lower by, say, 20 feet. When flying fast and low the need to glance away continually at the altimeter would be dangerous, so auditory warnings are an obvious choice for the radalt.

The ergonomic requirements of warning sounds needed for the military radalt differ radically from those of other warning sounds in several respects. These differences are explained in section 4.6.

In civil helicopters the radalt is used to trigger a safety warning if the helicopter descends to a preset height above ground or sea. A radalt with an accompanying voice warning has recently been made mandatory in any civil helicopter flying over water for more than 3 minutes in any flight [3]. Because of their different meanings the warning sounds for military and civil radalt will differ. The civil radalt sound is outside the scope of this report.

3.0 ADVANCED AUDITORY WARNINGS: AN INTRODUCTION

This section describes the structure of an advanced auditory warning, gives the reasons for and the advantages of this structure, and defines the terminology used. Only a brief summary can be given here - for a full exposition of design criteria and guidelines refer to CAA Paper 82017 by Patterson [1]. Although this section is based mainly on CAA Paper 82017, additional features and terminology have been incorporated from an unpublished draft international standard on warning sounds in hospitals [4].

3.1 Reasons for advanced auditory warnings

Auditory warnings presently used in civil airliners have many failings. Most of the bells, buzzers, sirens and electronic sounders currently used are too loud. Some are so loud that they interfere with crew communication. Often the crew's attention will be directed, not to the real problem, but to the problem of finding the warning-cancel button [5].

The onset of many sounds is too abrupt and startling. The temporal patterns of the warnings are not sufficiently distinctive. Many sounds are continuous and many continue unnecessarily long after they have signalled their presence. Some of the less important warnings even sound more urgent than the more important warnings.

Advanced auditory warnings are an attempt to correct these problems by adopting the following design criteria.

3.2 Design criteria for advanced auditory warnings

The following points are important in designing a set of auditory warnings if the problems of traditional warnings are to be avoided.

(i) The warning sounds for a particular environment should be designed as a coherent set.

(ii) Each warning sound within a set should be coarsely graded for priority. An urgent warning should sound urgent, a less urgent warning should sound less urgent.

(iii) Warnings should be loud enough to be reliably heard, yet not so loud as to disrupt thought or communication.

(iv) Warning sounds should be as distinctive as possible in their spectral character (pitch and timbre), and in their temporal character (pace, rhythm, regularity or irregularity) to aid recognition. A pulsed sound will have a distinctive character and will not disrupt communication as much as a continuous sound.

(v) The warning should not be present any longer than is necessary. Usually as soon as a warning sound is recognised it has served its main purpose. If a warning need continue to indicate a continuing problem, then it can continue at a quieter level and less urgent pace.

(vi) There should not be too many different sounds.

3.3 Structure of an advanced auditory warning

An auditory warning with a pulse-burst structure as described here and illustrated in Figure 1 will satisfy the above requirements and is the form given in CAA Paper 82017. Words underlined are defined in a glossary in Appendix A.

The basic building block of an advanced auditory warning is the pulse. A pulse is a brief sound, about 100 milliseconds long, with a specific frequency spectrum, rise-time and fall-time, and therefore a characteristic pitch and timbre. Each warning sound has its own, distinctive pulse.

Pulses are repeated to make a burst. A burst is typically five to ten pulses sequenced to give a distinctive pace, temporal pattern and rhythm, either regular or irregular. Although each pulse within a burst is a repetition of the same basic waveform, the amplitude and pitch may be modified for each repetition. The pitch is modified by changing the speed at which the pulse waveform is played; the timbre of the pulse is hardly affected. The fundamental frequency of the highest pitched pulse can be up to 1.5 times that of the lowest pitched pulse, a range of 7 semitones in musical terms. The sets of amplitude and pitch values used to construct a burst are referred to as the amplitude envelope and pitch contour.

The duration of the pulses and the rhythm of the burst are major factors in communicating the degree of urgency of a warning. A rapid burst of brief pulses has most urgency, a slow burst of long pulses has least. In general a rising pitch contour increases the perceived urgency of a burst. The amplitude envelope affects the urgency of a burst, but is mainly used to prevent startle by making the initial pulse or pulses less intense than those following.

Three versions of a burst are normally, though not always, made for each warning. These are the initial, urgent and background versions, each with a specific purpose. In the urgent version of the burst, the pitch of the pulses will usually be raised, the pulse spacing decreased, and the sound level increased relative to the initial burst. The urgent form will usually sound like a louder, speeded-up version of the initial burst, though other more subtle differences may be introduced. In the background burst the pitch will usually be lowered and the pulse spacing increased relative to the initial burst, making the background burst sound slower than the initial burst. In the background burst the amplitude envelope will be flat - all pulses will have the same sound levels - and this level will be quieter than in the initial burst.

The initial, urgent and background versions of the burst are combined into a warning sound in a sequence which depends on the priority of the warning. A voice warning is also included in each warning sound to reinforce meaning. There are three priorities of warning and hence three different forms of warning sound.

A priority 1 warning signifies an emergency; immediate action is required.
A priority 2 warning is cautionary; it is important but does not need immediate action.
A priority 3 warning is advisory or informative, and may not require any action.

Figure 2 shows the sequence of bursts and verbal messages in priority 1, priority 2 and priority 3 warning sounds. Note that these specific forms may be modified in the light of experience and feedback from pilots. Other forms might be used in different applications.

The initial burst of a priority 1 warning is designed to sound more urgent than the initial burst of a priority 2 warning which in turn is designed to sound more urgent that a priority 3 warning.

The initial burst in each case should elicit a reaction from the pilot. If not, the priority one warning goes straight into the urgent form, whereas a priority two or three warning goes into the background form for some seconds before using the urgent burst. The background bursts are reminders to the pilot that the warning is still active and are designed not to 'pester' the pilot while he is busiest. If the pilot reacts to the initial burst, or if he cancels the warning, then he will not hear the urgent burst.

3.4 Sound levels and frequency content

The sound levels and frequency spectrum of an advanced auditory warning are tailored to the noise in which they are heard. The main spectral components of a pulse are set to be between 15 dB and 25 dB above the masked threshold imposed by the noise. Masked threshold is the minimum sound level of a signal which can just be heard above the noise by an attentive listener. It varies with the noise level and spectrum and for any given noise and spectrum it is a function of the frequency of the signal.

The minimum level of 15 dB above threshold ensures that the warning sound is loud enough to be reliably heard when the warning is not expected and the listener is busy. It also ensures that the character of the warning sound does not change subjectively if the background noise level changes slightly. The maximum of 25 dB above threshold is set to prevent startle, disruption to thought, or annoyance.

CAA Paper 82017 recommends that the appropriate frequency range for the spectral components is 0.5 to 5.0 kHz; that the fundamental of harmonically related components should fall in the range 150 Hz to 1000 Hz; and that at least four main components should fall between 1 kHz and 4 kHz.

3.5 Auditory warning parameters and perceived urgency

Generating an auditory warning sound with a degree of urgency to match the priority of the warning requires experience and a knowledge of the situation in which the warning can arise as well as knowledge of the science. The factors which can be adjusted to change the perceived urgency of a warning sound include [6,7]:-

(i) pulse duration: a shorter pulse increases urgency

(ii) inter-pulse spacing: reducing inter-pulse spacing increases the pace of the burst and increases urgency

(iii) pulse rise-time: a shorter rise time increases urgency

(iv) pulse spectral content: the more high-frequency energy the harsher the pulse and the greater the urgency

(v) pitch contour: a rising pitch contour increases urgency

(vi) burst rhythm: a quickening tempo increases urgency

(vii) inter-burst spacing: reducing the time between bursts increases urgency

Note that some of these factors have more effect than others and that some are more immediate in their effect. Note also that it is difficult to predict the combined effect when varying more than one factor.

3.6 Advanced auditory warning guidelines

The structure of advanced auditory warnings and the parameters affecting their effectiveness have been described. The guidelines controlling these parameters, as set out in CAA Paper 82017, are summarised for convenience in Appendix B.

3.7 Installation and hardware needed

Advanced auditory warnings are designed to be stored digitally in a ROM in an Automatic Voice Alerting Device (AVAD) or a similar microprocessor-controlled unit. For each warning sound it is sufficient to store the digitised waveform for one pulse, the digitised waveform of the voice message and the timing and sequencing parameters needed to reconstruct the entire warning. The warning sound is then generated in real time as and when it is needed.

The same hardware can be installed in many aircraft provided an AVAD containing the appropriate ROM is fitted.

4.0 EXTENDING THE AIRLINER GUIDELINES TO MILITARY HELICOPTER REQUIREMENTS

The requirements for auditory warning sounds in military helicopters differ from those in civil airliners. Some of these different requirements are imposed by the equipment used to present the warnings. Other differences arise because a helicopter pilot often needs to react more quickly than an airline pilot because of the handling characteristics and operational role of the helicopter. There are also the special requirements of the radalt sound. This section describes how the guidelines of CAA Paper 82017 have been extended to cover the specific requirements of helicopters. Most of the warnings made for helicopters would conform to the guidelines of CAA Paper 82017; not all the warnings conforming to CAA 82017 would suit helicopters. A demonstration set of auditory warnings was made for flight crew to assess at the beginning of this project (see Appendix B). Many of their criticisms and suggestions have been incorporated here.

4.1 Compatibility of warning sounds among helicopter types

A specific design requirement is that a particular warning sound will always have the same meaning in whatever type of UK military helicopter that warning is heard. Flight crew will not have to relearn all the sounds from scratch when converting to or flying in a new helicopter type, and are more likely to correctly identify familiar sounds in an emergency if they fly in more than one helicopter type.

In practice it may not be possible to use physically identical sounds in each type of helicopter because the cabin noise spectrum varies from type to type. But by tailoring the warning sounds to the particular noise spectrum, it should be possible to make warnings which, subjectively, sound the same in each helicopter. This task is more difficult for helicopters than for civil airliners because the cabin noise spectrum in a helicopter is more complex.

4.2 Influence of the helicopter cabin noise spectrum

The noise spectrum inside any helicopter is fundamentally different from the spectrum in a fixed-wing aircraft, especially an airliner, because the noise sources are different. In a fixed-wing aircraft, the noise is generated mainly by airflow and turbulence over the aircraft fuselage and flight deck transparencies. The noise spectrum is broadband with few, if any, tonal components. In a helicopter the noise is generated by aerodynamic and mechanical sources, in particular the rotor, gearboxes, transmission and tail-rotor drive. The noise spectrum has a broadband component, which is usually fairly steady in level, but superimposed on this are intense low-frequency components and many tonal "whines". Levels of tonal components vary spatially and temporally within the helicopter. Effectively there is a slowly changing pattern of quasi-standing waves within each helicopter. The frequencies and levels of the tonal components vary from type to type of helicopter.

In principle the nature of helicopter noise spectra does not affect the calculation of the appropriate level for a warning sound. In practice, however, it is more difficult to specify the background noise in a helicopter. It is also difficult to find frequency components for a set of warning sounds that would be satisfactory in all RAF helicopter types. Work is in progress to assess the noise spectra of various helicopters in order to try and find a common "design window" for auditory warning sounds.

4.3 Requirements imposed by equipment

In military helicopters the crews wear flying helmets and auditory warnings will be presented through the communications telephones in the helmets. The warning system must therefore be integrated with the communication control system, (CCS).

4.3.1 Sound levels of auditory warnings

The noise at the ear under the helmet sets the masked threshold, and hence the sound levels needed for warning sounds. The noise at the ear has two components. The first is the external cabin noise passing directly through the helmet; this is always present. The second is the cabin noise which is picked up by the crews' microphones and fed to the ear through the communications telephones. This second component is present if one or more crew members has his microphone switched on.

A single active microphone can add up to 30 dB to the residual noise at the ear. A second microphone will add a further 3 dB or so. An auditory warning with an appropriate sound level when a microphone is on may be startlingly loud when the microphone is switched off. Conversely a warning with an appropriate sound level when the microphones are off may be inaudible when a microphone is switched on. The shape of the noise spectrum through the communications system also differs from the spectrum of the residual noise passing directly through the helmet. Therefore an active control system will be needed to adjust the sound level and spectrum of auditory warning sounds to suit the noise level at the ear. Any such system would need to accommodate any future installation of Active Noise Reduction (ANR) or Adaptive Noise Cancellation (ANC).

In some circumstances, for example with no microphones switched on and possibly with ANR in use, the noise levels at the ear may be quite low. Masked thresholds could conceivably be as low as 40-50 dB at the frequencies appropriate to warning sounds. In such circumstances, a warning sound at 15 dB above masked threshold could have a sound level as low as 55 or 60 dB. Although perfectly audible, such a low level signal might lose some urgency. Therefore the criterion for the appropriate sound level for warning sounds has been modified to set the minimum level at 15 dB above masked threshold or 70 dB SPL, whichever is the higher.

4.3.2 Bandwidth of warning sounds

Further limitations of presenting warnings through the communication system are the restricted bandwidth and peaky frequency response of the telephones. The peaky response can be compensated for simply by tailoring the voltage spectrum at the input to the telephones.

The bandwidth is a more serious limitation. Although future telephones may have an extended frequency range the current Mk4 telephones have an upper limit between 3 kHz and 3.2 kHz. The upper limit of 5 kHz allowed in CAA Paper 82017 must be reduced to about 3.2 kHz if a Mk4 helmet and telephones are in use.

The reduced bandwidth firstly restricts the frequency range available for warning sound detection, removing some of the redundancy in the sounds. It also limits the highest pitch available for a pulse. For minimum redundancy in the detection task CAA 82017 states that there ought to be five or more harmonically related spectral components. The highest fundamental frequency which will give five harmonically related components with a 3.2 kHz upper limit is 640 Hz.

4.4 Priorities of warnings in military helicopters

Allocating priorities to particular warning sounds is beyond the scope of this project. Priorities must be assigned by a competant authority with experience and knowledge of a particular helicopter and the role in which it will be used. However, airworthiness warnings in a military helicopter are already sorted into categories of priority for the pilot by the colour and position of warning lights on the Central Warning Panel. In assigning priorities to auditory warning sounds, logical inconsistencies between the priorities suggested by the lights and by the sounds should be avoided.

It was originally intended that each Priority 1 warning should have its own sound and voice message. However, when helicopters other than the Sea King were considered as well, this was found to be impracticable. Far too many different warning sounds would be needed. Consequently only the one or two most important warnings will be able to have individual sounds, and the majority of Priority 1 warnings will have to be grouped together under a general "Priority 1" sound, although they will be distinguished by their own, unique, voice messages.

Priority 2 warnings will also be grouped under a general "Priority 2" sound -- a "master caution" -- with distinguishing voice messages. Similarly, all priority three warnings will be grouped under one sound, though the voice message may be omitted. By keeping the total number of sounds to a minimum the pilot should more quickly and easily recognise those few warnings which have unique sounds.

The priority of a given event may differ from one type of helicopter to another. Problems with an engine, for example are usually more urgent in a single-engined helicopter than a dual engined one. An event might be signalled by a Priority one sound in one helicopter, but by a priority two sound in another, although the voice message would be the same.

To cater for all military helicopters about 10 to 12 sounds will be needed in all. Each helicopter, however, will only need a subset of typically six to eight, of which three would be the general priority one, two and three sounds. The number of voice messages associated with each sound will be high.

4.5 Urgency and speed of warning sounds

A warning sound must convey its meaning to the flight crew quickly enough to enable them to act correctly and in time. This is vital if the warnings are to be useful and hence acceptable to the crew. Although the appropriate speeds for warnings in civil airliners have been established [8] the pace of life in a military helicopter is much faster. Flight crew must respond more quickly in a helicopter and warning sounds must convey their meaning more quickly.

The most urgent warning is for rotor droop in a single-engined helicopter. Depending on the airspeed, a pilot might have less than one second to respond, although it is likely that the pilot would have some advance warning from the handling of the aircraft and anticipate the warning. A warning of this urgency is a special case, more urgent than the normal priority one warnings.

A priority one warning sound would normally require a pilot to begin to respond within about 3 seconds. This would allow the pilot time to confirm the warning sound by looking at the CWP, but suggests that the initial burst of a warning sound should be recognised in the first second or so and be completed in under, say 1.4 seconds. This in turn suggests that priority one bursts should have 9 or fewer pulses. The sequences in Figure 2 are recommended but may be modified after experience has been gained in trials. The timings allow the initial burst to be played twice in the first 3 seconds if required.

4.6 Military radio altimeter sounds

The ergonomic requirements for the warning sounds of a military radio altimeter differ from those of other warning sounds in that:-

i) the condition being monitored, i.e. low flying, is deliberate, not accidental;

ii) the condition may exist for long periods of time;

iii) the information presented to the pilot is quantitative, and shows trend, it is not merely present or absent;

iv) the pilot will know in advance that the sound will occur or continue to occur, he will be listening for it and will not need to identify it as he would an unexpected warning.

All the above requirements differ from those of airworthiness warnings and in fact from those of the civil radio altimeter use. Military radalt sounds therefore will not conform exactly to the guidelines covering airworthiness warnings.

4.7 Summary of additional guidelines for military helicopters

The following guidelines for airworthiness warning sounds in military helicopters are additional to and in some cases supersede those for civil airliners. These guidelines do not apply to radalt or to rotor-droop warnings in a single-engined helicopter, which require special consideration.

i) A sound will always mean the same, in any helicopter in which it is installed.

ii) There will be 3 categories of warning priority.

iii) Most priority 1 warnings will be grouped under one priority 1 sound. All priority 2 warnings will be grouped under one priority 2 sound. All priority 3 warnings will be grouped under one priority 3 sound. These 3 sounds will be the same in every helicopter. Only the few most urgent priority one warnings will have their own sounds.

iv) Priority 1 and Priority 2 general warning sounds will be accompanied by voice messages for specific malfunctions or events. The Priority 3 sound may have accompanying voice messages, if required.

v) The initial burst of a priority one sound should have nine or fewer pulses and be complete in 1.4 seconds or less.

vi) The general formats of Figure 2 will be used.

vii) Warning sounds will be heard through the CCS.

viii) The level (and if necessary the spectrum) of the warning sounds will be adjusted automatically as communication microphones are switched on and off, to maintain an appropriate relationship between warning sound levels and noise levels at the ear.

ix) The lower limit for the range of levels appropriate for the prominent spectral components of auditory warning sounds is 15 dB above the threshold imposed by the background noise, or 70 dB SPL, whichever is the higher.

x) The frequency range for the auditory warning main spectral components will be 500 Hz to 3.2 kHz (cf 500 Hz to 5 kHz in civil airliners). There will be at least 5 harmonically related components in that range.

Note that these guidelines may be modified in the course of further work.

5.0 AUDITORY WARNINGS FOR THE SEA KING

A set of auditory warnings was made for the Westland Sea King helicopter, assuming "hot microphone" communications, to be used in conjunction with NVG trials. The Sea King has no auditory warnings at present.

5.1 Warnings required

The following airworthiness warnings were originally specified.

Sound	Priority	Meaning	Specific Voice Messages
A	1	Engine fire	"Fire, engine number one" "Fire, engine number two"
B	1	Servo pressure	"Servo pressure, primary" "Servo pressure, auxiliary"
C	1	Transmission oil	"Transmission oil, temperature" "Transmission oil, pressure"
D	1	Gearbox chip	"Gearbox chip"
E	2	Caution	"Fuel bypass" "Fuel computer" "Generator fail" "Anti-ice"
F	3	Attention	"Fuel low" "Rectifier failure"

Subsequently, military rad-alt sounds were added to the requirements

The specification was modified during the project to regroup the priority one warnings under a single sound. This was to minimise the total number of sounds required to provide for all types of UK military helicopters (see Section 4.4). In addition, since the requirement for the radalt had not been completely formulated, temporary "low height" and "no track" warnings were introduced. These may eventually be superseded by a more comprehensive set of sounds indicating rad-alt function, which will be separately reported.

The revised specification is as follows:-

Sound	Priority	Meaning	Specific Voice Messages in the Sea King
A	1	Emergency	"Fire, engine number one" "Fire, engine number two" "Servo pressure, primary" "Servo pressure, auxiliary" "Transmission oil, temperature" "Transmission oil, pressure" "Gearbox chip"
E	2	Caution	"Fuel bypass" "Fuel computer" "Generator fail" "Anti-ice"
F	3	Attention	"Fuel low" "Rectifier failure"
G	-	Low height	
H	-	No track	

Other voice messages may accompany the same sounds when they are installed in helicopters other than the Sea King, and additional voice messages may be added, even in the Sea King.

5.2 Specifying levels for warning sounds

The sound levels needed for auditory warnings are determined by the noise spectrum at the listener's ears. This spectrum must either be estimated or measured. When all the communications microphones in the helicopter are switched off, the noise levels at the flight crew's ears are low and there is some leeway in specifying acceptable levels for warning sounds. Under these circumstances, the noise spectrum at the ear can be estimated with sufficient accuracy by subtracting the helmet attenuation characteristic from the cabin noise spectrum. This method has several advantages and is illustrated in Appendix C for the Puma helicopter.

When one or more communication microphone is switched on, estimation is not, at present, reliable. We do not have sufficient data on the spatial and temporal variations in noise level within the cabin which will be picked up by the microphones and fed into the CCS. Neither do we have sufficient data on the CCS gain settings set by flight crew or their preferred listening levels under various conditions. Little confidence could be placed in any estimate. Instead we have to rely on such measured data as are available.

5.2.1 The noise spectrum at the ear in the Sea King

Figure 3 shows a spectrum measured at the ear in a Sea King. Two communications microphones were switched on feeding cabin noise without speech into the CCS. The crew were equipped with MK4 Helmets with Socapex noise-cancelling microphones.

The spectrum was obtained from a calibrated tape recording supplied by RAE. The recording was made on a Nagra IV SJ with a Knowles BT1759 microphone taped to the pilot's ear under his helmet. The recording was played into a Bruel and Kjaer Type 2032 Dual Channel Analyser and the measured spectrum transferred to a Hewlett-Packard 9816 computer for storage on magnetic disc.

The recording was analyzed with a frequency span from 0 Hz to 6.4 kHz which gave an 801 line spectrum with a resolution of 8 Hz and, because of the Hanning weighting used, an effective noise bandwidth of 12 Hz for each line. The measurement duration was 6 seconds.

Note that by convention in the auditory masking and auditory warning fields, the levels are plotted as spectrum levels. The spectrum levels were calculated from the measured band levels by subtracting ten times the logarithm of the ratio of the measurement bandwidth to one hertz, which is 10.8 dB in this case, i.e. 10 Log (12 Hz/1Hz). This is common practice and is valid for the broadband components of the spectrum but not strictly valid for the tonal components. It does not affect any of the calculations described below.

5.2.2 Threshold calculation

The masked threshold for pure tones imposed by the noise spectrum in Figure 3 was calculated using the computer program developed at ISVR for the MOD(PE) under contract A94B/3593. The program, which at present runs in BASIC 3.0 on a Hewlett-Packard 9816 desk-top computer , was designed specifically for predicting threshold in complex noise environments such as those in helicopters, and has been validated in trials with Chinook, Lynx and Sea King noise at realistic levels in the RAE Helicopter Simulator [9,10].

The input to the program is a narrow-band spectrum of the masking noise, such as that obtained from the B&K 2032 Dual Channel Analyzer. The program calculates a masked threshold at any frequency by calculating the shape of the auditory filter centred at that frequency, weighting the masking noise spectrum by the filter shape and integrating the power in the filter pass band. The sensitivity factor which is essentially the signal to noise power ratio required for threshold is then added to give the predicted masked threshold. This method differs from the analytical approach given in the CAA Paper and is more convenient for predictions for helicopters where noise levels change rapidly with frequency across the spectrum.

Various models of auditory filter may be chosen. For these calculations the Roex(p) model described by Patterson et al [11] was used. It has been shown to give the best prediction for helicopter noise of the available models.

Figure 4 shows the predicted threshold curve. This was calculated at 40 Hz increments from 240 Hz to 5120 Hz.

5.2.3 Appropriate level range for warning-sound components at the ear

Figure 5 shows the upper and lower limits between which the levels of the spectral components of auditory warning sounds should lie. The upper and lower limits are respectively 25 dB and 15 dB above the threshold in Figure 4, in line with the guidelines in CAA Paper 82017. The broken line shows 90 dB SPL for comparison only.

5.2.4 Voltage limits for auditory warning sounds at the telephone input

Figure 6 shows the upper and lower limits for auditory warning components in terms of the drive voltage across the Mk4 telephone. A voltage between the limits shown in Figure 6 will produce a sound level within the limits shown in Figure 5, assuming an average Mk4 telephone is used. The broken line shows the drive voltage required to give 90 dB SPL at the ear. It corresponds to the broken line in Figure 5 and its shape is the inverse of the telephone frequency response.

In deriving the limits shown in Figure 6 the response of the Mk4 telephone was assumed to be midway between the average responses in the size 3 and the size 4 helmet as measured by Rood and Lucas [12]. The voltage scale in decibels is nominal, assuming a telephone output at 1 kHz of 93.5 dB SPL for 0.55 volts input (a sensitivity of approximately 1.6 Pa/V).

Above about 3.3 kHz the telephone output is too low to be useful for auditory warning components. Above 4 kHz there is considerable variation between the outputs of different telephone samples. The response is therefore plotted up to 4 kHz only and the frequencies of warning components should be limited to about 3.2 kHz.

5.3 Methods used to make the warning sounds

The auditory warning sounds for the Sea King were all computer generated using SEDIT, the sound editing facility at APU. The various stages are outlined below and described in detail in Appendices D and E.

5.3.1 Pulse generation

The fundamental frequency for a pulse was selected from the set 150, 200, 240 and 530 Hz. The harmonics of the fundamental were then chosen. A considerable range of timbres can be generated by including or omitting various harmonics. The relative amplitudes of the harmonics were set to fall within the range of voltage levels calculated for the Sea King and shown in Figure 6. These frequencies and levels were entered into the SEDIT computer and, in essence, the Fourier transform of the required pulse spectrum was 'drawn' in computer memory.

The Fourier spectrum was then inverse Fourier transformed to produce a digitised waveform in the computer memory and this waveform was multiplied by a pulse envelope with appropriate rise and fall times to produce the finished pulse waveform. The waveform could at this point be played through a D to A converter, amplified and auditioned through a loudspeaker or headphones. Each completed waveform was stored in a file on magnetic disc for future use.

Various refinements to the above technique were used to make the pulse sound less synthetic and more like a naturally occurring sound. For example the frequencies of alternate harmonics were displaced by a few percent from the exact multiple of the fundamental frequency, and with some sounds the entry of higher harmonics was delayed relative to the entry of the lower harmonics, as in brass musical instruments.

The set of fundamental frequencies was chosen to avoid harmonic relationships. Pulse durations were between 150 and 200 ms. Rise-times and fall-times were either 'standard' at 25 ms or 'slow' at 175 ms legal combinations depending on the pulse duration. Subjectively the long rise-time is perceived as similar to a bowed stringed instrument or woodwind. The standard rise-time with the long fall-time resembles a plucked string.

Full details of the methods used are given in Appendix D.

5.3.2 Burst generation

To produce each burst a pulse waveform was selected and recalled into computer memory from disc. The pulse was sequenced into a burst by specifying the number of pulses (i.e. the number of plays of the basic waveform) in the burst, the waveform play speed for each pulse which determines its pitch, the relative amplitude for each pulse and the time intervals between successive pulses. These burst parameters were stored with the pulse waveform and used to generate the burst each time the burst is required. This is a more economical use of computer memory than generating and storing the entire burst waveform.

Once the basic burst, usually but not necessarily the initial burst, had been designed, the burst parameters were manipulated to produce the other versions, namely, the urgent and background bursts. When the bursts have been finalised, the parameters that specify their construction are stored on disc.

5.3.3 Voice message

Voice messages were created by recording a female voice and digitising the recording. The waveforms of processed recordings were edited and stored on magnetic disc. These voice messages are provisional to illustrate one possible format and will be re-recorded later.

5.3.4 Final warning assembly

The final assembly of each warning was effected by specifying the names of the disc files containing the initial, urgent and background burst data and the voice message waveform, with instructions to sequence these as a priority 1, 2 or 3 sound as illustated in Figure 2. The complete warning could then be auditioned and any minor modifications made.

The completed warning sounds were replayed from the SEDIT computer and recorded digitally using a Sony PCM-F1 Digital Audio Processor and video recorder. Recording level controls were not adjusted, so that each warning sound was at the correct level relative to all the others. Ten sounds were supplied initially, including some spare sounds so that the most discriminable could be selected. The recording was supplied to RAE FS(F)4 where the warning sounds were evaluated for memorability and discriminability.

6.0 DISCRIMINABILITY TRIALS OF THE WARNING SOUNDS

The warning sounds were evaluated for discriminability in the Helicopter Noise Simulator at RAE. Two groups of 10 subjects, one group of pilots, one of non-pilots took part. The experiment was structured as a self-paced learning programme in which the subjects were required to learn and later identify the initial bursts of the warning sounds. All the sounds were presented through telephones in Mk4 flying helmets at a level of 18 dB above masked threshold while subjects sat in a realistic Sea King cabin noise environment. Full details of the experiment are given in Appendix F.

It was found that subjects quickly learned the first few sounds they were presented with but the time taken to learn each new sound increased sharply when the number of sounds exceeded 5. Nevertheless none of the subjects had any difficulties and could identify at least 9 out of 10 sounds by the end of the experiment when these were presented once each in random order. Some infrequent but statistically significant confusions were found between some specific warnings, and these warning sounds were subsequently modified or replaced.

The experiment was repeated with the revised set of warnings and a new group of 10 non-pilot subjects, the first experiment having shown no major differences between pilots and non-pilots for the purpose of these experiments. Again there were some infrequent but statistically significant confusions with particular pairs of warnings. Nevertheless from these two experiments a satisfactory set of maximally mutually discriminable, warnings has been defined by RAE. There are sufficient warnings to satisfy the immediate requirements for the Sea King, and two 'spares' for future use in other helicopters.

7.0 DOCUMENTATION AND DESCRIPTION OF THE WARNING SET APPROVED FOR THE SEA KING

To avoid any confusion only the warning sounds approved on the basis of the discriminability trials will be described here. Details of the sounds which were not selected are available on request.

The best documentation of the warning sounds is the digital audio recording. However, it is also possible to document the bursts by specifying the pulse parameters and burst parameters, as in Figures 7 to 20. These Figures and Figure 2 contain all the necessary information for constructing the warnings using the SEDIT software or a similar suite of programs, with the exception of the voice messages which are talker specific.

Figures 7 to 13 specify the pulse parameters. The "weighting" column shows the relative magnitude of each component on a linear scale proportional to voltage.

Figures 14 to 20 specify the burst parameters. In the graph at the top of each figure, each box represents a pulse. The pulse duration is shown by the length of the base of the box; the fundamental frequency or pitch, P, is shown by the ordinate of the box base-line; the amplitude of the pulse is proportional to the height of the box.

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12. ROOD, G.M. and LUCAS, S.H. 1983: "Measurement of telephone frequency response on the Mk2/3 series and Mk4 flying helmets, and correlation between semi-objective and objective measurement techniques for the Mk4 telephones". Technical Memorandum FS(F)518, Royal Aircraft Establishment, Farnborough.

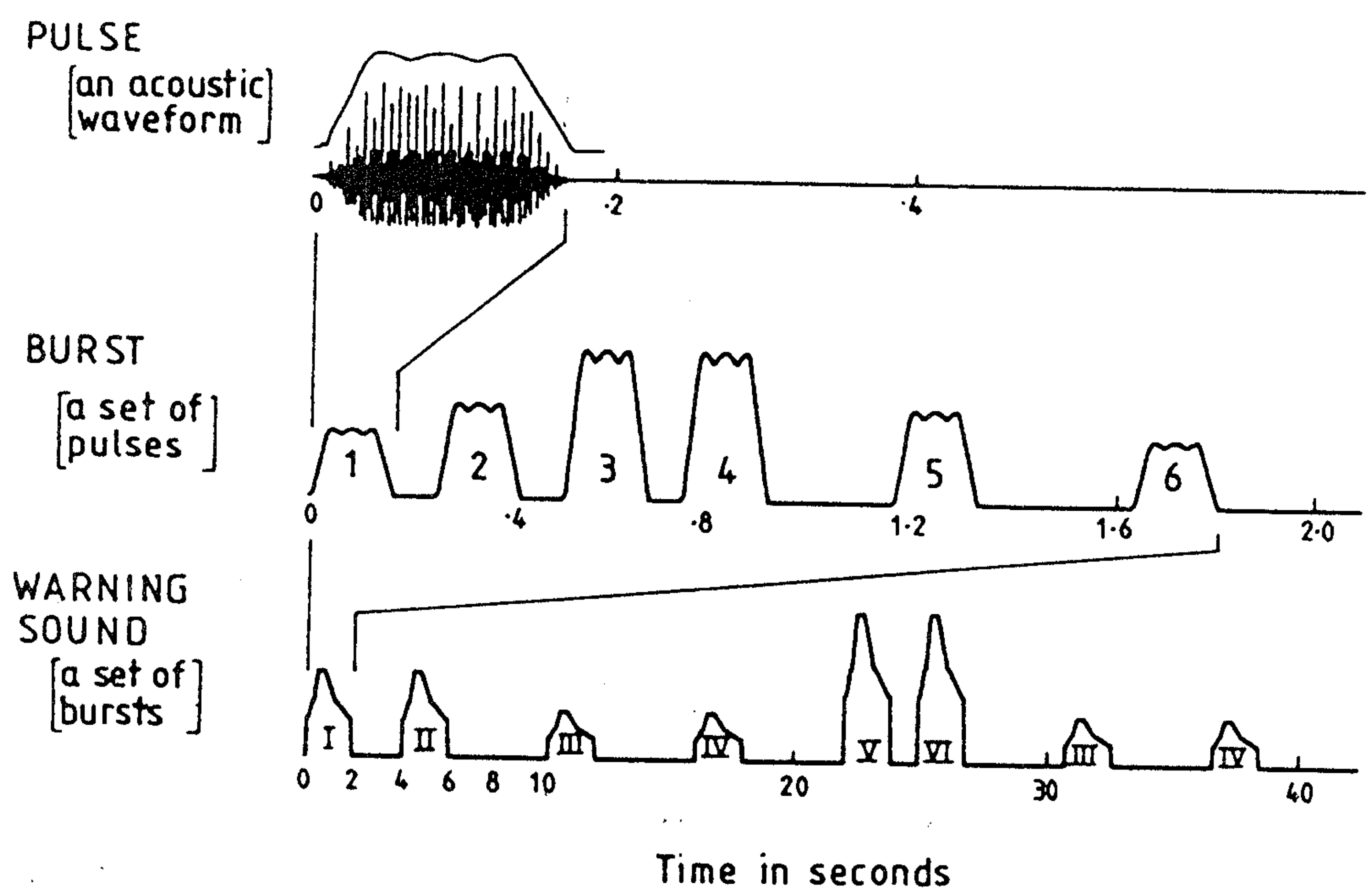


Figure 1: The general structure of an advanced warning sound

FIGURE 1

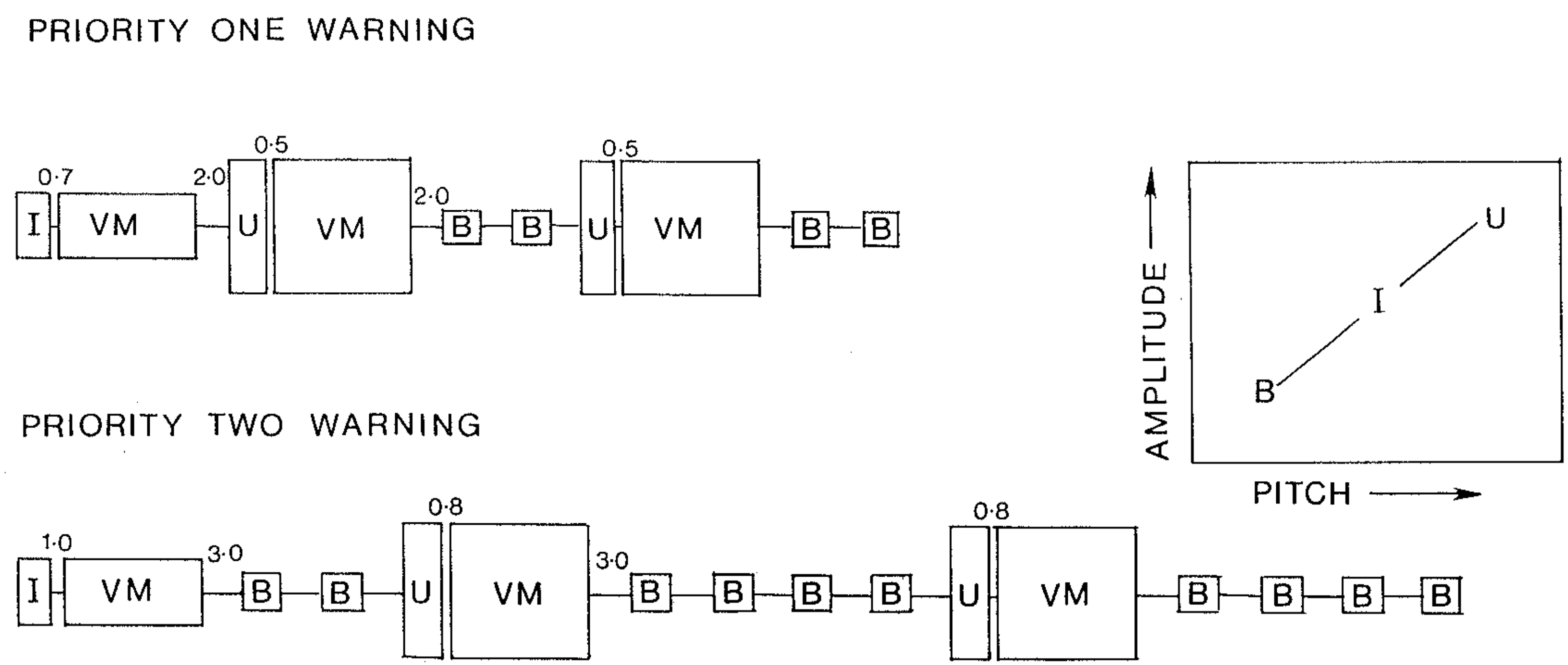


FIGURE 2 AUDITORY WARNINGS FOR HELICOPTERS:

FORMAT FOR PRIORITY 1 AND PRIORITY 2 WARNINGS

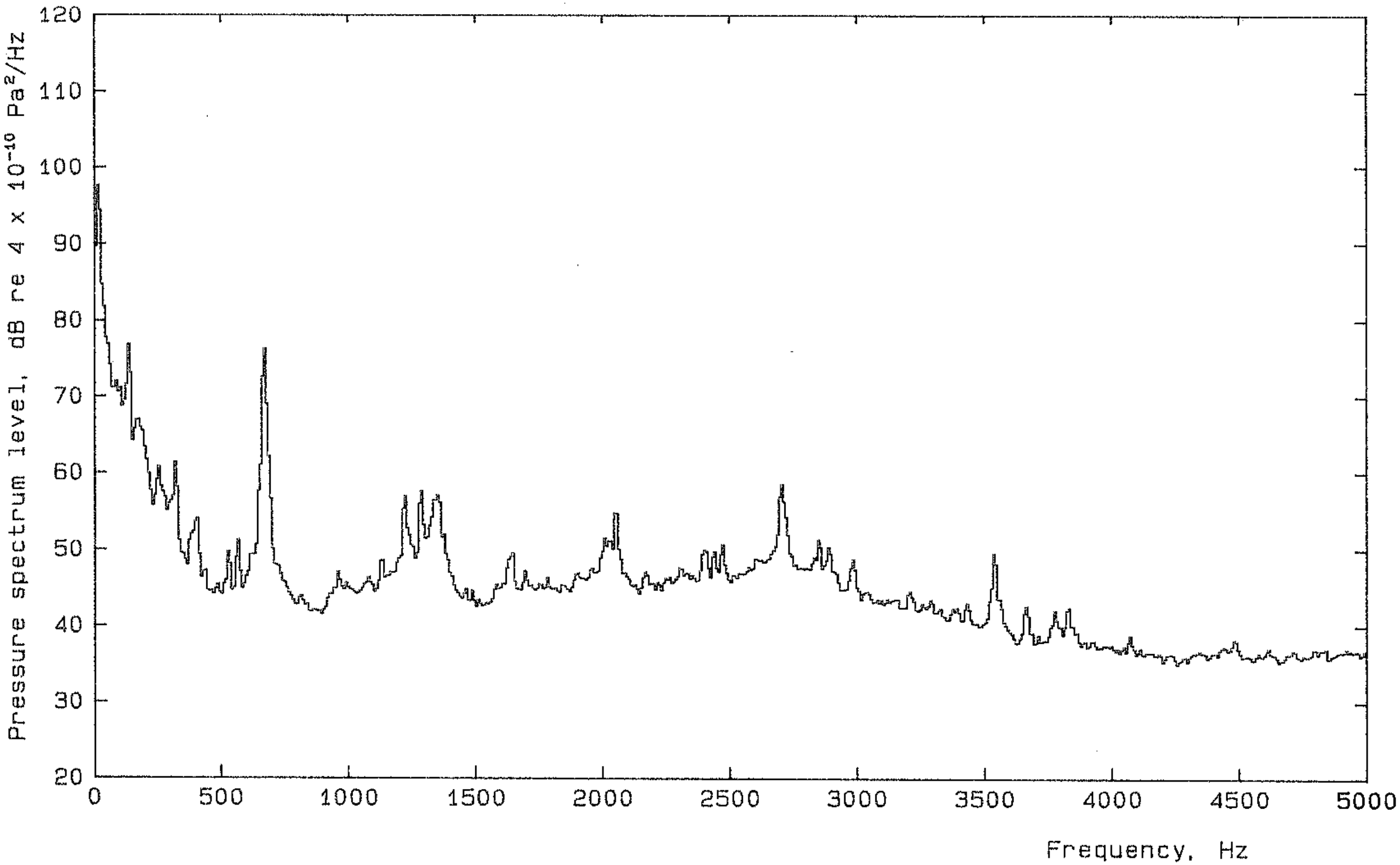


Figure 3 Sea King noise spectrum measured at the ear, CCS on, without speech.

Figure 3

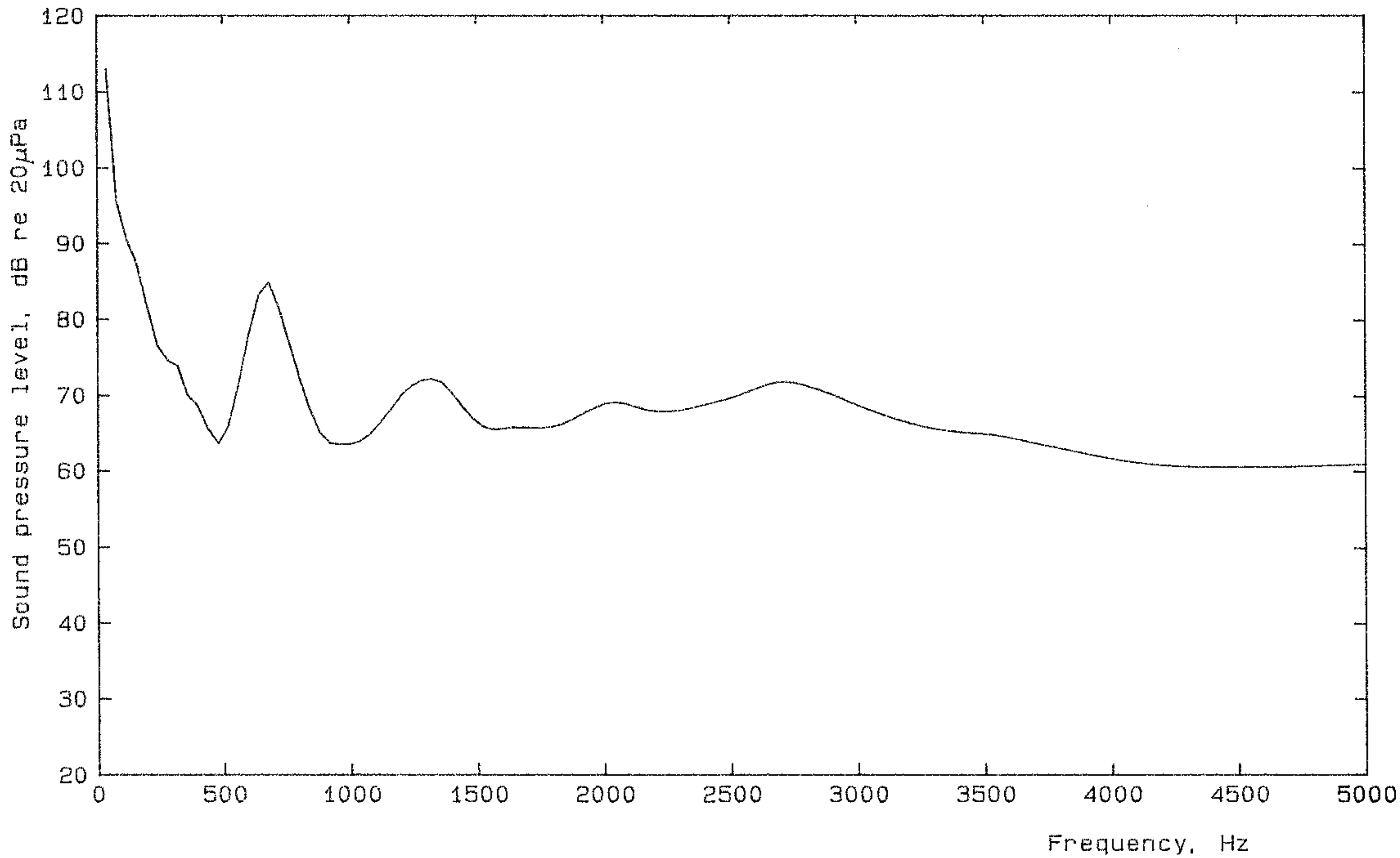


Figure 4 Masked pure-tone threshold calculated for the spectrum in Figure 1.

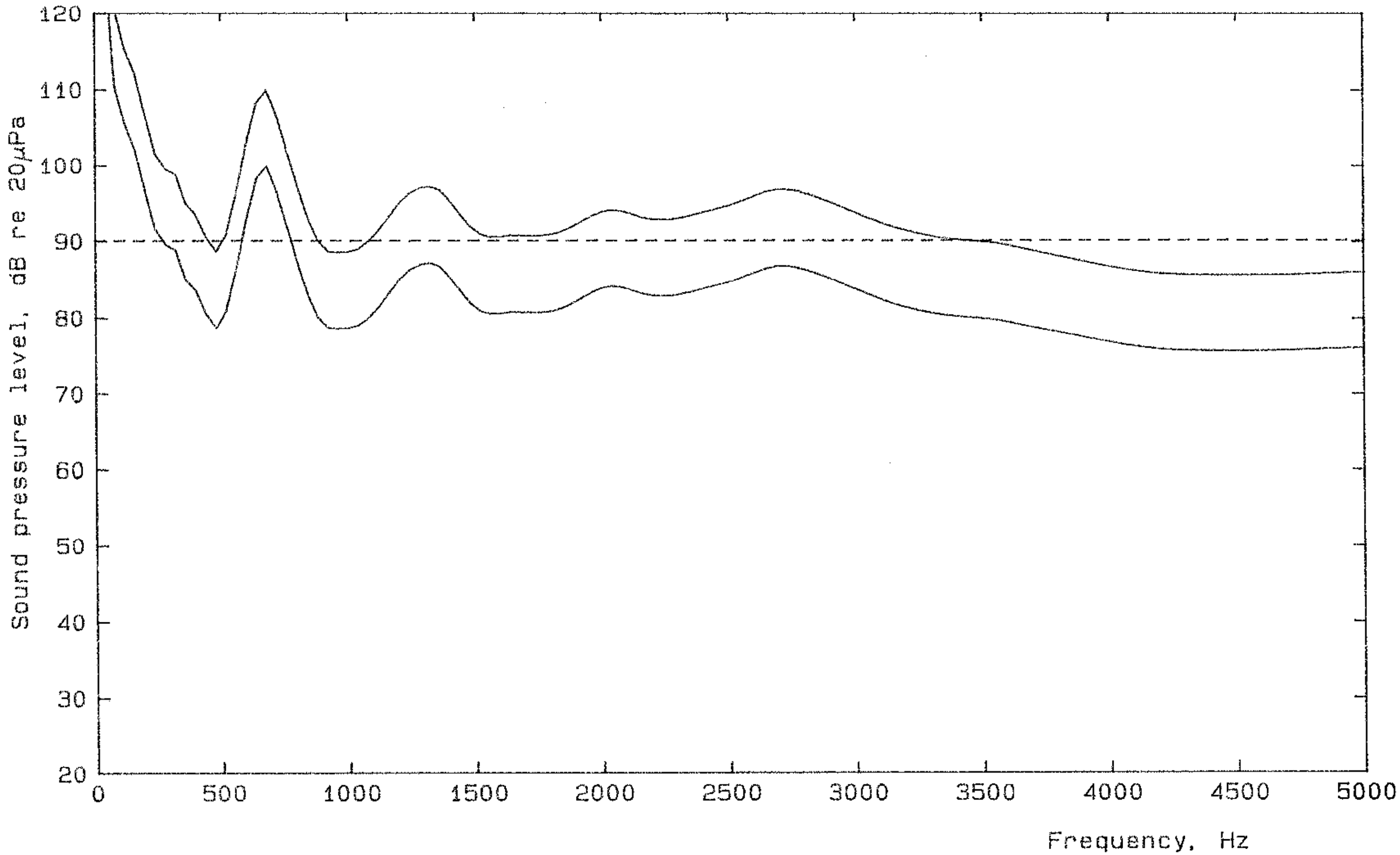


Figure 5   Upper and lower limits for warning components, 15dB and 25dB above threshold.

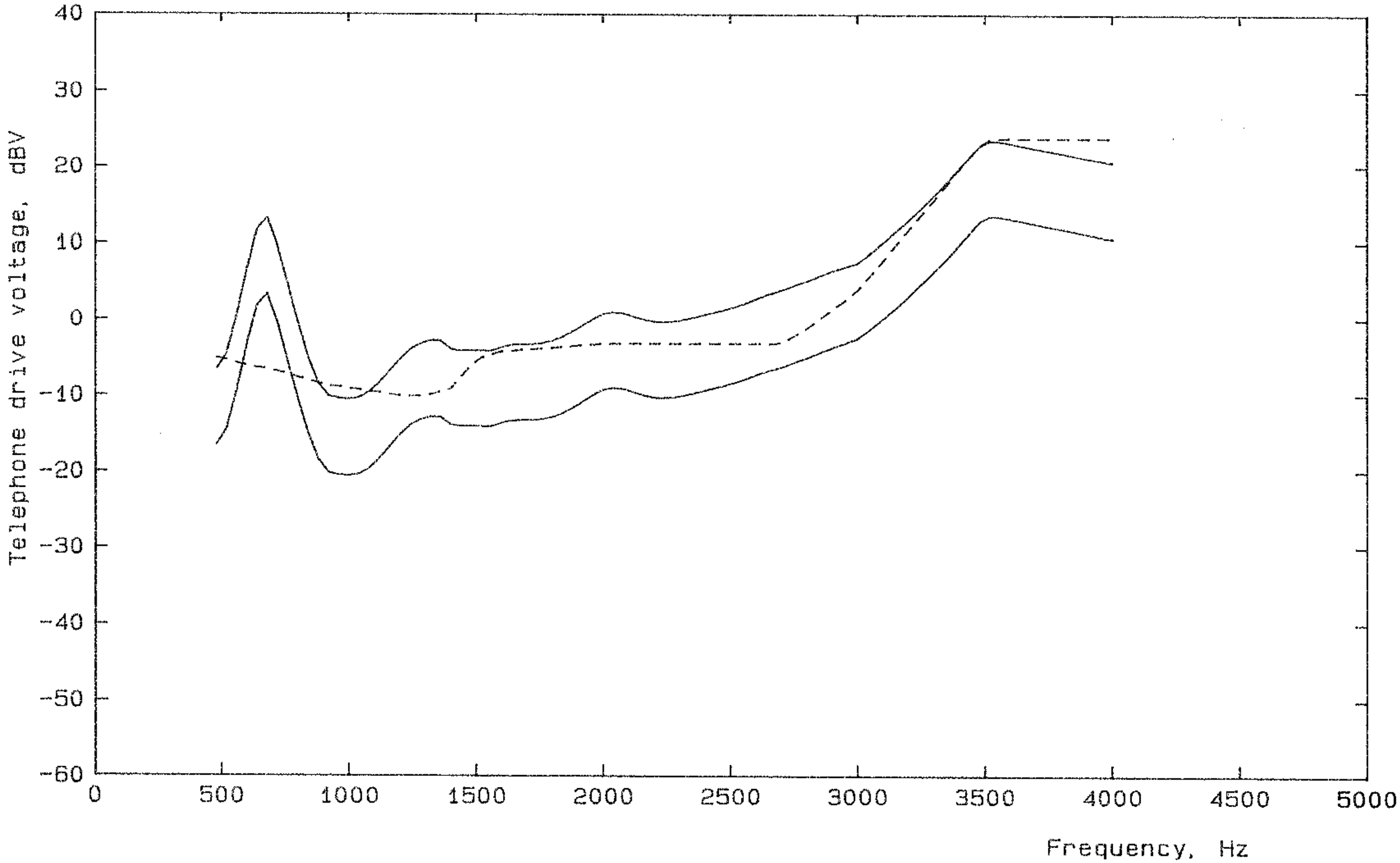


Figure 6 Input voltages to the Mk4 telephone to give the sound level limits in Figure 3.

Figure 6

SEAKING AUDITORY WARNING PULSE: PRIORITY ONE

Priority one, warning one.

Voice messages: "Fire, engine number one."
"Fire, engine number two." (demonstration)
"Servo pressure, primary".
"Servo pressure, auxiliary."
"Transmission oil, temperature."
"Transmission oil, pressure."
"Gearbox chip."

Pulse characteristics:

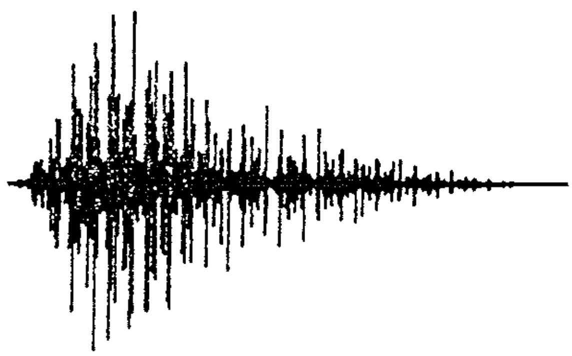
Slow offset envelope. Delayed harmonics (50 ms).

Fundamental = 240 Hz.

Alternate harmonics shifted by $\mp$ 10% (of fundamental)

Duration = 150 ms.

Pulse waveform:



Pulse spectrum:

Frequency (Hz)	Weighting
985	300
1175	498
1465	630
1655	690
1945	982
2135	1026
2425	1119

FIGURE 7 SEAKING AUDITORY WARNING PULSE:

PRIORITY ONE

PROJECT: RAE ADDITIONS - SEAKING

AUDITORY WARNING PULSE: PRIORITY TWO

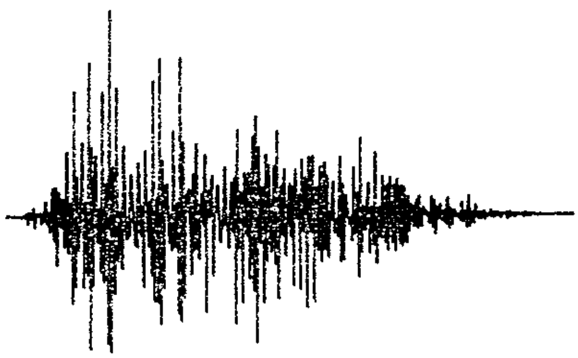
Priority: two

Voice messages: "Fuel bypass."
"Fuel computer."
"Generator fail."
"Anti-ice."

Pulse characteristics:

Pitch: 225 Hz match.
Harmonicity: Non-harmonic.
Duration: 150 ms.
Delayed Harmonics: None.
Envelope: Slow offset.

Pulse wavform:



Pulse spectrum:

Frequency (Hz)	Weighting
500	545
900	347
1200	557
1400	641
1500	628
1550	626
1575	641
1590	656
1595	660

FIGURE 8 SEAKING AUDITORY WARNING PULSE:

PRIORITY TWO

SEAKING AUDITORY WARNING PULSE: PRIORITY THREE

Priority three

Voice messages: None.

Pulse characteristics:

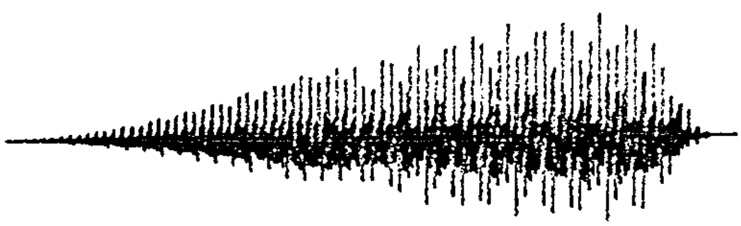
Slow onset envelope. Delayed harmonics (100 ms).

Fundamental = 200 Hz.

Harmonic series.

Duration = 200 ms.

Pulse waveform:



Pulse spectrum:

Frequency (Hz)	Weighting
400	873
800	964
1000	298
1200	557
1400	641
1600	665
1800	730
2000	1099
2200	969
2400	1091

FIGURE 9 SEAKING AUDITORY WARNING PULSE:

PRIORITY THREE

SEAKING AUDITORY WARNING PULSE: LOW HEIGHT

Voice message: "Low height."

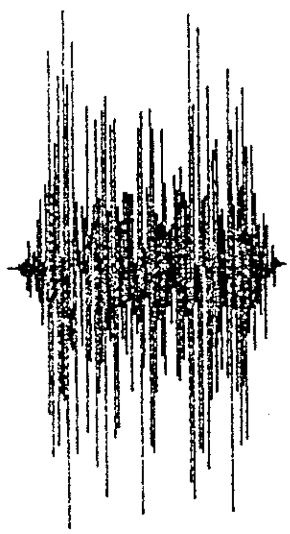
Pulse characteristics:

Standard envelope.

Non-harmonic. Pitch match = 200 Hz.

Duration = 150 ms.

Pulse waveform:



Pulse spectrum:

Frequency (Hz)	Weighting
600	2184
1000	298
1400	641
1800	730
2000	1099
2100	1073
2150	1009
2175	987
2190	976
2200	969

FIGURE 10 SEAKING AUDITORY WARNING PULSE: LOW HEIGHT

SEAKING AUDITORY WARNING PULSE: NO TRACK

Voice message: "No track."

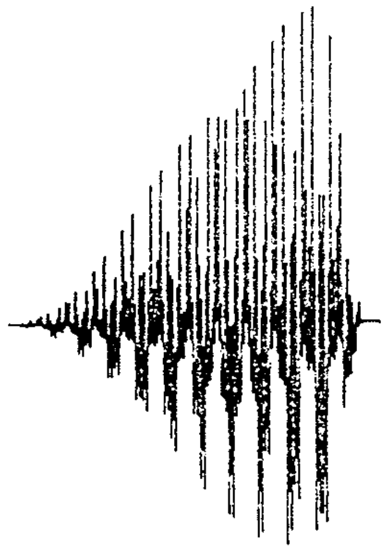
Pulse characteristics:

Slow onset envelope.

Harmonic series. Fundamental = 250 Hz.

Duration = 200 ms.

Pulse waveform



Pulse spectrum:

Frequency (Hz)	Weighting
500	545
750	2042
1000	298
1250	655
1500	628
1750	702
2000	1099
2250	968
2500	1208
2750	1689

FIGURE 11 SEAKING AUDITORY WARNING PULSE:

NO TRACK

SEAKING AUDITORY WARNING PULSE

Priority one, warning two.

Voice messages: "Servo pressure, primary."
(for demonstration purposes)

Pulse characteristics:

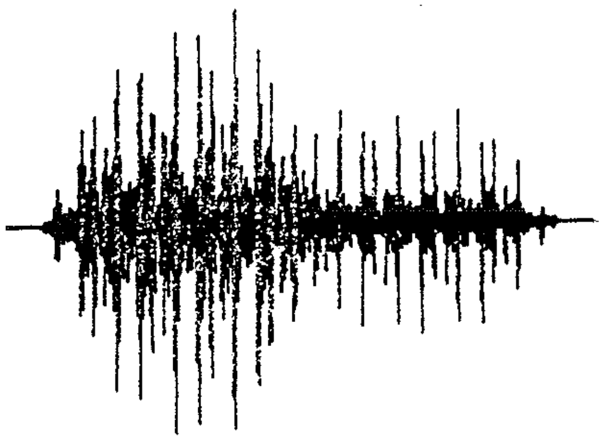
Standard envelope. Delayed harmonics (75 ms).

Fundamental = 150 Hz.

Alternate harmonics shifted by $\mp$ 10% (of fundamental).

Duration = 150 ms.

Pulse waveform:



Pulse spectrum:

Frequency (Hz)	Weighting
885	372
1065	320
1185	510
1365	723
1485	630
1665	690
1785	720
1965	1020
2085	1100

FIGURE 12 SEAKING AUDITORY WARNING PULSE:

SPARE #1 FOR FUTURE USE

PROJECT: RAE ADDITIONS - SEAKING

AUDITORY WARNING PULSE: IMMEDIATE ACTION

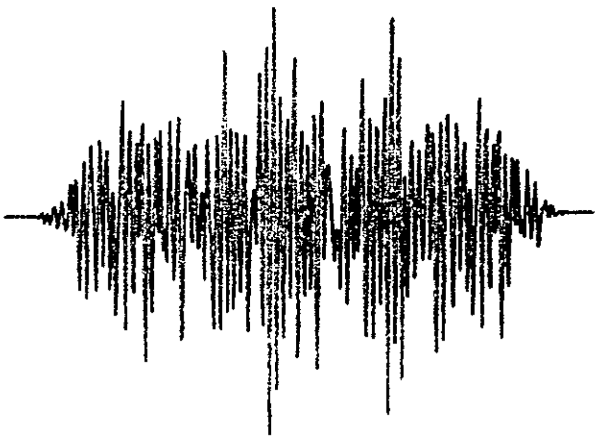
Priority: One.

Voice messages: "Gearbox chip."
(for demonstration purposes)

Pulse characteristics:

Pitch: 520 Hz match.
Harmonicity: Non-harmonic.
Duration: 150 ms.
Delayed Harmonics: None.
Envelope: Standard.

Pulse waveform:



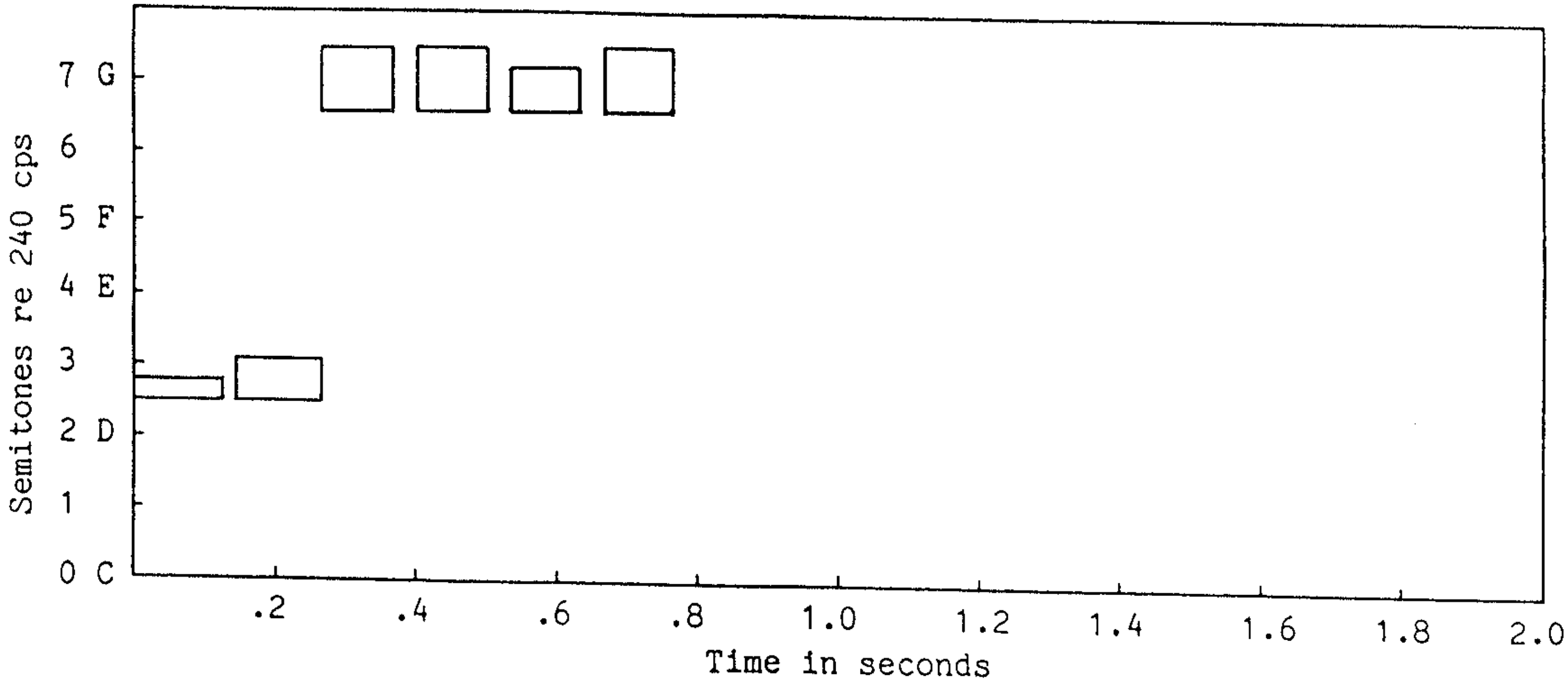
Pulse spectrum:

Frequency (Hz)	Weighting
530	733
540	854
560	1095
600	2184
840	573
1160	463
1800	730
1810	744
2450	1144
2770	1738
2930	2187
3010	2465
3050	2781
3070	2957
3080	3045

FIGURE 13 SEAKING AUDITORY WARNING PULSE:

SPARE #2 FOR FUTURE USE

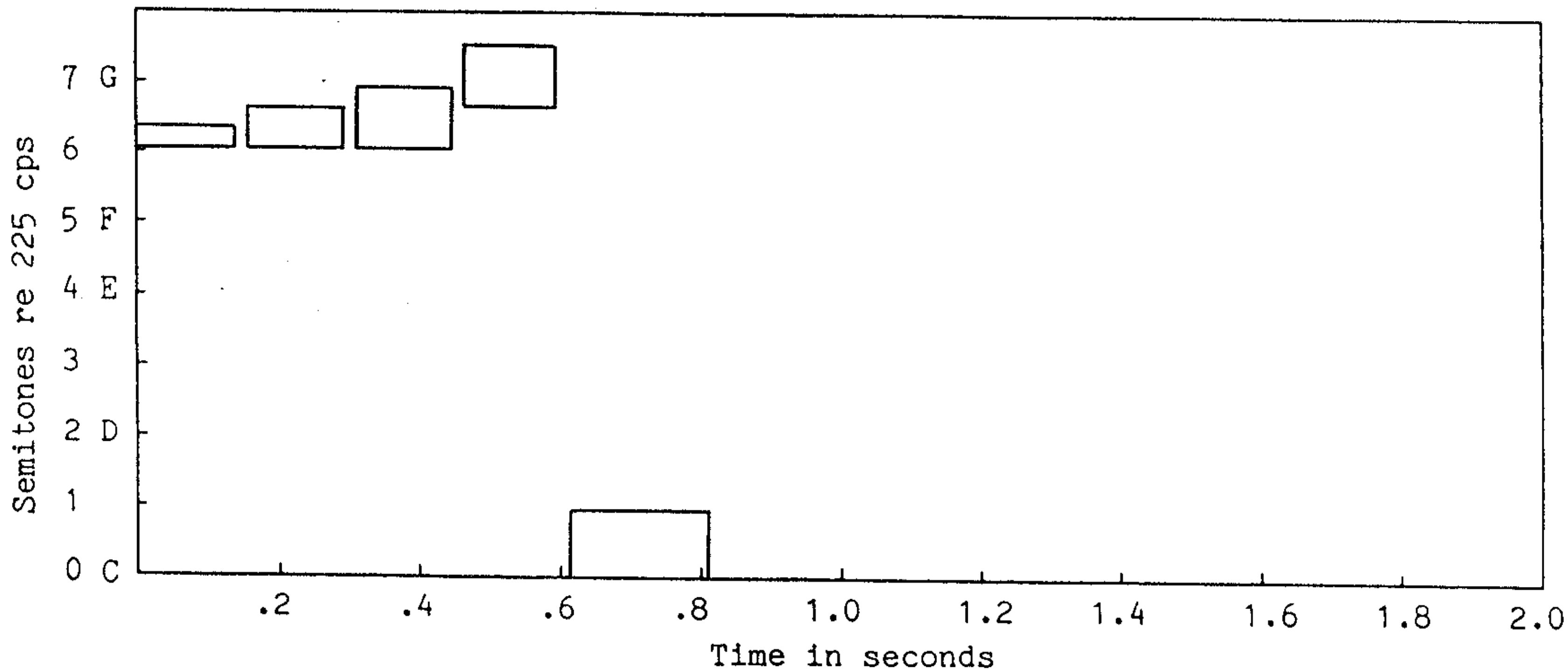
SEAKING AUDITORY WARNING BURST: PRIORITY ONE



Pulse Number			1		2		3		4		5		6
Initial Burst	P	(Hz)	279		279		352		352		352		352
	A	(dB)	14		10		6		6		10		6
	PS	(ms)		132		132		132		132		132	
Urgent Burst	P	(Hz)	314		314		387		387		387		387
	A	(dB)	8		4		0		0		4		0
	PS	(ms)		120		120		120		120		120	
Background Burst	P	(Hz)	255		255		328		328		328		328
	A	(dB)	12		12		12		12		12		12
	PS	(ms)		132		132		132		132		132	

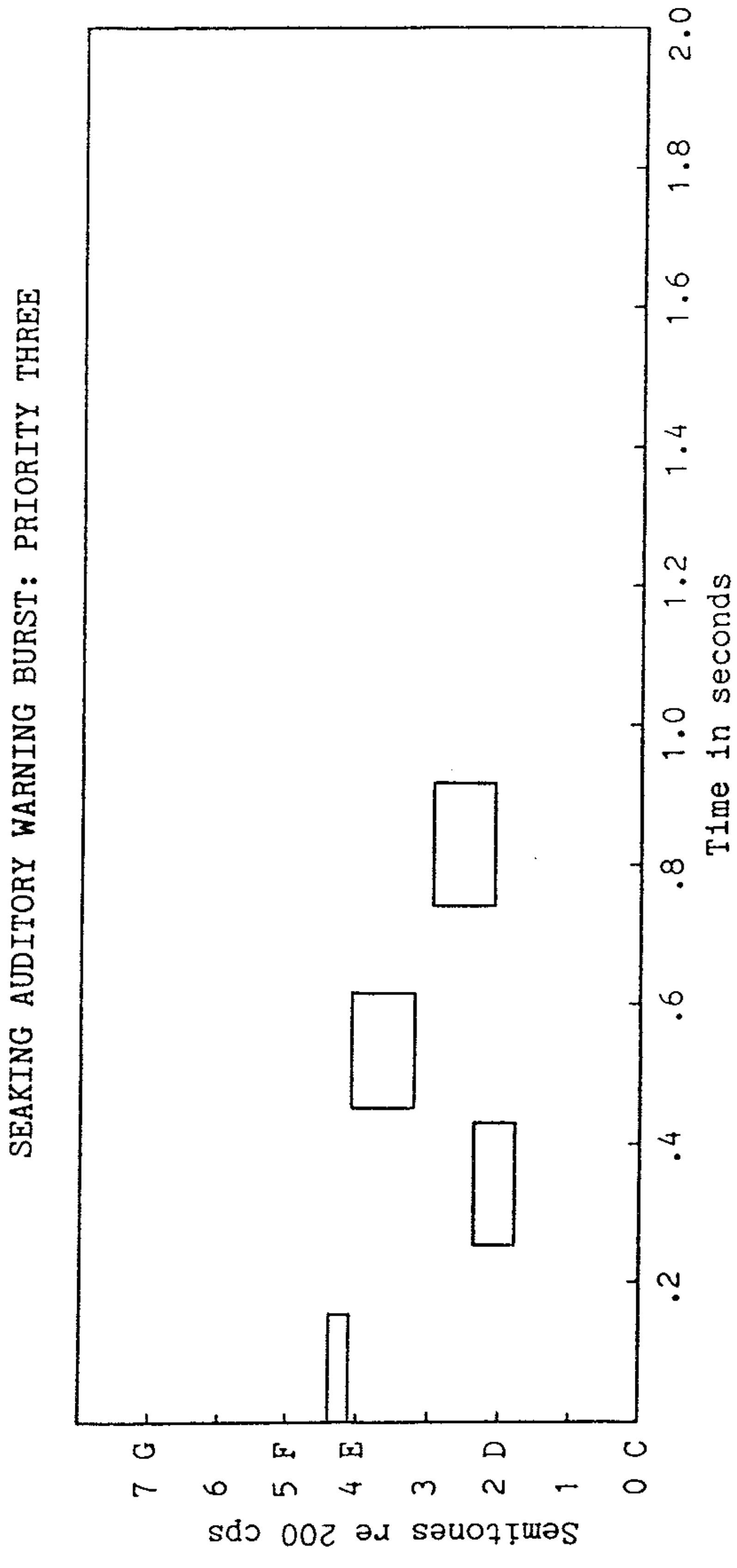
FIGURE 14 SEAKING AUDITORY WARNING BURST: PRIORITY ONE

SEAKING AUDITORY WARNING BURST: PRIORITY TWO



Pulse Number			1		2		3		4		5
Initial Burst	P	(Hz)	317		317		317		330		225
	A	(dB)	14		10		6		6		6
	PS	(ms)		153		153		153		153	
Urgent Burst	P	(Hz)	341		341		341		352		247
	A	(dB)	8		4		0		0		0
	PS	(ms)		126		126		126		126	
Background Burst	P	(Hz)	297		297		297		308		203
	A	(dB)	12		12		12		12		12
	PS	(ms)		175		175		175		175	

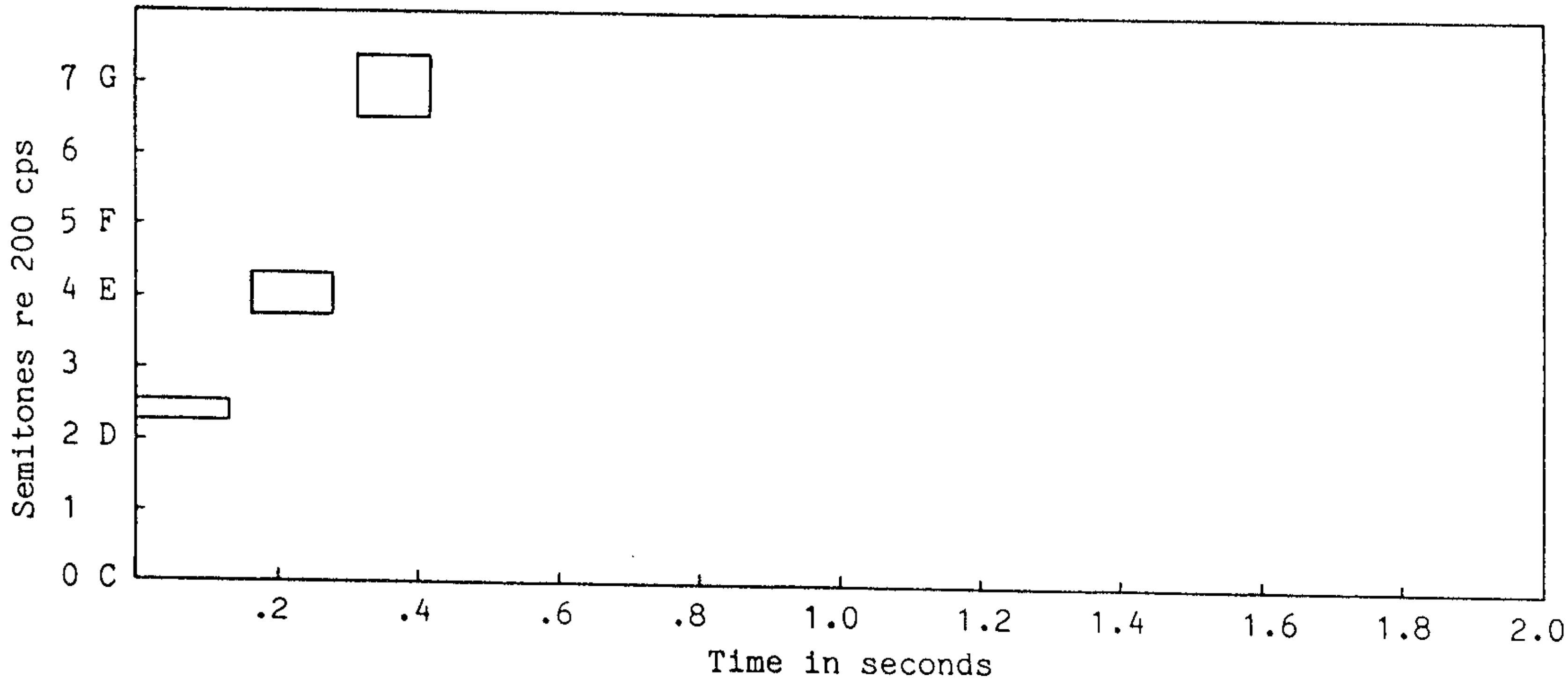
FIGURE 15 SEAKING AUDITORY WARNING BURST: PRIORITY TWO



Initial Burst		1	2	3	4
Pulse Number		1	2	3	4
P	(Hz)	254	221	240	227
A	(dB)	14	10	6	6
PS	(ms)	250	200	290	

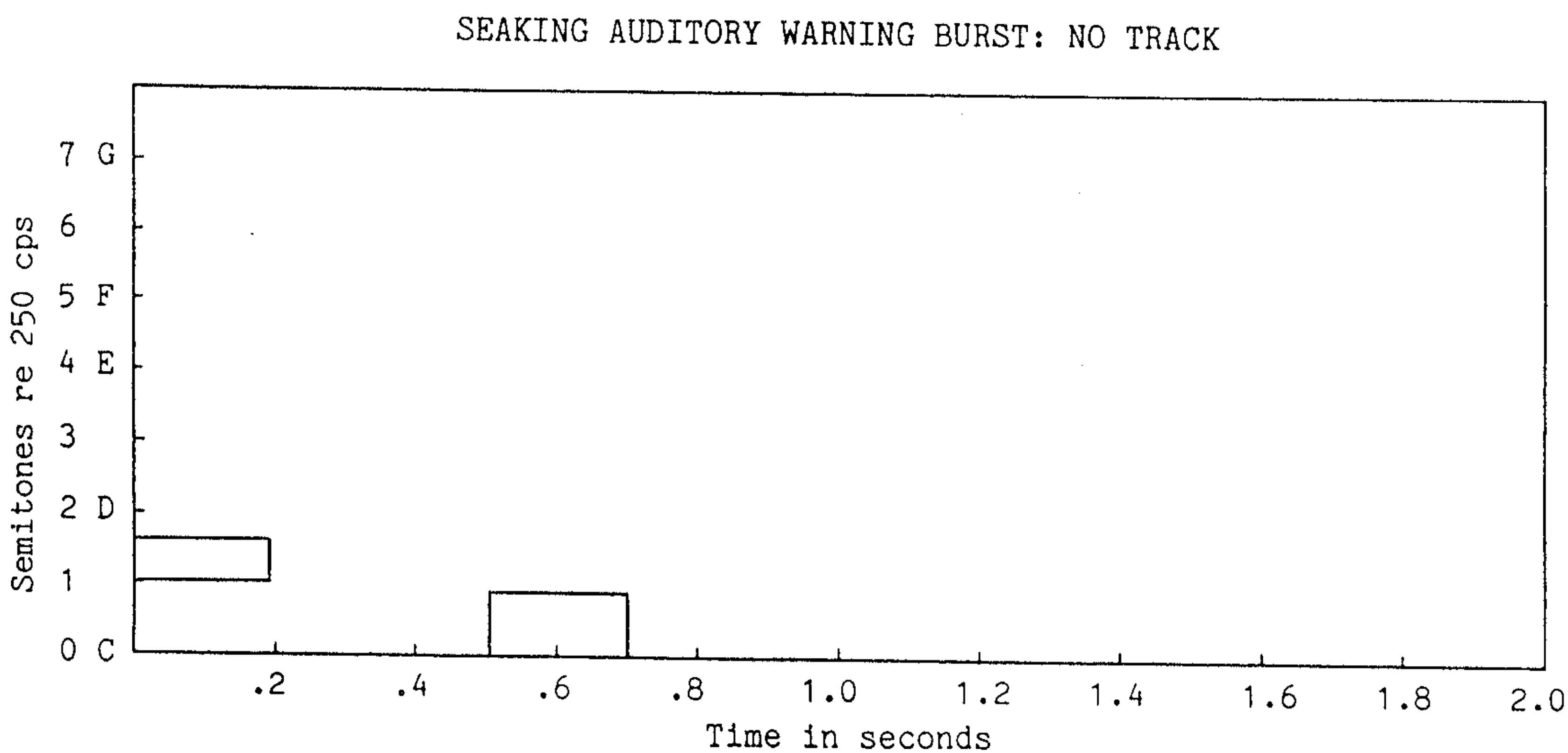
FIGURE 16 SEAKING AUDITORY WARNING BURST: PRIORITY THREE

SEAKING AUDITORY WARNING BURST: LOW HEIGHT



Pulse Number			1		2		3
Initial Burst	P	(Hz)	229		249		293
	A	(dB)	14		10		6
	PS	(ms)		158		158	
Urgent Burst	P	(Hz)	249		269		313
	A	(dB)	8		4		0
	PS	(ms)		142		142	
Background Burst	P	(Hz)	210		229		273
	A	(dB)	12		12		12
	PS	(ms)		175		175	

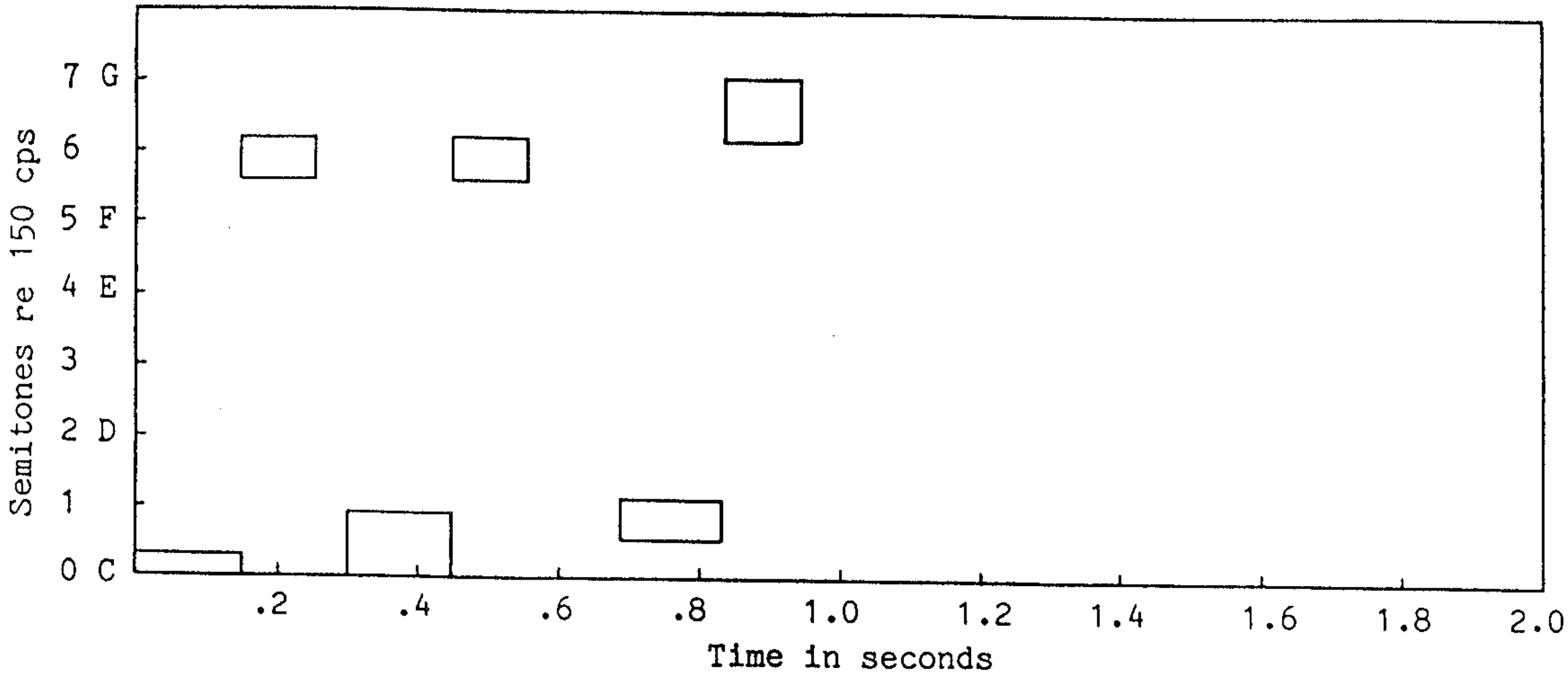
FIGURE 17: SEAKING AUDITORY WARNING BURST: LOW HEIGHT



			1		2
Pulse Number			1		2
Initial Burst	P	(Hz)	265		250
	A	(dB)	10		6
	PS	(ms)		520	
Urgent Burst	P	(Hz)	289		274
	A	(dB)	6		0
	PS	(ms)		465	
Background Burst	P	(Hz)	240		226
	A	(dB)	12		12
	PS	(ms)		570	

FIGURE 18 SEAKING AUDITORY WARNING BURST: NO TRACK

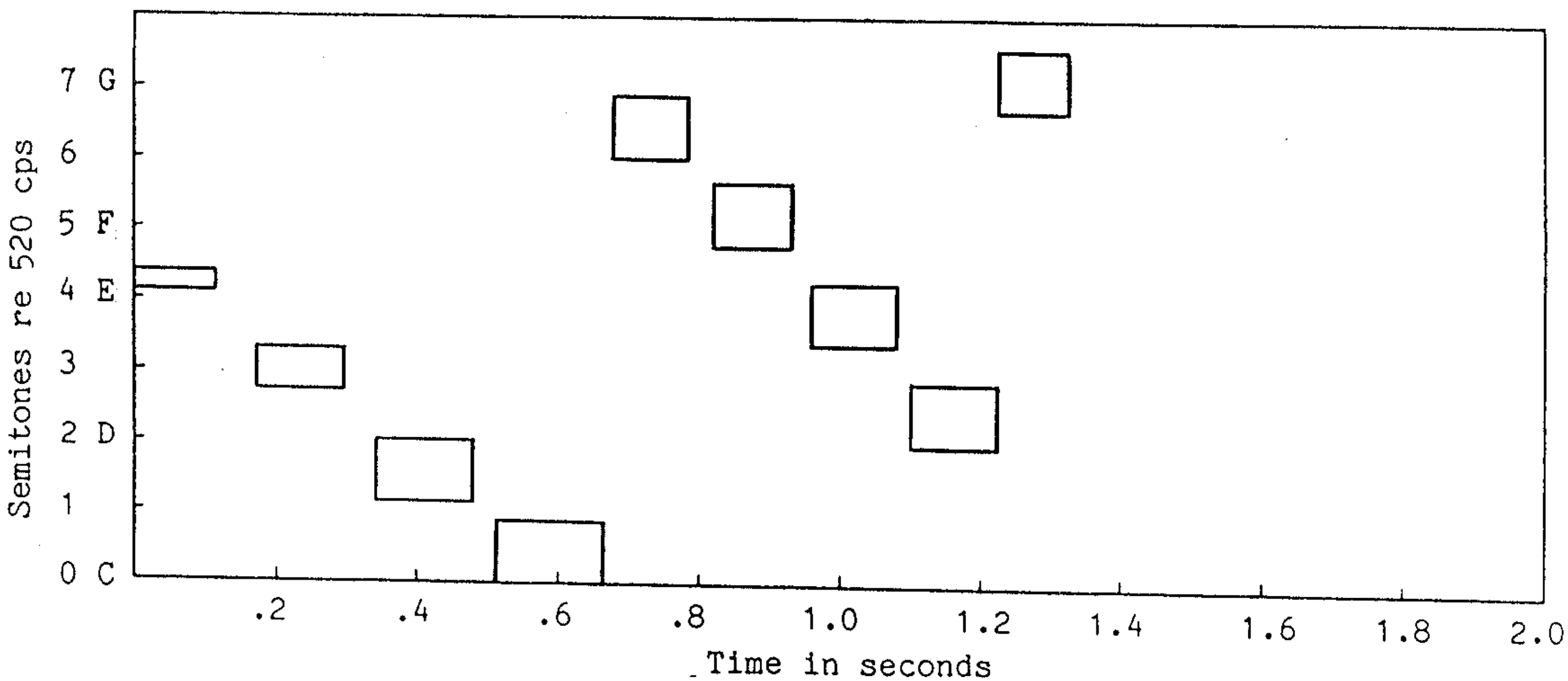
SEAKING AUDITORY WARNING BURST: SPARE #1



Pulse Number			1	2	3	4	5	6
Initial Burst	P	(Hz)	146	207	146	207	155	214
	A	(dB)	14	10	6	10	10	6
	PS	(ms)	150	150	150	230	150	
Urgent Burst	P	(Hz)	168	229	168	229	177	236
	A	(dB)	8	4	0	4	4	0
	PS	(ms)	135	135	135	210	135	
Background Burst	P	(Hz)	131	192	131	192	141	200
	A	(dB)	12	12	12	12	12	12
	PS	(ms)	150	150	150	230	150	

FIGURE 19 SEAKING AUDITORY WARNING BURST: SPARE # 1

SEAKING AUDITORY WARNING BURST: SPARE #2



Pulse Number			1	2	3	4	5	6	7	8	9
Initial Burst	P	(Hz)	660	609	558	508	736	686	635	584	762
	A	(dB)	14	10	6	6	6	6	6	6	6
	PS	(ms)	170	170	170	170	140	140	140	125	
Urgent Burst	P	(Hz)	711	660	609	559	787	736	685	635	813
	A	(dB)	8	4	0	0	0	0	0	0	0
	PS	(ms)	155	155	155	155	133	133	133	120	
Background Burst	P	(Hz)	609	559	508	457	686	635	584	533	711
	A	(dB)	12	12	12	12	12	12	12	12	12
	PS	(ms)	200	200	200	200	180	180	180	140	

FIGURE 20 SEAKING AUDITORY WARNING BURST: SPARE # 2

APPENDIX A

DEFINITIONS OF AUDITORY WARNING TERMS

Pulse	-	A brief sound (eg about 100 ms) having a specific frequency spectrum.
Start of pulse	-	The point at which the pulse envelope begins to rise from zero amplitude.
End of pulse	-	The point at which the pulse envelope returns to zero amplitude.
Rise time	-	The time over which a pulse envelope increases from 0% to 100% of its maximum amplitude (eg. 25 ms).
Fall time	-	The time over which a pulse decrfeases from 100% to 0% of its maximum amplitude (eg. 25 ms).
Pulse duration	-	The period of time between the start of the pulse and the end of the pulse.
Pulse spacing	-	The period of time between the start of one pulse and the start of the succeeding pulse.
Burst	-	A group of pulses with a distinctive rhythm (eg. 6 pulses, spread over 2 secs.).
Initial burst		The first burst in a warning sound.
Urgent burst		A highly urgent form of burst which will follow the initial bursts if no action appears to have been taken.

Background burst A low urgency "reminder' burst to indicate a continuing situation which has already been signalled with an initial or urgent burst.

Warning sound - An emergency sound or a cautionary sound composed of a series of bursts which is repeated.

Emergency sound - A warning sound which indicates a dangerous condition requiring immediate action.

Cautionary sound - A warning sound which indicates a potentially dangerous condition requiring prompt action.

Information sound- A warning sound drawing attention to a non-urgent condition, for information rather than for action.

Muting - Turning off a warning sound.

Silence period - The period of time that an alarm sound can be muted.

Masking - a) The process by which the threshold of hearing of one sound is raised due to the presence of another.
b) The increase, expressed in decibels, of the threshold of hearing of the masked sound due to the presence of the masking sound.

Priority 1 sound - Synonym for emergency sound.
Priority 2 sound - Synonym for cautionary sound.
Priority 3 sound - Synonym for information sound.

APPENDIX B

SUMMARY OF AUDITORY WARNING GUIDELINES FROM CAA PAPER 82017

The guidelines developed for civil airliners in CAA Paper 82017 are listed below. Those guidelines marked with an asterisk have been changed or qualified for militiary helicopter applications (see Section 4.7, in main text).

B.1 The overall level for flight-deck warnings

* The lower limit for the range of levels appropriate for the prominent spectral components of auditory warning sounds is 15 dB above the threshold imposed by the background noise on the flight-deck.

* The upper limit for warning-sound components is 25 dB above threshold since the levels imposed by the noise in level flight are already rather high.

B.2 The temporal characteristics of flight-deck warnings

The pulses of sound used to build a warning sound should have rise-times and fall-times that are 20 - 30 ms in duration. The gating function should be rounded and concave down.

* The sound pulses should be 100 - 150 ms in duration.

For urgent warning sounds the inter-pulse interval should be less than 150 ms. For non-urgent warnings the interval should be over 300 ms.

The warning sound should be composed of 3 or more pulses in a distinctive temporal pattern to minimise the probability of confusion among the members of the warning set.

B.3 The spectral characteristics of flight-deck warnings

* The appropriate-frequency region for the spectral components of flight-deck warnings is 0.5 - 5.0 kHz.

  The warning sounds should contain more than four components and the components should be harmonically related so that they fuse into a concise sound.

* The fundamental of the harmonics should be in the range 150 - 1000 Hz, and at least four of the prominent components should fall in the range 1.0 - 4.0 kHz.

  For immediate-action warnings the sounds might contain a few quasi-harmonic components and/or a brief frequency glide to increase the perceived urgency of the sounds.

B.4 Ergonomics

* Manual volume control should be avoided. Automatic volume control should be restricted to a range of 10 - 15 dB and used primarily to reduce the volume when the aircraft is on the ground or in the climb or approach phases of flight.

  There should be no more than six immediate-action warning sounds and up to three attentions.

B.5 Voice warnings on the flight-deck

The voice warnings incorporated into the immediate-action warnings should be brief and use a key-word format. They should not be repeated in the background version of the warning.

The voice warnings used as immediate-awareness warnings should use a full-phrase format and be repeated after a short pause.

The frequency range appropriate for warning-sound components is also appropriate for speech (0.5 - 5.0 kHz).

The appropriate level for voice warnings can be achieved by positioning the maximum of the average speech spectrum (typically the components of the first formant) near the maximum of the appropriate-level range for warning components.

In the region 0.5 to 5.0 kHz, a progressive amplification of about 3 dB per octave will improve the speech intelligibility.

APPENDIX C

DEMONSTRATION WARNING SET FOR THE PUMA : SETTING WARNING SOUND LEVELS FOR COLD MICROPHONE COMMUNICATIONS

C.1 Introduction

Before making warning sounds for the Sea King, a demonstration set of warnings was made which was tailored to the noise at the ear in the Puma helicopter. The demonstration set, which will not be issued for service, was used for the following:

(i) to demonstrate the concepts and sounds of advanced auditory warnings to flight crew;

(ii) to promote discussion of the needs of flight crew for auditory warnings, the situations in which warnings would be needed and the reactions and urgency involved;

(iii) to assess the applicability to military helicopters of the guidelines for civil airliners, and to modify these if necessary;

(iv) to develop and test methods and software.

The methods used to specify appropriate sound levels for warning sounds are described here to illustrate the approach with "cold microphone" communications.

C.2 Cabin noise measurements

In military helicopters, auditory warnings will be presented through the communications telephones in a flying helmet. The background noise spectrum at the ear under the helmet will determine the appropriate sound levels for the warnings. The noise at the ear can be measured directly with miniature microphones. At present this is necessary when communications microphones are transmitting cabin noise into the CCS and thereby increasing noise levels at the ear. But if all the communications microphones are off, the noise at the ear can be estimated rather than measured, by subtracting the helmet's noise attenuation characteristic from the noise spectrum measured in the cabin.

In practice the estimation has three advantages:-

a) fewer in-flight measurements are needed;

b) the range of measured sound levels over the audio frequency range is much narrower; and

c) the instrumentation is simpler.

For this project these advantages are academic because the only available data on the Puma noise environment were recordings of the cabin noise at a position between the pilots. However, for future reference, we shall consider these advantages in a little more detail at this point.

The first advantage - fewer in-flight measurements - arises because the variations in noise level spatially and temporally are no longer confounded with level variations caused by helmet fit from person to person and on separate occasions.

The variation in helmet attenuation from person to person and on different occasions, is well documented from laboratory measurements. Provided sufficient noise measurements are made to characterise the environment in the cabin around the flight crew, then the expected range of levels at the ear can be predicted with confidence. The necessary measurements could be collected in a single flight. To gather the same range of levels with the same statistical confidence by direct measurement, would require many flights with different crew. One cannot tell, from a single measurement, whether that measurement was made with a well-, badly- or an averagely-fitted helmet.

The second advantage is that, when measuring in the cabin rather than at the ear, the range of sound levels across the spectrum is narrower. Measurements at the ear require a dynamic range exceeding that of currently available recorders and FFT analyzers, whereas measurements in the cabin do not.

A low-frequency de-emphasis can be used to reduce the range of levels required by measurements at the ear. If a Nagra IV SJ recorder is used, the built in A-weighting should suffice in all but the most extreme cases. A recorder with a wider dynamic range such as the Sony PCM-F1 system, might just be adequate but an external weighting circuit might be necessary. This system, however, is bulky and heavy.

The third advantage of estimation over direct measurement is the simpler instrumentation. Miniature microphones and their associated power supplies, preamplifiers and trailing cables between crew members' helmets and the recording equipment are avoided.

C.3 Analysis and definition of the Puma cabin noise spectrum

As mentioned above, the only available data on the Puma noise environment were cabin noise recordings. These were supplied by RAE (FS4). One set of recordings made in Puma XW231 on 9th July 1975 was analysed in detail (Tape number 21). These recordings were made in level flight at speeds from 40 knots to 140 knots, and in hover, with the microphone positioned between the two pilots.

The spectrum of the cabin noise for each flight condition was measured by replaying each recording from a Nagra IV SJ tape recorder to a Bruel and Kjaer Type 2032 Dual Channel Analyzer. The tape recorder was of the same type as that used to make the recordings. The measured spectra were transferred from the analyzer to a Hewlett-Packard 9816 computer and stored on magnetic disc.

The analyzer had been calibrated against the reference tones on the tape to read directly the band pressure levels in dB SPL. For the calibration the analyzer was set to continuous exponential averaging of 10 instantaneous spectra with flat-top weighting applied to the time records. This weighting gives the level of a pure tone undiminished by spectral spreading. It is ideal for calibration but unsuitable for analysis, since a tone appears as a narrow band of frequencies. For the analysis proper the analyzer was set to linear averaging of 200 instantaneous spectra with a nominal 50% overlap and Hanning time weighting.

All the recordings were analysed with a frequency span from 0 Hz to 6.4 kHz which gave an 801 line spectrum with a resolution of 8 Hz and an effective noise bandwidth of 12 Hz per line. The measurement duration was approximately 12 seconds. In addition the recordings at the highest flight speed and in hover were reanalysed with a frequency span of 12.8 kHz, giving a resolution of 16 Hz. The measured spectra are given in Figures C.1 and C.9.

Each spectrum has many narrow-band and discrete frequency components. The frequencies of some of these components are independent of the helicopter's speed, whilst the frequencies of others are not. The narrow tone complex visible in Figure C.1 at about 6.2 kHz for example, increases in frequency as the helicopter's speed increases. The broadband noise levels between the tonal components appear to remain constant up to a flight speed of 120 knots, but increase between 120 knots and 140 knots. The levels of the tonal components vary but some of this may be an artefact caused by slight changes in microphone positions in a standing-wave field.

C.4 Worst case Puma noise spectrum

To specify levels for auditory warnings a "worst case" noise spectrum is needed, i.e. the spectrum which will give the highest masked threshold curve. A warning audible in this "worst case" will be audible in any other case. To establish which of the spectra in Figures C.1 to C.7 represented the worst case, each spectrum was converted to the corresponding spectrum at the ear by subtracting the attenuation curve of a flying helmet, and the masked threshold was calculated as described in the main body of this report.

The spectrum recorded at 140 knots air speed was found to represent the worst case from below 500 Hz to above 5 kHz with the exception of a narrow frequency range from about 1.6 to 2.2 kHz. In this narrow range, a tonal component at 1780-1790 Hz, caused the spectrum recorded at 100 knots air speed to represent the worst case. All the measured spectra show this tone at 1780-1790 Hz, but it is most prominent in the 80 and 100 knots recordings.

Since no single flight condition produced a worst-case threshold over the range from 0.5 kHz to 5 kHz a worse-case spectrum was fabricated. This was based on the spectrum recorded at 140 knots, but the tonal component at 1784 Hz was increased to a level similar to that present at 100 knots by additing 5 dB to bands 222, 223 and 224. Since the spectrum contains elements from two different flight conditions, it is effectively a composite spectrum. It is plotted as Figure C.10. Note that the frequency span in this and the following figures if 5 kHz.

C.5 Estimated noise spectrum at the ear

Figure C.11 shows the spectrum which would occur at the ear given the cabin noise spectrum in Figure C.10 and assuming that a "poorly fitting" Mk4 helmet were worn. The "poorly fitting" helmet may be more precisely defined as the notional helmet with an attenuation at any frequency equal to the mean attenuation of real helmets on real individuals minus 1.64 times the standard deviation at that frequency. In practice, the noise attenuation of this notional helmet is exceeded on 95% of occasions.

The means and standard deviations of attenuation were taken from measurements by Pratt et al [C.1]. Their measurements were made in third-octave bands using miniature microphones at the ears of nine subjects. For the purposes of this project, Pratt's measured values were assumed to apply at the nominal centre frequencies of the relevant third-octave bands and attenuations at intermediate frequencies were interpolated linearly in decibels.

C.6 Masked threshold

Figure C.12 shows the predicted threshold curve. This was calculated at 40 Hz increments from 240 Hz to 5120 Hz using the full measured noise spectrum up to 6400 Hz in the calculation of threshold at the higher frequencies.

C.7 Limits for auditory warning sounds at the ear

Figure C.13 shows the upper and lower limits between which the levels of the spectral components of auditory warning sounds should lie. The upper and lower limits are respectively 25 dB and 15 dB above threshold in line with the guidelines in CAA Paper 82017.

The upper limit is a recommendation based on flight deck noise levels in civil aircraft. It is a compromise to limit the absolute levels of warning sound components which can exceed 80 dB SPL while still maintaining a respectable margin above masked threshold. In the Puma applying this recommendation leads to a fairly modest upper limit shown in Figure C.13. This limit will be perfectly satisfactory but could be exceeded without causing annoyance or discomfort should flight crews prefer a higher level. Consideration should be given to specifying the upper limit for helicopters as, say, 75 dB SPL or 25 dB above threshold, whichever is the higher.

C.8 Production of warning set

Subsequent stages in the production of the warning set were as described for the Sea King in the main section of this report.

REFERENCE

C.1 PRATT, R.L., ROBERTS, S. and PARKINSON, J.N. 1981: "The acoustic attenuation of in-flight headgear", IAM Report No. 603, RAF Institute of Aviation Medicine, Farnborough.

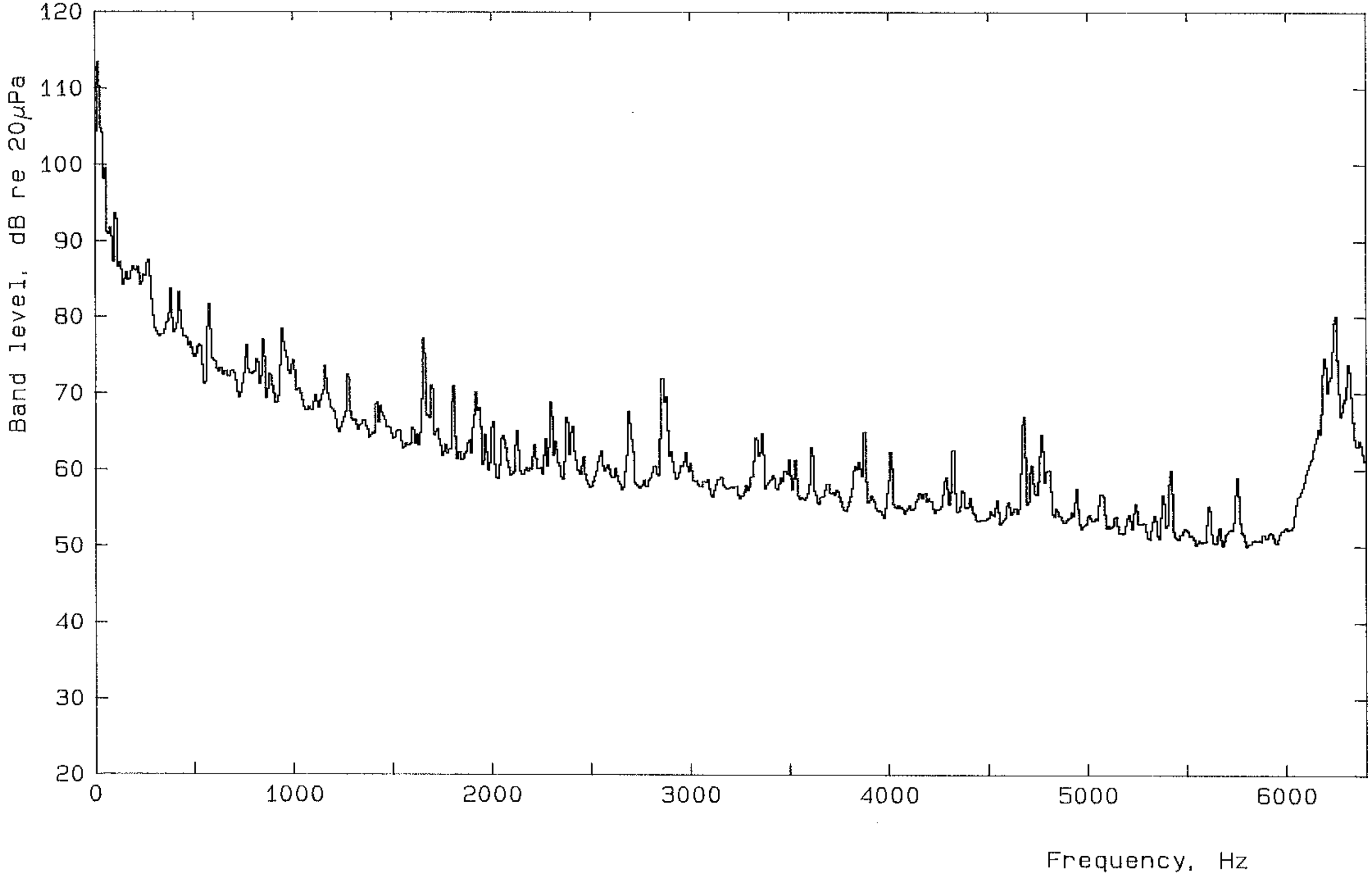


Figure C.1 Puma XW231 at 40 knots: noise measured between pilots, 8 Hz resolution.

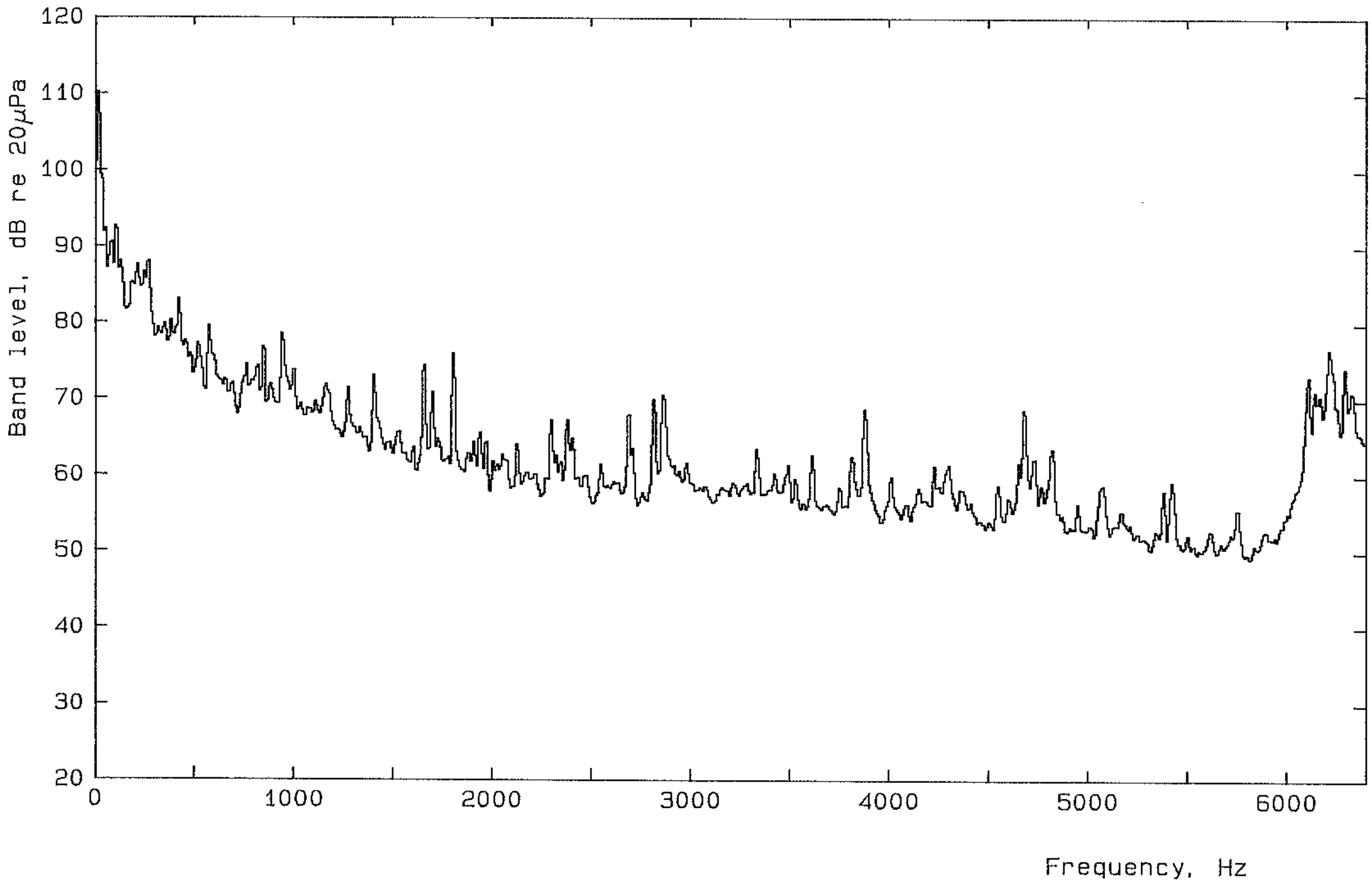


Figure C.2 Puma XW231 at 60 knots: noise measured between pilots, 8 Hz resolution.

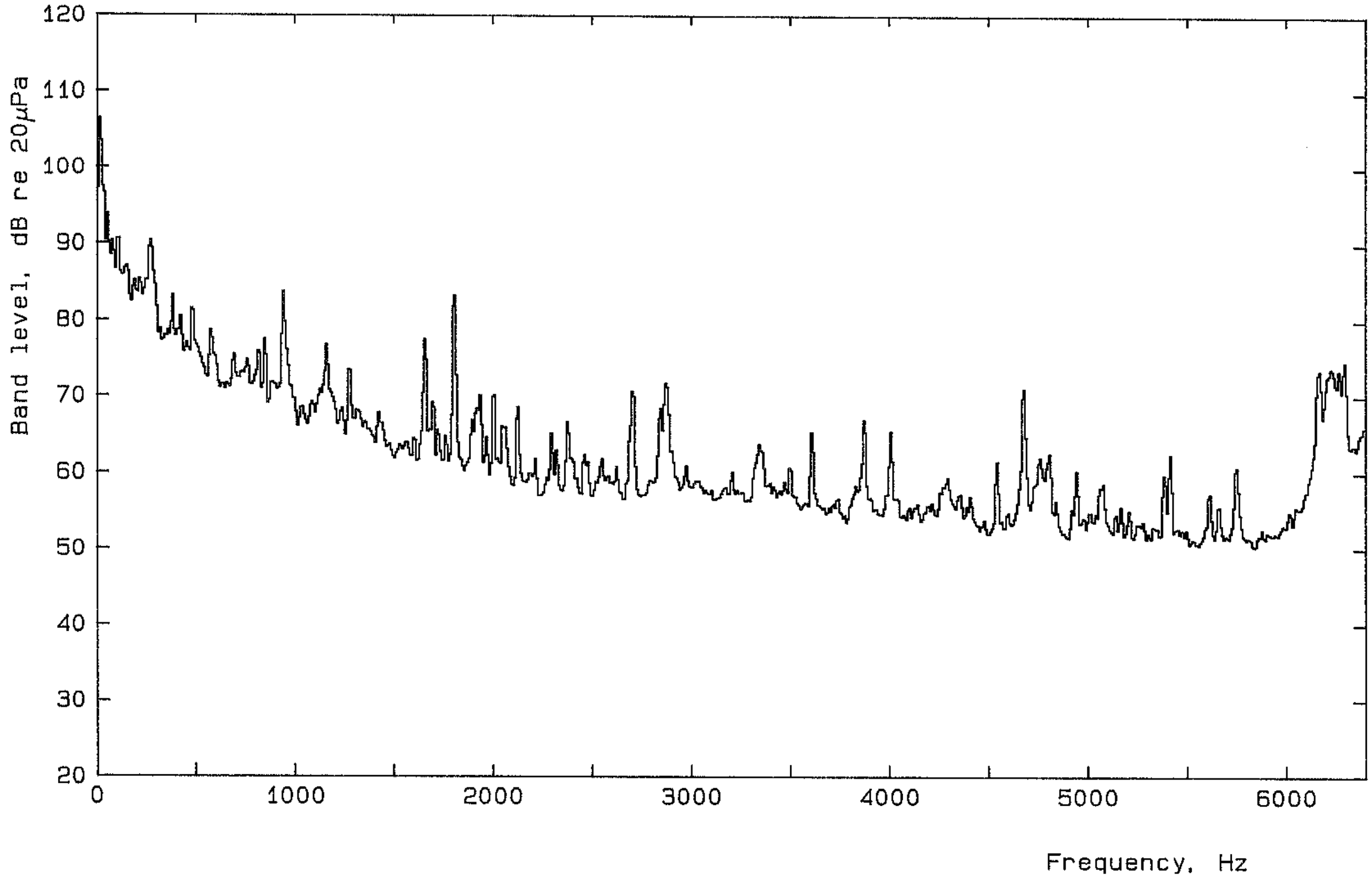


Figure C.3 Puma XW231 at 80 knots: noise measured between pilots, 8 Hz resolution.

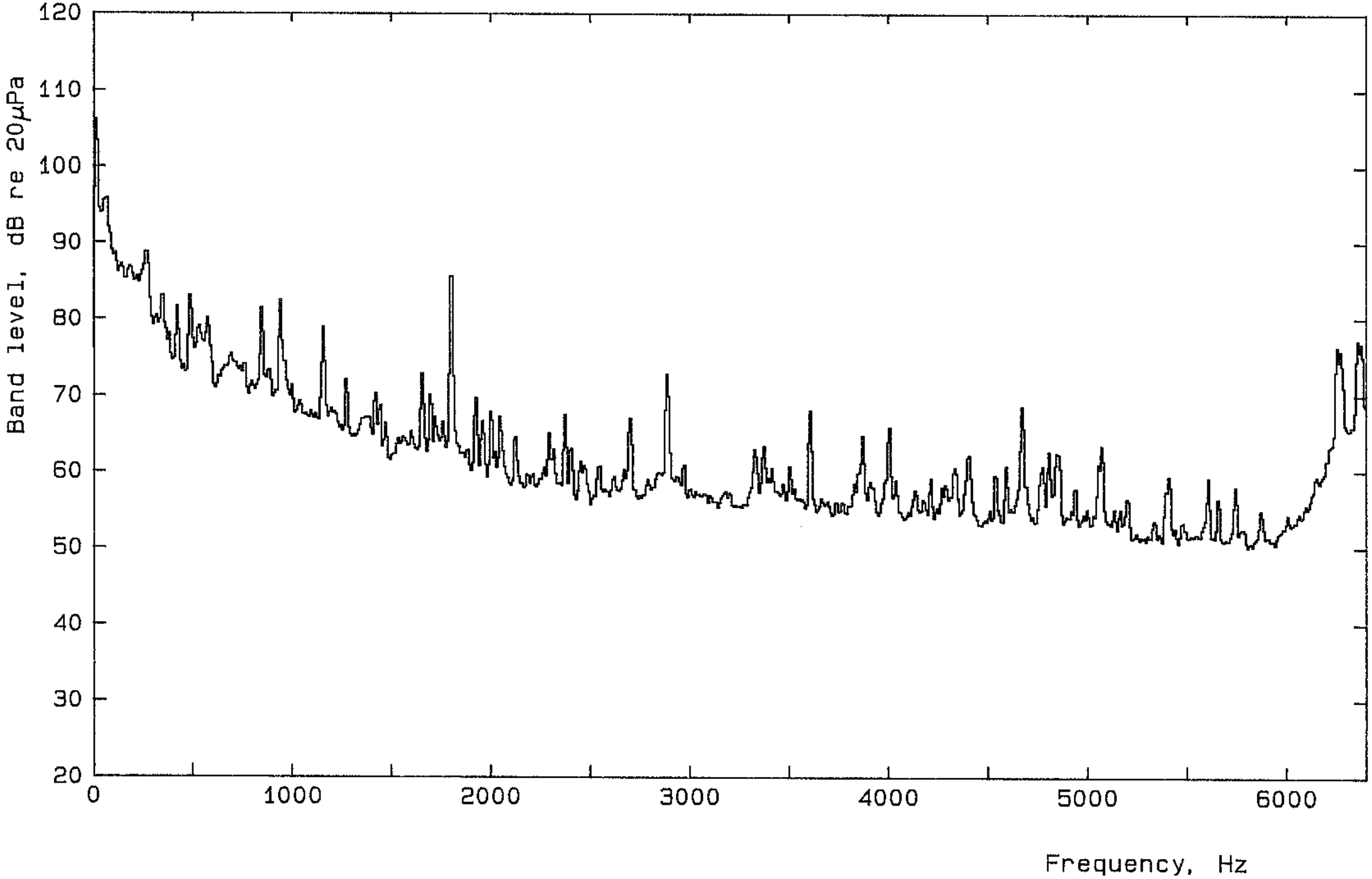


Figure C.4 Puma XW231 at 100 knots: noise measured between pilots, 8 Hz resolution.

Figure C.4

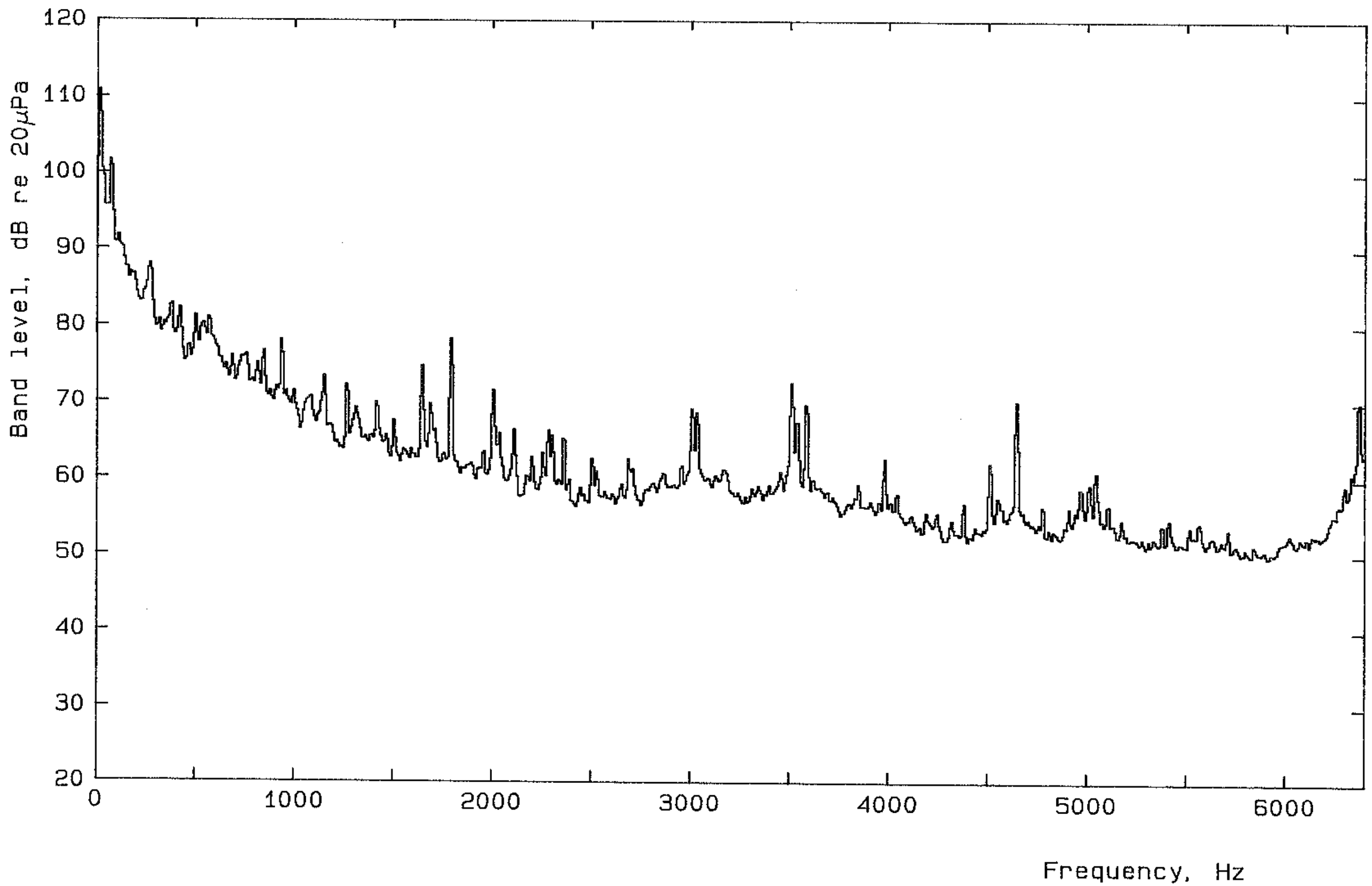


Figure C.5 Puma XW231 at 120 knots: noise measured between pilots, 8 Hz resolution.

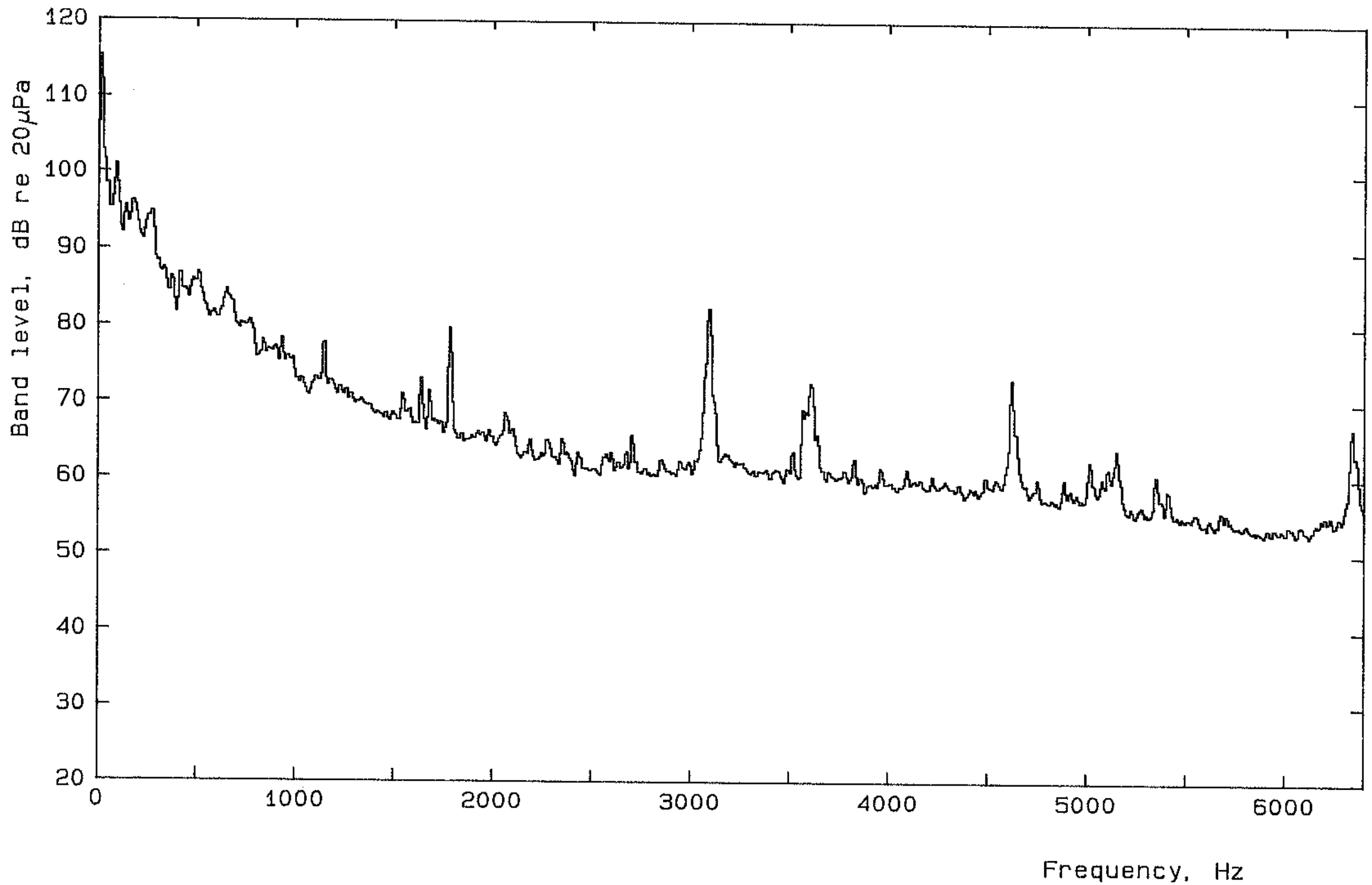


Figure C.6 Puma XW231 at 140 knots: noise measured between pilots, 8 Hz resolution.

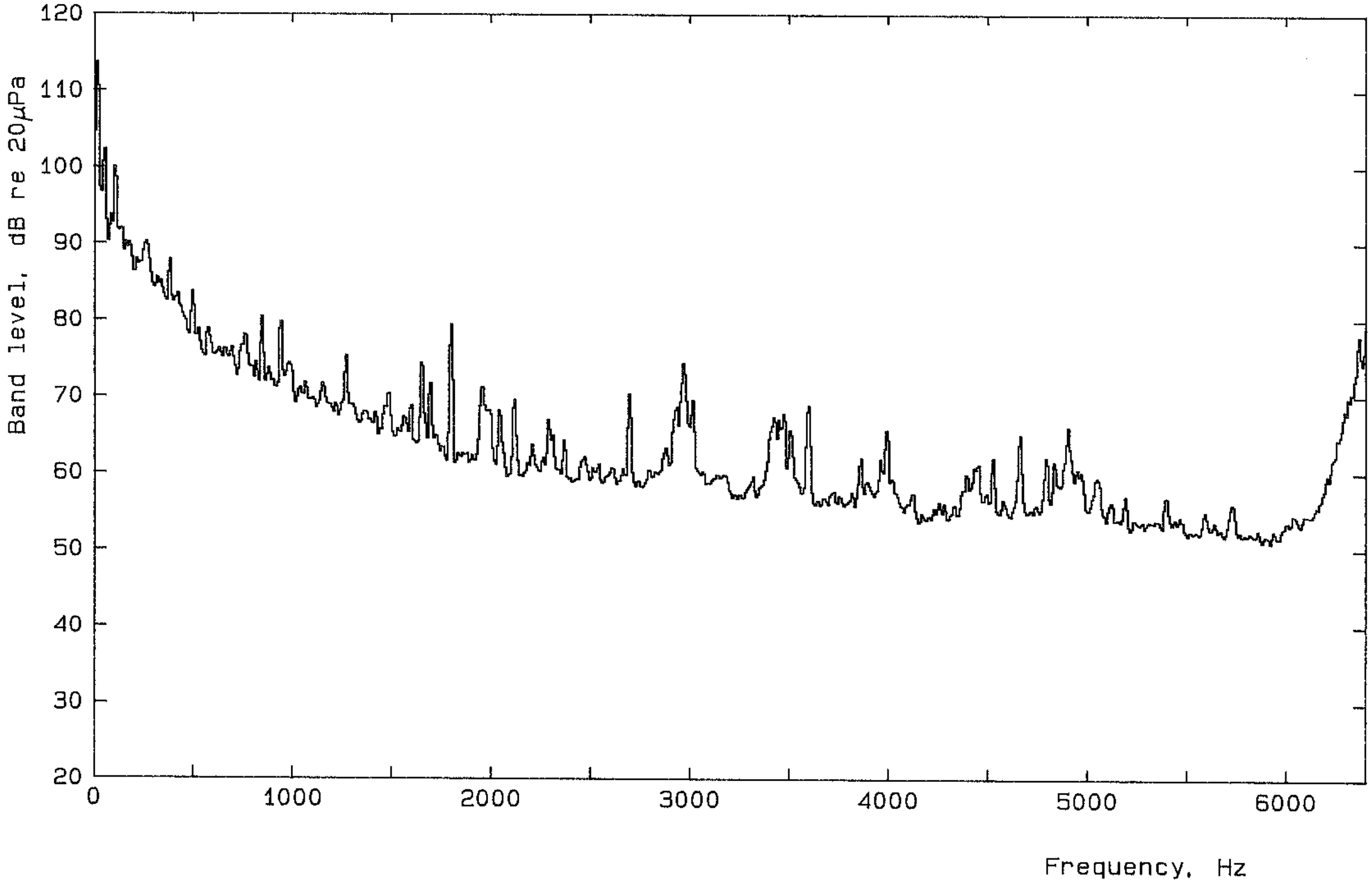


Figure C.7 Puma XW231, hovering at 1000ft: noise between pilots, 8 Hz resolution.

Figure C.7

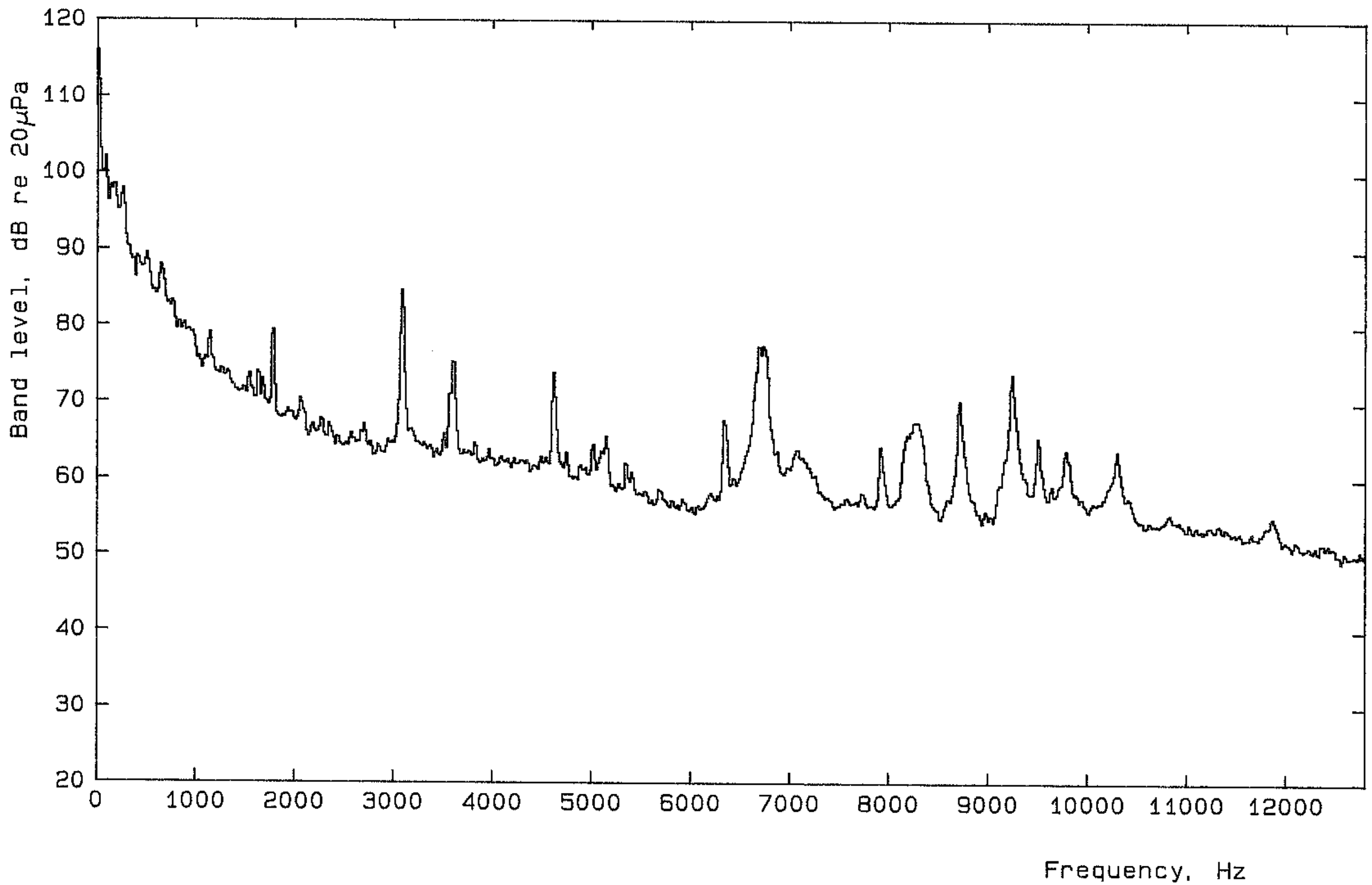


Figure C.8 Puma XW231 at 140 knots: noise measured between pilots, 16 Hz resolution.

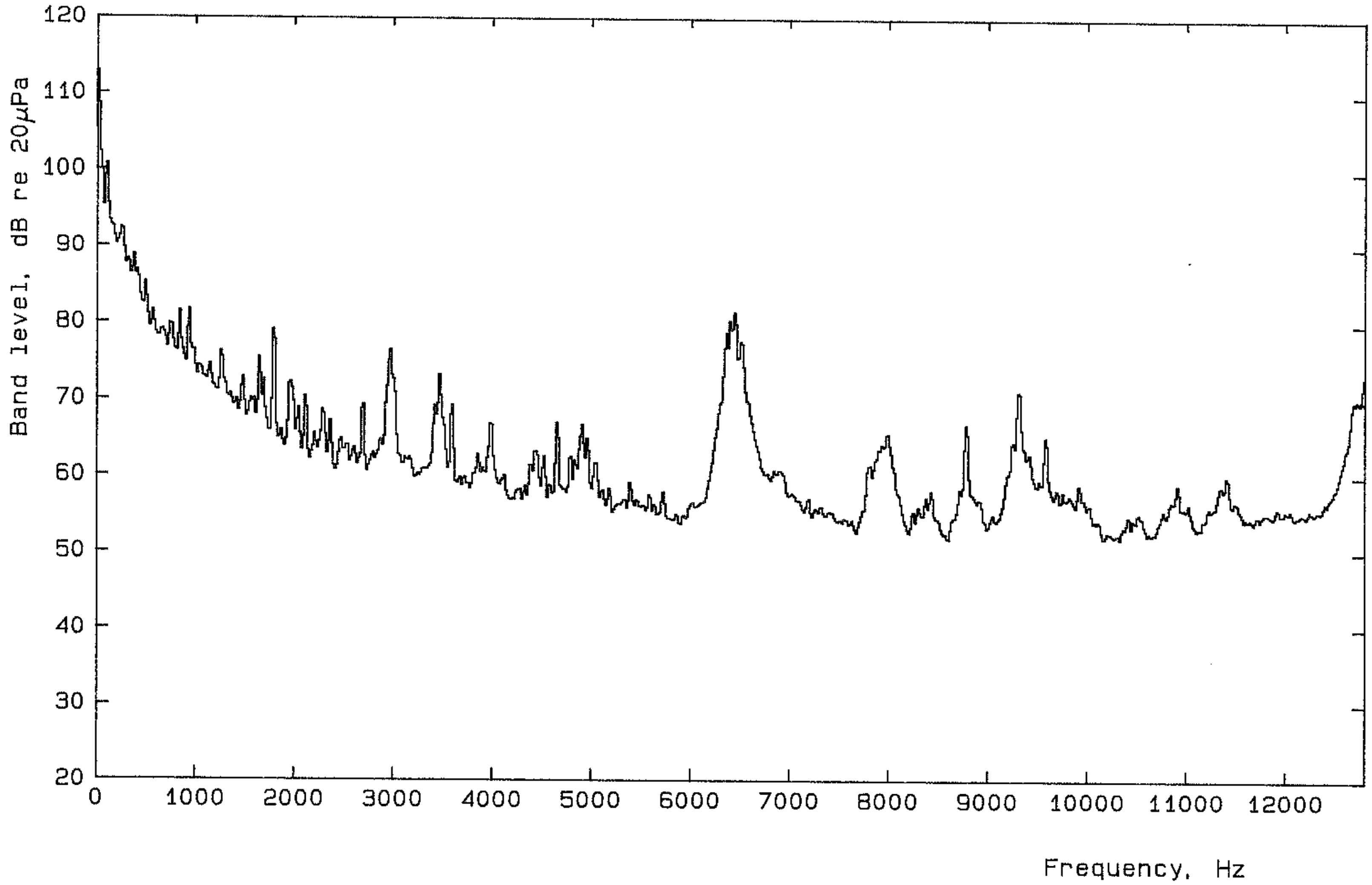
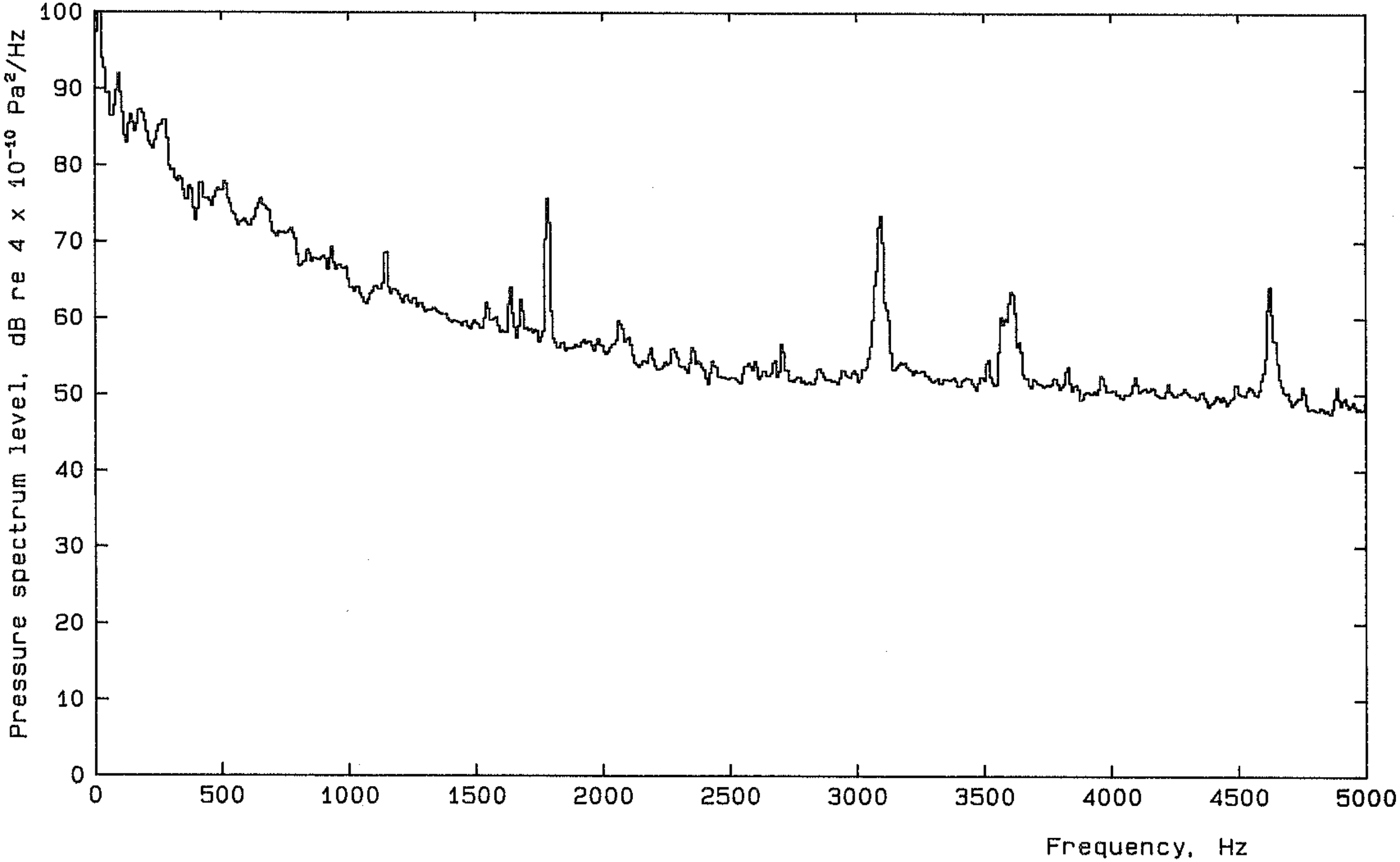


Figure C.9 Puma XW231, hovering at 1000ft: noise between pilots, 16 Hz resolution.



FigureC.10 Composite noise spectrum in a Puma cabin (see text).

Figure C.10

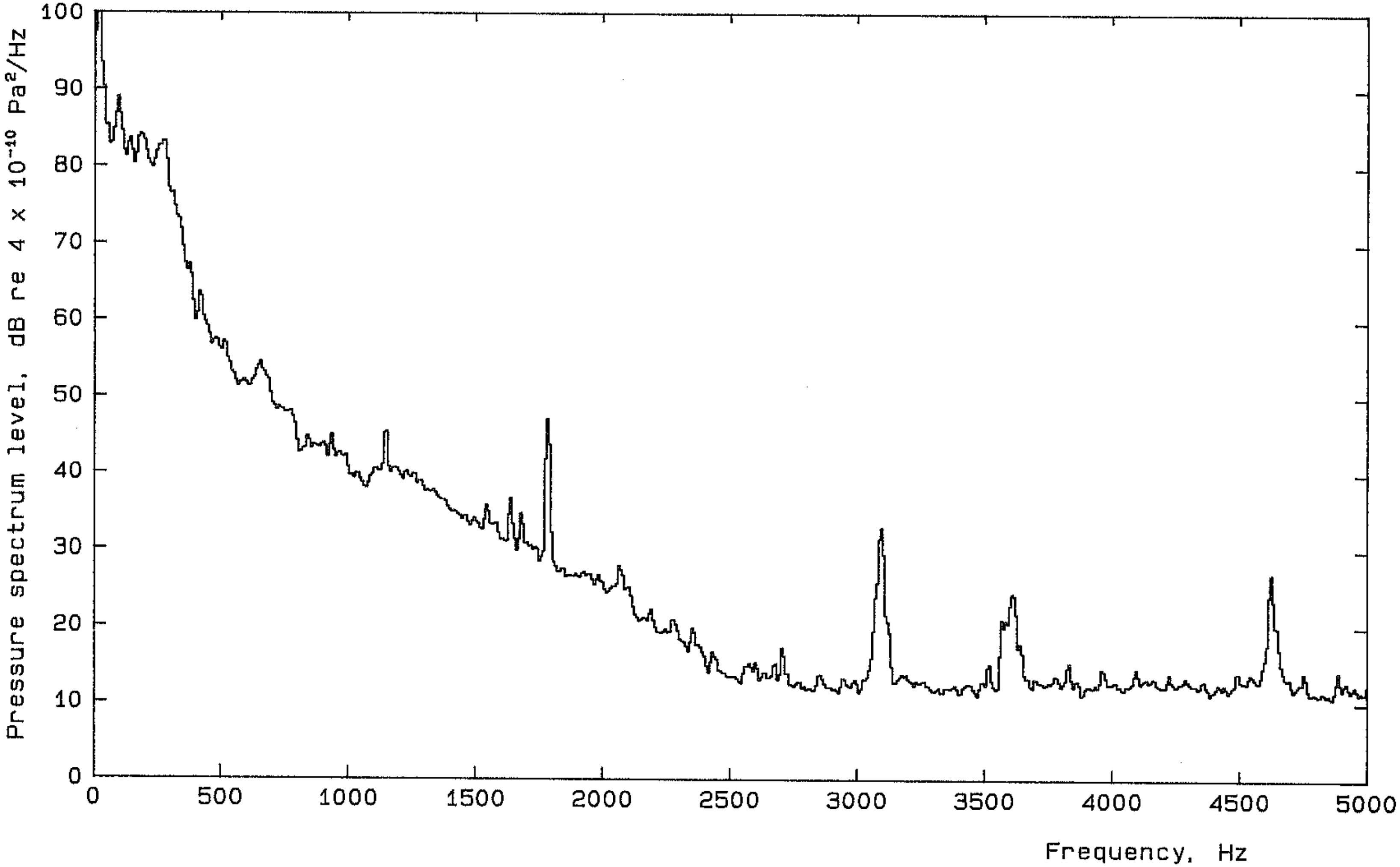


Figure C.11 Estimated noise spectrum at the ear with a poorly fitting helmet.

Figure C.11

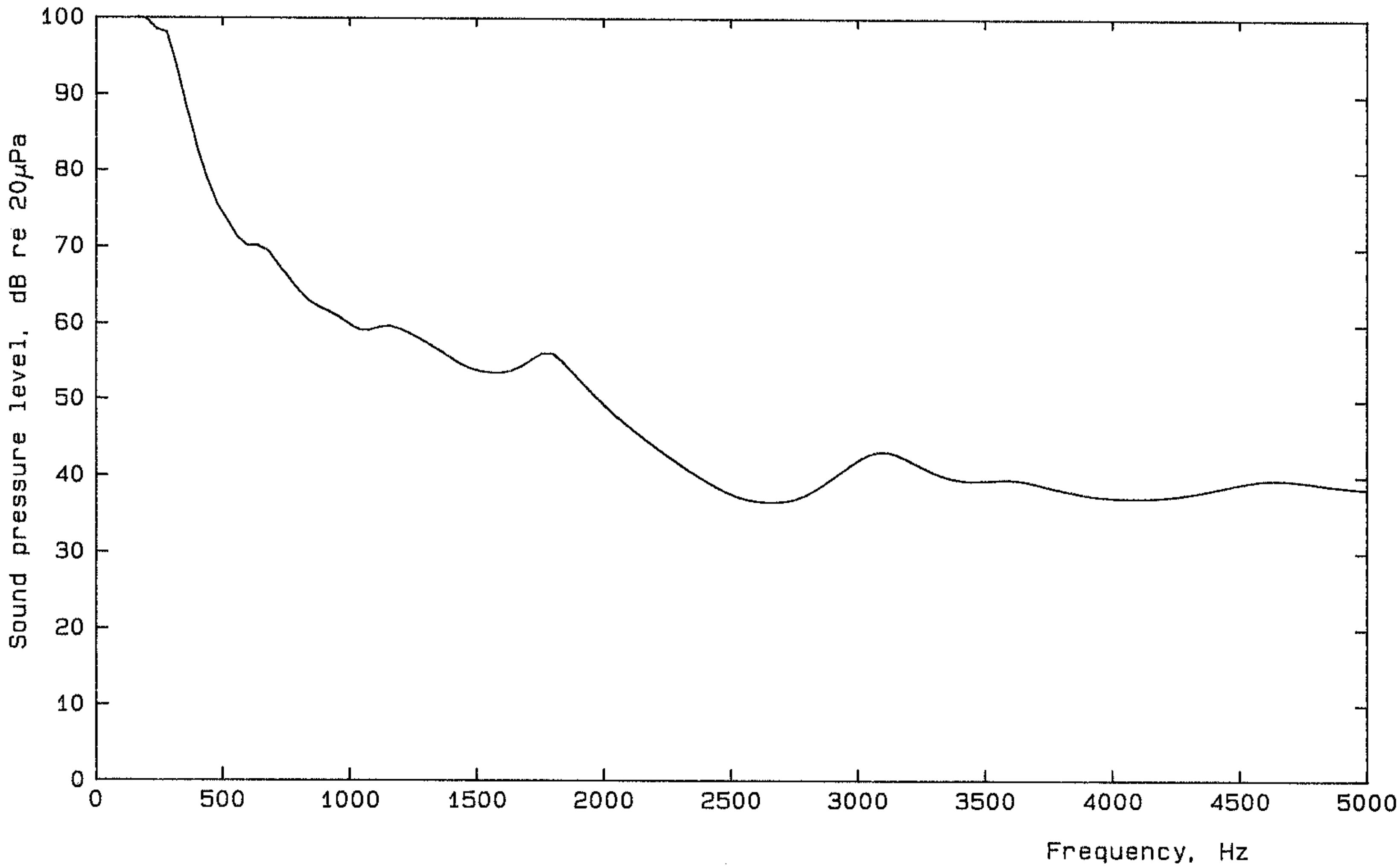


Figure C.12 Masked pure-tone threshold calculated for the spectrum in Figure 2.

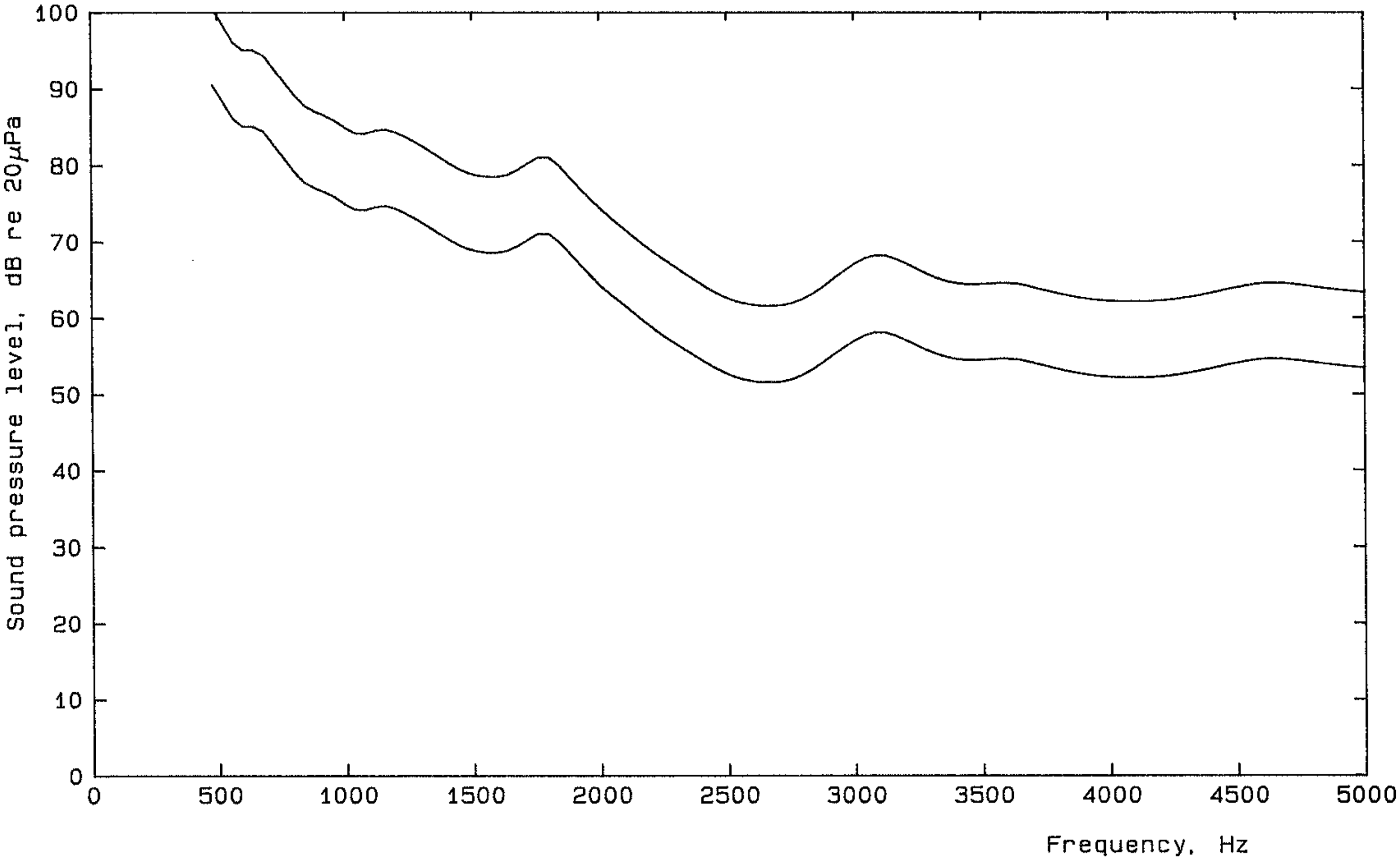
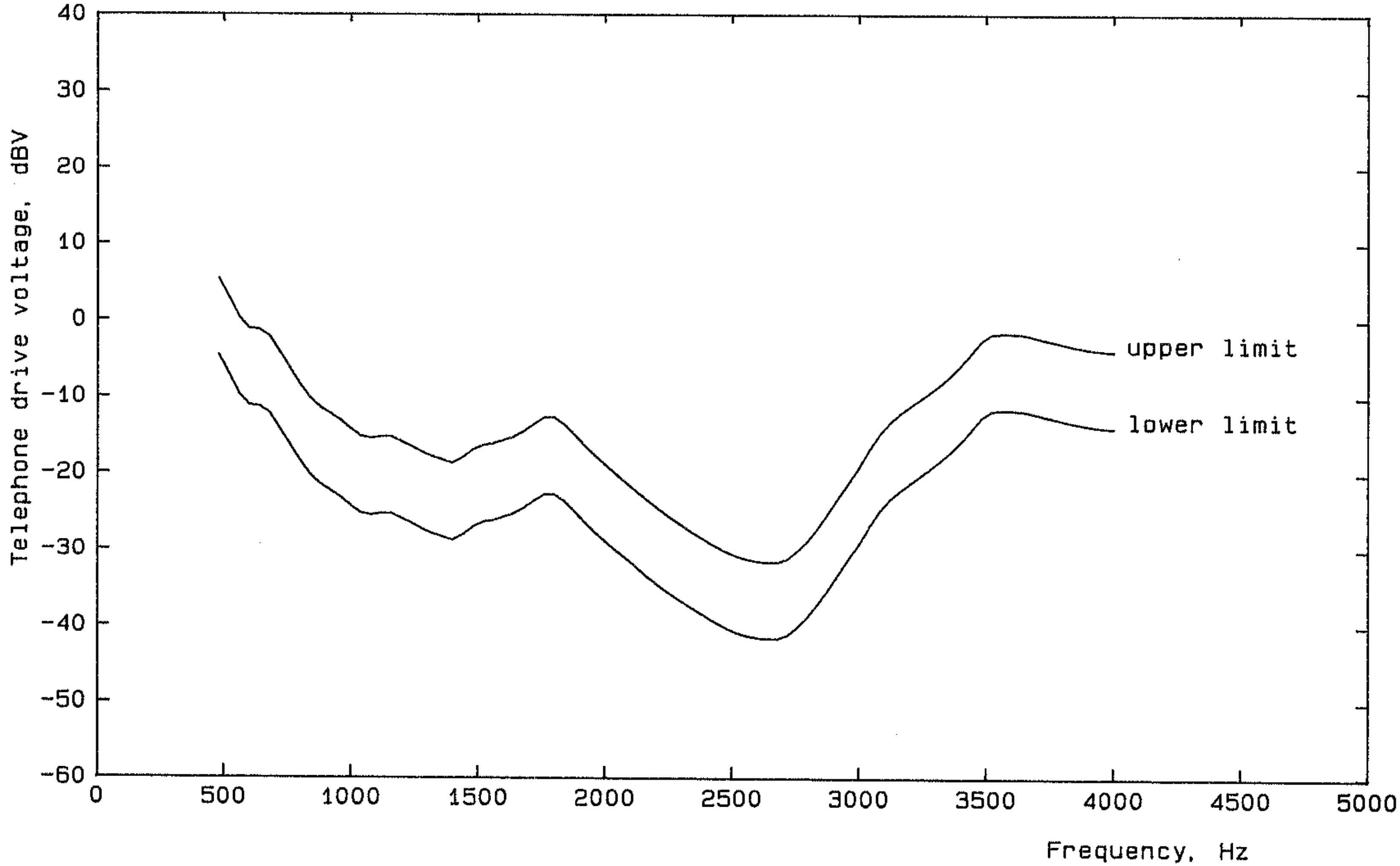


Figure C.13 Upper and lower limits for auditory warning components.

Figure C.13



FigureC.14 Limits of input voltage to the Mk4 telephone for auditory warning components.

Figure C.14

APPENDIX F

DISCRIMINABILITY OF AUDITORY WARNING SIGNALS DEVELOPED FOR THE SEA KING HELICOPTER

F.1 Introduction

It is important that pilots be able to learn warning sounds quickly and recognise any member of the set without hesitation. Accordingly an experiment was carried out to measure the ability of pilots to memorise and distinguish the signals provided by APU as part of the joint APU/ISVR/RAE research programme [1].

The experiment was structured as a computer-controlled, self-paced learning programme [2-5]. Subjects were required to learn and subsequently identify the warning sounds, starting with one sound and adding sounds to the learned set one at a time until all ten sounds were included. A new sound was given to the subject to learn only when he could correctly identify every sound already included in his set.

The experiment was designed to show the number of sounds which could be easily learned and also the frequency with which any sound was confused with any of the others. Any poorly identified sound could, then, be detected and rejected from the final approved set.

All tests were conducted with subjects seated in a Sea King recreated inside the FS(F)4 Helicopter Noise Simulator. Warning sounds were presented through the telephones of Mk4B flying helmets.

The experiment was conducted on two separate occasions. The first occasion was during November 1985, with the original set of 10 warning sounds and two separate subject groups. The first group consisted of 10 experienced helicopter pilots, the second group comprised 10 RAE staff. The second occasion was during January 1986 with a modified set of warning sounds. For this second experiment another group of 10 RAE staff took part, since these were more readily available than pilots and the first experiment had shown no major statistical differences between the pilot and non-pilot groups.

F.2 The Helicopter Noise Simulator and Experiment Instrumentation

The Helicopter Noise Simulator [6-8] consists of a Lynx helicopter cabin in which an array of loudspeakers and acoustic drivers has been installed. Cabin noise recorded in real helicopters is stored digitally on computer disc and is replayed from a controlling mini-computer and array processor via digital-to-analogue convertors, amplifiers and filters to the simulator loudspeakers. The sound field produced around the pilot's and co-pilot's positions closely approximates that of the real helicopter in which the original noise was recorded.

For this series of trials, the mini-computer was also used to control every stage of the experiment. Warning sounds were stored on the magnetic disc used for the helicopter noise and were output from the mini-computer via a digital-to-analogue convertor and preamplifier to a normal aircraft CCS installed in the simulator. Subjects then heard the warnings through the communications telephones in their helmets.

A microcomputer linked to the mini-computer received text from the mini-computer and displayed this on a VDU to the subject to identify the warnings during learning phases. The microcomputer also monitored a panel of illuminated press buttons, one button for each sound, which the subject used to identify the sounds during the test phases of the experiment. The Subjects responses were relayed by the microcomputer back to the main computer.

F.3 Experimental Procedure

Each experiment comprised four sections with the first and third and the second and fourth being identical. The last three sections were performed one week after the first.

The first and third sections were learning sections containing at least ten stages each consisting of a signal presentation and identification followed by a test of memory of all signals presented so far.

During these sections subjects were presented with a signal to be learnt, identified by text on the VDU, which they were subsequently asked to identify by pressing the appropriate illuminated button. At the first stage the first signal was presented and followed immediately by a test. If a correct answer was obtained, a new signal was presented and the subject asked to identify both signals, which were presented in random order. If these were correctly identified then a third signal was added and so on. The order in which sounds were added was different for each subject and was determined by a fully balanced Latin square design.

It may be seen that to complete the experiment each subject was required to correctly identify all ten signals in a single test stage. If an incorrect response was obtained during any stage, then the signals incorrectly identified were re-presented and re-identified. The subject was then required to repeat the test for that stage for the entire set of signals in current use. Only when all correct responses were obtained was the subject allowed to proceed to the next stage.

The second and fourth sections were simply test sections. Subjects were presented with all ten signals once, in an order again determined by a randomised, balanced Latin Square, and asked to identify each.

F.4 Signal Details

In the first experiment the signals used were the original set of ten signals supplied to RAE from APU. Only the initial burst of each warning sound was used not the full warning. The name attached to each of these was chosen to be typical of names of current aircraft warnings and was typical of the category of warning that the signal had been designed to represent. The names actually used are shown in Table 1 and, for example, 'fire' is a typical priority 1 warning and was therefore chosen for signal 1, which was designed as a priority 1 warning sound. Different meanings will be assigned to these warnings in use.

The data from the first experiment indicated certain confusions existed and, therefore, APU re-designed some of the signals to give a second set of ten, also shown in Table 1. The 'Fire' warning and the 'Low Height' were changed and 'Priority 2', 'Priority 3', and 'Master Caution' were replaced by 'Undercarriage', 'Information' and 'No Track'. 'Transmission Oil' was renamed 'Rotor' (for reasons given below in F.5).

Although some of these changes were indicated by the confusion data, others were introduced because of changes in overall strategy. For example, the 'No Track' similar to but distinguishable from, the new 'Low Height', was introduced after discussion with pilots and RAF technical personnel.

Warning sound replay levels were adjusted, during a preliminary subjective threshold determination experiment, such that signals were output from the helmet telephone at levels of 18 dB above masked threshold.

F.5 Results

Both experiments showed that a small amount of confusion did exist amongst some of the signals and that the time taken to memorise new signals increased sharply after the fifth signal. All subjects were able to correctly identify at least nine of the ten signals in section four at the end of each of the experiments.

The confusion tables for all three experiments are shown in Tables 2-4 with the statistically significant confusions indicated by underlined values. In these tables the signal actually presented is shown by the row labels. The subjects' responses are shown by the column headings. If all signals were correctly identified there would be numbers only in the diagonal from top left to bottom right. Off-diagonal numbers show confusions. For example, in Table F2 for the pilots, out of the 99 times that the 'Fire' warning was presented it was correctly identified 88 times, and erroneously identified once as a 'Servo pressure', five times as 'Transmission', three times as 'Gearbox' etc.

Although Chi-squared analysis of the data from the first experiment showed pilots and non-pilots not to be significantly different, a comparison of the significant cells in Table F2 shows that the RAE personnel experienced a greater number of significant confusions than the pilots, although examination of the response errors, shown in Figure F1, indicate very similar errors per stage and error standard deviations. The response times and standard deviations, shown in Figure F2, also indicate a strong similarity although the data from sections 2 and 4, shown in Figure F3, show the non-pilots to have a slightly wider spread of correct responses than the pilots.

Assessing these data to isolate any intolerable confusions between sounds is not easy. However, it is clear that there was a mild confusion between 'Fire' and 'Transmission' for both sets of subjects in the first section of the first experiment, and between 'Gearbox' and 'Transmission' on the part of the pilots but not the non-pilots. This latter suggests a semantic confusion. Pilots also confused

'Master Caution' and 'Priority 2', again possibly a semantic confusion between similar meanings. By section 3 of the first experiment discrimination amongst warnings had improved with only 3 statistically significant confusion rates remaining, although traces of the same confusions found in section 1 may still be discerned.

As mentioned above, the data from the first experiment together with adjustments to overall strategy, resulted in APU modifying some signals and substituting others. In the second experiment, the modified set of signals was examined.

The confusion tables for the second experiment are shown in Table F4. Although not shown, the response error and response time behaviour were very similar to those found for the first experiment.

The significant confusions of Table 4 are 'Rotor' and 'Gearbox', 'Low Height', 'Electrics' and 'Undercarriage'. Changing the name of 'transmission oil' to 'gearbox' has not prevented confusion between this sound and 'Gearbox'. The confusion is evidently not merely semantic. It is recommended that one or both of these sounds be excluded from a final set of signals.

The introduction of 'Undercarriage' as a substitute for the 'Priority 2' signal has not solved the problem of finding a suitable second priority signal. Study of the eighth column in the section 1 table of Table F4 shows this signal accrued 34 erroneous identifications, being mistaken for every other signal except 'No Track'. A significant confusion, between this and 'Rotor', may still be seen in the section 2 table.

Although there was a worrying confusion between the 'Low Height' and 'No Track' in section 1 this had totally disappeared in section 3 data.

The new design for the 'Fire' signal has not produced any significant confusion but may be criticised from another point of view.

Discussion with pilots has made it clear that priority one signals must be short, firstly to avoid distraction at a crucial time and secondly to avoid "consumer resistance" on the part of the pilots. The new 'Fire' is appreciably longer and seems to perform no better than the first and it is suggested that this signal be replaced by its predecessor.

F.6 Conclusions and Recommendations

Overall there were relatively few confusions between warning sounds although some specific systematic confusions were identified. An amended set, designed to eliminate these confusions, also suffered similar problems. Nevertheless by eliminating either 'Rotor' or 'Gearbox' or both, together with 'Electrics' and 'Undercarriage' a set of 7 warnings remains which are rarely if ever confused.

The previous 'Fire' warning was more acceptable to flight crew than the revised warning.

There is a sharp increase in the time taken to memorise extra warnings after the fifth.

Non-pilots may be substituted for experienced pilots for the purposes of these experiments.

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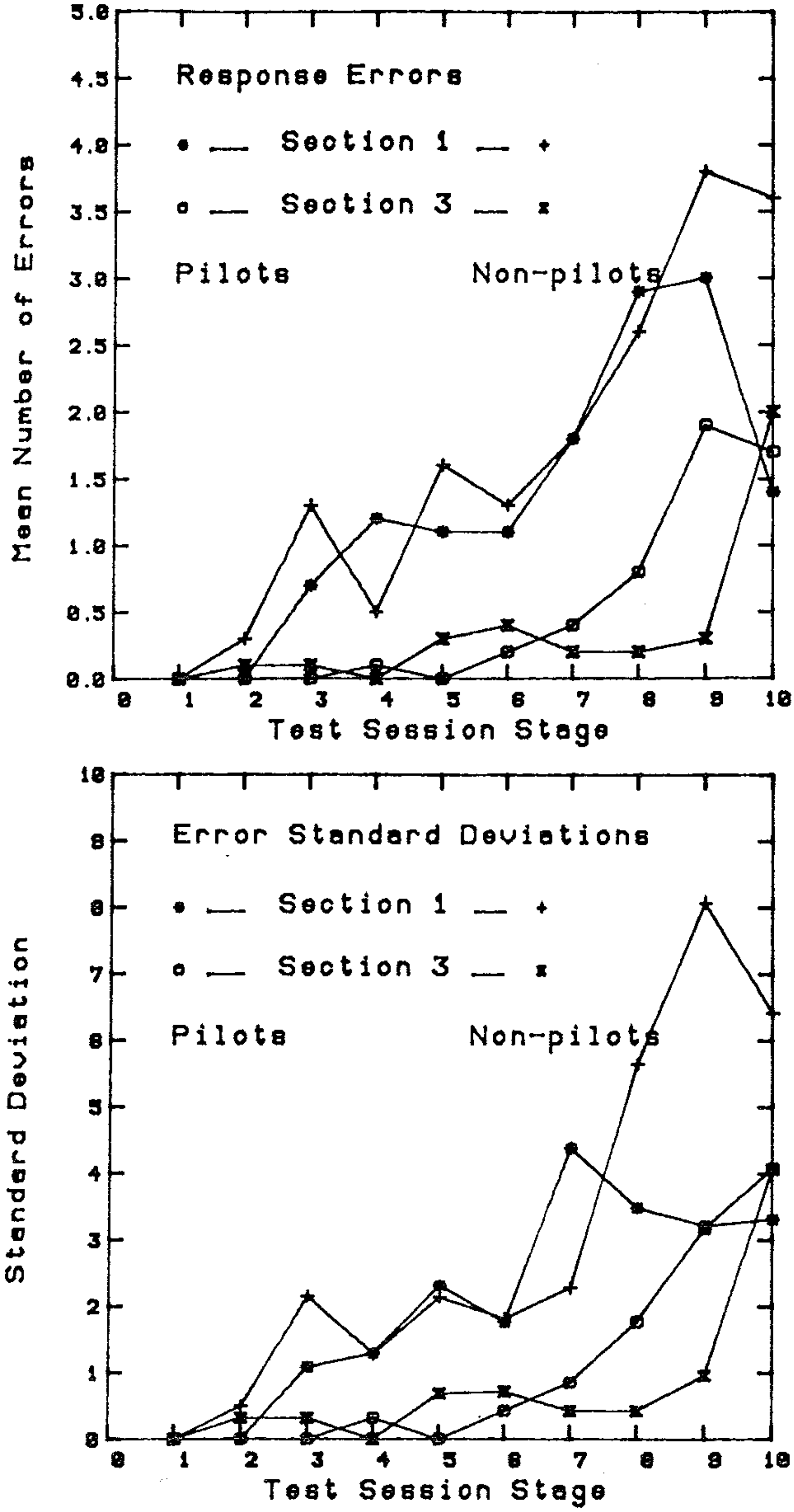

Figure F.1; Mean number of errors per subject during each stage of experiment.

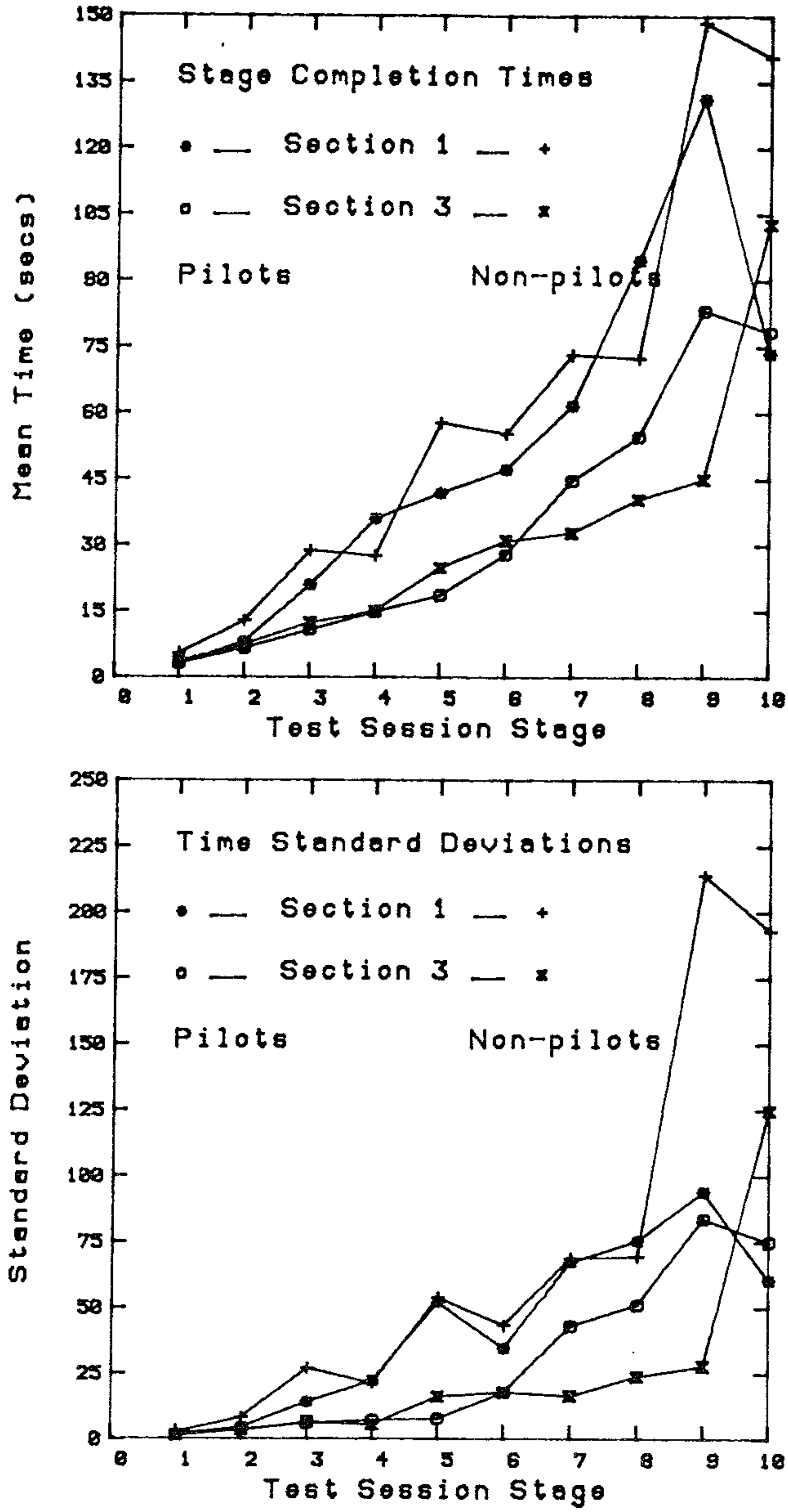

Figure F.2: Mean time taken for a subject to complete each stage of the experiment

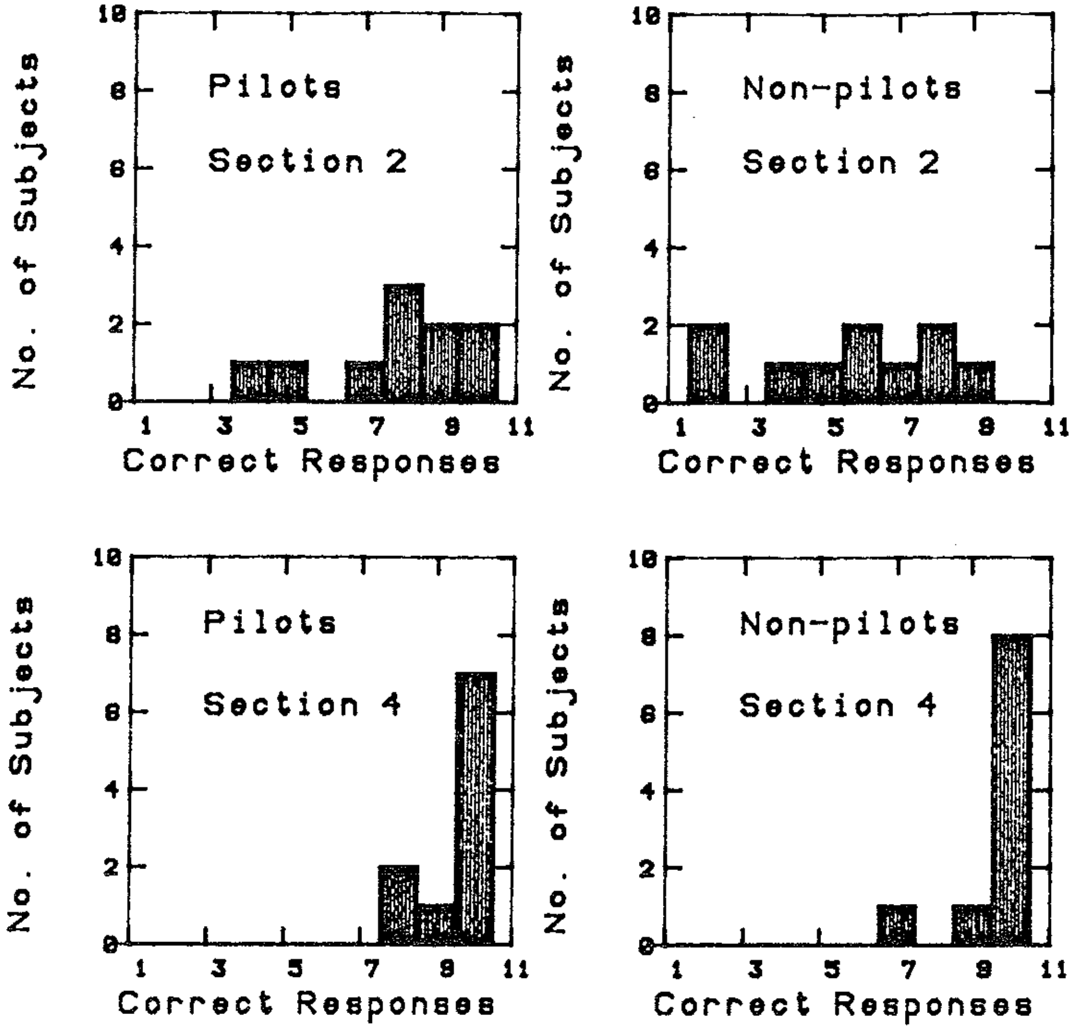

Figure F.3: Intermediate and final test scores for pilots and non-pilots

Signal Number	Signal Name
1	Fire
2	Servo Pressure
3	Transmission Oil
4	Gearbox Chip
5	Threat
6	Electrics
7	Master Caution
8	Priority 2
9	Priority 3
10	Low Height

Names used in first experiment

Signal Number	Signal Name
1	Fire (new version)
2	Servo Pressure
3	Rotor (former Transmission Oil)
4	Gearbox Chip
5	Threat
6	Electrics
7	No Track
8	Undercarriage
9	Information
10	Low Height (new version)

Names used in second experiment

Table F1: Names chosen to identify warning signals.

Confusion Table

Section 1 - Pilots

SIGNAL PRESENTED	RESPONSE 1	2	3	4	5	6	7	8	9	10	TOTAL
1 FIRE	88	1	5	3	0	0	1	1	0	0	99
2 SERVO PRESSURE	0	110	2	3	0	4	0	2	0	5	126
3 TRANSMISSION	3	4	89	11	0	0	2	0	1	0	110
4 GEARBOX	3	2	7	90	0	1	0	5	0	0	108
5 THREAT	0	2	2	0	106	0	2	4	0	0	116
6 ELECTRICS	1	5	2	2	0	105	4	5	3	2	129
7 MASTER CAUTION	0	0	1	1	2	4	97	7	0	0	112
8 PRIORITY 2	1	0	1	0	0	2	6	89	2	0	101
9 PRIORITY 3	0	0	0	0	0	0	1	1	113	0	115
10 LOW HEIGHT	0	2	0	0	0	1	0	0	0	113	116
	96	126	109	110	108	117	113	114	119	120	

Confusion Table

Section 1 - Non-Pilots

SIGNAL PRESENTED	RESPONSE 1	2	3	4	5	6	7	8	9	10	TOTAL
1 FIRE	111	3	8	6	1	1	1	0	0	0	131
2 SERVO PRESSURE	0	107	3	4	2	7	0	1	0	0	124
3 TRANSMISSION	7	0	106	8	3	0	4	2	0	0	130
4 GEARBOX	8	3	4	95	4	1	7	0	0	1	123
5 THREAT	0	2	0	2	114	0	4	0	0	0	122
6 ELECTRICS	0	5	0	0	1	95	3	6	0	2	112
7 MASTER CAUTION	0	0	2	7	2	1	103	5	5	1	126
8 PRIORITY 2	0	2	1	0	0	1	2	113	4	1	124
9 PRIORITY 3	0	0	1	0	0	1	1	5	115	6	129
10 LOW HEIGHT	0	2	0	0	0	4	0	0	0	121	127
	126	124	125	122	127	111	125	132	124	132	

Table F2: Confusion tables for Section 1 of the first experiment (Nov.1985) Pilots and Non-Pilots

Confusion Table

Section 3 - Pilots

SIGNAL PRESENTED	1	2	3	4	5	6	7	8	9	10	TOTAL
						RESPONSE					
1 FIRE	69	2	1	1	0	1	0	1	0	0	75
2 SERVO PRESSURE	0	81	0	0	0	1	0	0	0	0	82
3 TRANSMISSION	0	0	73	4	0	0	4	1	1	0	83
4 GEARBOX	1	0	5	72	0	0	4	1	0	0	83
5 THREAT	0	0	0	0	70	0	1	1	0	0	72
6 ELECTRICS	0	1	0	0	0	81	0	0	0	1	83
7 MASTER CAUTION	1	0	2	1	0	2	69	2	0	0	77
8 PRIORITY 2	0	0	0	0	0	2	4	74	3	0	83
9 PRIORITY 3	0	0	0	0	0	0	0	1	76	0	77
10 LOW HEIGHT	1	0	0	0	0	0	0	0	0	78	79
	72	84	81	78	70	87	82	81	80	79	

Confusion Table

Section 3 - Non-Pilots

SIGNAL PRESENTED	1	2	3	4	5	6	7	8	9	10	TOTAL
						RESPONSE					
1 FIRE	65	0	1	4	0	0	0	0	0	1	71
2 SERVO PRESSURE	0	74	0	0	0	0	0	0	0	3	77
3 TRANSMISSION	0	0	73	1	0	0	1	0	0	0	75
4 GEARBOX	3	0	1	74	0	0	0	0	0	0	78
5 THREAT	1	0	0	0	69	1	1	0	0	1	73
6 ELECTRICS	0	1	0	1	0	72	1	1	0	1	77
7 MASTER CAUTION	0	0	0	0	0	0	65	3	1	0	69
8 PRIORITY 2	0	0	0	1	1	0	0	72	2	1	77
9 PRIORITY 3	0	0	0	0	0	0	0	2	2	1	73
10 LOW HEIGHT	0	0	0	0	0	0	0	0	0	77	77
	69	75	75	81	70	73	68	78	73	85	

Table F.3: Confusion tables for Section 3 of the first experiment (Nov. 1985)
Pilots and Non-pilots

Confusion Table

Second experiment - Section 1

RESPONSE

SIGNAL PRESENTED	1	2	3	4	5	6	7	8	9	10	TOTAL
1 FIRE	97	1	0	1	1	0	0	5	0	0	105
2 SERVO PRESSURE	0	92	0	0	4	1	0	4	0	0	101
3 ROTOR	0	0	97	8	2	3	1	5	2	2	120
4 GEARBOX	1	0	13	97	2	1	2	5	1	1	123
5 THREAT	0	4	2	1	105	0	0	3	0	0	115
6 ELECTRICS	0	1	1	2	1	98	0	7	0	0	110
7 NO TRACK	0	2	0	0	0	0	114	0	1	1	118
8 UNDER CARRIAGE	1	1	5	2	1	4	0	100	2	5	121
9 INFORMATION	0	0	0	2	3	0	1	2	102	0	110
10 LOW HEIGHT	1	2	2	1	0	0	6	3	0	106	121
	100	103	120	114	119	107	124	134	108	115	

Second experiment - Section 3

RESPONSE

SIGNAL PRESENTED	1	2	3	4	5	6	7	8	9	10	TOTAL
1 FIRE	79	0	1	4	0	1	0	2	1	0	88
2 SERVO PRESSURE	1	79	0	0	1	3	0	2	0	0	86
3 ROTOR	0	0	72	0	0	0	0	5	0	0	77
4 GEARBOX	4	0	5	76	0	0	0	0	0	1	86
5 THREAT	1	0	3	2	78	0	0	0	0	0	84
6 ELECTRICS	1	0	0	1	0	80	0	2	0	2	86
7 NO TRACK	0	1	0	0	0	0	82	0	0	1	84
8 UNDER CARRIAGE	1	0	0	2	0	2	0	82	0	0	87
9 INFORMATION	0	0	0	1	0	1	0	1	74	0	77
10 LOW HEIGHT	0	0	0	0	0	1	0	0	0	83	84
	87	80	81	86	79	88	82	94	75	87	

Table F.4: Confusion tables for Stages 1 and 3 of the second experiment Jan (1986)

APPENDIX D

THE GENERATION OF INDIVIDUAL SOUND PULSES FOR AN AUDITORY WARNING

D.1 Introduction

This brief introduction gives an overall description of the suite of programs that generates and modifies the basic pulses which are subsequently used to the construct an auditory warning. It will be followed by a detailed discussion of each program in turn.

Figure D.1 shows the structure of the suite of programs.

The first of the two input programs (PULS, D.2.1) deals with the input of the required spectrum and the levels of the individual components. The second program (TSFM, D.2.2) then carries out a Fast Fourier Transform (FFT) on the input spectrum. The transformed input spectrum is passed to the main program (MENU, D.2.3) which controls the subprograms dealing with various waveform manipulations. This program also enables printing of input frequencies and levels. The MENU offers a choice of one of three waveform modification programs:

a. A frequency-shift program (SHFT, D.2.4.1), which changes the frequency of all components by a specified amount halfway through the duration of a pulse; alternatively, it can be used to generate a waveform that has all frequency components shifted for the duration of the whole pulse.

b. Delayed harmonics (DELH, D.2.4.2); this enables the higher harmonics to be added after a specified time delay.

c. The basic waveform from the FFT may be left unmodified.

If required, the waveform from these modification programs can then be 50% amplitude-modulated with program MOD1 (D.2.5).

The gating programs which follow the modulator enable the operator to shape the waveform envelope with a standard 25 ms rise/fall or a slow rise or slow fall (gating programs, D.2.6).

Having generated a complete pulse, the operator may either store it and return to MENU in order to generate further pulses, or else add the pulse to one already constructed and stored (ADDE, D.2.7; STOR, D.2.8) and then return to MENU.

During the running of the complete program, there are full instructions to the user regarding operations and options available at each stage; there are also visual displays and auditory playback options available during pulse construction and these facilities will be fully explained in Section D.2, which follows. The total pulse construction program lends itself to the easy introduction of further modules, or programs, that can further increase the flexibility of the system. The main constraint on this increase would be the limitations of the direct access memory (DMA), a listing of which (with respect to the pulse construction program), is given in Table D.1. A simplified block diagram of the complete program is given in Figure D.1.

A completed pulse may be stored in a 2K segment of memory on a hard disc by using SEDIT system commands and may be recalled and replayed at will. In the construction of complete auditory warnings, pulses stored on hard disc are easily fed into the warning generation program, either at the beginning of construction or into the completed warning; the latter option means that a completed warning may be tried with different sound pulses.

D.2 Pulse generation programs

The following sections describe in detail each subprogram in the pulse generation program. Subprograms are generally referred to as programs. The first two deal with data input.

D.2.1 Input of discrete spectral information (PULS).

This initial program deals with the input of the required spectral components and their levels. The frequency and level of components will have been estimated in advance from the data provided by noise measurements carried out in situ, modified by earphone responses and headphone attenuation characteristics (see Section 5.2) and processed by the auditory filter model to give threshold estimates.

On initializing the pulse construction program (by using the command FS PULS), the operator is asked to

"Enter number of frequencies in warning (4-10):"

and, having entered this information, he or she is asked (for each frequency) to

"Enter frequency (multiple of 5 Hz):"

The spectral resolution is 5 Hz; this is a function of sampling rate and the number of sampling points, so with the sampling rate of 10 kHz and 2 kHz transform used in this program we have a 5 Hz resolution. It should be noted that although the program asks for between four and ten frequency components, it will actually accept numbers outside this range.

The operator is then asked for the level of each frequency component in turn:

"Enter level (1-9999) of component 'i':"

where 'i' is the level of the 'i'th component. Levels are entered according to the criteria assessed in Section 5.2.

D.2.2 Fourier Transform of input spectrum (TSFM).

Once frequencies and levels have been entered, the TSFM program plots the line spectrum of the pulse on the screen. Components are alternately designated as being either in cosine or sine phase in order to minimize the peak factor in the subsequent waveform. While plotting the spectrum, the program splits the screen and shows the cosine (real) components on the left half of the screen and the sine phase (imaginary) components on the right. When all components have been plotted, the program carries out a Fast Fourier Transform (FFT) on the line spectrum, stores the waveform and passes automatically to the next program, MENU.

D.2.3 Master program (MENU).

On entry to this program, the memory automatically displays the line spectrum, and the VDU gives the following information:

"Your basic spectrum is stored in blocks 0-2 and its transform in 2-4. You may continue by choosing one of the following options:

1. Basic waveform.
2. Frequency-shifted pulse.
3. Delayed upper harmonics.
4. Print pulse spectrum values.

Enter option number:"

Option four prints the required values (PRIN, D.2.4.1) and returns to MENU; option one passes direct to the modulation program MOD1; options two and three pass to programs SHFT (D.2.4.2) and DELH (D.2.4.3) respectively before going on to the modulation program.

D.2.4.1 Printout (PRIN).

This option merely controls printout, which gives a complete list of input frequencies and their levels on the printer terminal. Input of data is described in Section D.2.1 (PULS).

Printout is of the form

Frequency 1 =	1200 Hz	Level	5136
Frequency 2 =	1450 Hz	Level	2279
.	.	.	.
.	.	.	.

D.2.4.2 Frequency-shift (SHFT).

The operator is given the choice of two options with SHFT. He may create a pulse, the latter half of which has all components shifted up in frequency by a set amount (automatic); alternatively, it is possible to shift all the constituent frequencies of the pulse up in frequency (DIY). Repeated use of the latter may be used to build up short pulses with different frequency shifts into a longer pulse which thereby has a simulated frequency sweep throughout its duration.

On entry, the program operates as follows:

> "Insert frequency shift (1-50). These are multiples of 10 Hz (e.g. 5-50 Hz):"

As the digital resolution is actually 5 Hz, the program multiplies this input variable by two in order to obtain a 10 Hz multiple. This value is then added to each component of the basic pulse spectrum in turn and the new spectrum is plotted on the split memory screen as before with cosine phase on the left, sine on the right. The program then asks:

> "Automatic frequency shift (0) or DIY (1)?:"

If the user requests the automatic option, the program carries out an FFT on the shifted spectrum and stores the waveform. After appropriate gating (see D.2.6), half of the original stored waveform (100 ms) is added to half the frequency-shifted waveform (100 ms). The resultant waveform thus consists of a 200 ms signal with a frequency shift after 100 ms. The second option (DIY) simply stores the FFT of the shifted spectrum, ready to be added to other waveforms if required later. Both options end by calling the modulation program (MOD1, D.2.5).

D.2.4.3 Delayed harmonics (DELH, DEL1).

Although titled 'delayed harmonics' the program will operate on any discrete spectrum whether harmonic or not. It splits the number of components in the original spectrum into two, then generates and stores a waveform derived from the lower components only. It then calls DEL1, a continuation program, which asks:

"What delay to upper harmonics? Enter 25-125 in multiples of 12.5 ms:"

Once the required delay has been entered, DEL1 gates the necessary waveforms and adds them with the specified time delay. For example, if the basic input had been a ten-component spectrum, and a delay of 75 ms had been requested, the resulting waveform would start with the five lower components, the remaining five being 'switched in' after 75 ms and lasting for the remaining duration of the signal (for overall duration, see Section D.2.6). The program ends by calling the modulation program, MOD1.

D.2.5 Amplitude modulation (MOD1).

Before final gating of the waveform, all pulses may be amplitude modulated. For all but the longest pulses, it is probably not worth using this option as the saliency of short pulses is not greatly affected by modulation of this kind. If required, however, the program will modulate the waveform sinusoidally to a depth of 50% and pass the result on to the gating programs which follow.

D.2.6 Gating and duration (GATE, GAT1)

Having constructed a pulse waveform, the operator is now asked to enter the pulse duration and envelope shape required. Prompts are:

> "Enter pulse duration required (75-200 ms in multiples of 25 ms):"

followed by:

> "The envelope may be chosen from the following options:
>
> 1. Standard pulse (25 ms ramps).
> 2. Slow onset.
> 3. Slow offset.
>
> Enter option number:"

As seen, overall pulse duration can be requested from 75 to 200 ms. The standard pulse option automatically constructs the required length of pulse and fits it with rise/fall ramps of 25 ms duration (GATE, and its continuation CON1). Overall duration is defined with total ramp duration included (i.e. not 6-dB down points). A gating waveform is produced from the information given by the operator and this is multiplied with the pulse waveform. The gated pulse is then displayed on the DMA screen and the sound system plays the pulse six times through loudspeakers. It may be replayed again as many times as felt necessary by the operator.

Options 2 and 3 call program GAT1 (and its continuation CONT), which constructs asymmetric envelopes. A value of 25 ms is subtracted from the overall pulse duration and a raised cosine gate is generated for twice the resulting value. One half of this gate is then joined to a standard 25 ms gate to form a complete envelope. If a slow onset had been requested with an overall duration of 150 ms, for instance, the first half of a cosine gate of 250 ms would be joined to a standard offset ramp of 25 ms in order to complete the required envelope. This asymmetric envelope is then multiplied by the pulse waveform, displayed, and played six times with the option to replay as many times as desired.

Both standard and asymmetric programs conclude with the following prompts

> "If you have already stored a previous pulse, you may add it to the present pulse (with an optional time delay) up to a maximum duration of 200 ms. Further pulses may be created by returning to MENU. Return to MENU (0) or add pulses (1)?:"

The latter response takes the operator direct to program ADDE (2.7). A request for a return to MENU is followed by the further prompt

> "Store current pulse? Yes (1) or No (0):"

Thus the currently-displayed pulse can be stored if required before returning to MENU.

D.2.7 Addition and storage of pulses (ADDE, STOR).

On entry to this program the following prompt is displayed:

> "If you have previously stored a pulse, you may add it to the current pulse by retrieving it from from the following locations:

Basic spectrum pulse (4)
Frequency-shifted pulse (8)
Delayed-harmonic pulse (12)
DIY frequency shift (16)
Previously-added pulses (18)

Enter location of required pulse:"

The program calls the required pulse into working memory and then asks :

"Enter start-to-start delay (10-100 ms in multiples of 10 ms. Overall duration must not exceed 200 ms):"

If the instruction concerning duration is disregarded, the following error message is displayed:

"TOTAL DURATION GREATER THAN 200 MS. Press ',' in order to restart."

On restart, the program then reverts to the beginning of ADDE. Providing the overall duration is less than 200 ms, the added pulses are displayed visually and played six times through the sound system with the option to replay as many times as desired. The program then calls STOR (a continuation of ADDE) which asks :

"Do you wish to store this pulse?
Yes (1) or NO (0):"

On reciving an input, it carries out the command and prompts ;

"Do you wish to add another pulse to this one?
Yes (1) or No (0):"

If the answer is NO, the program returns to MENU; if YES, it continues ;

"Is the pulse you wish to add already available (0) or yet to be synthesized (1)?:"

If the pulse to be added is already available, the program returns to ADDE; if not, it returns to MENU to enable a new pulse to be created.

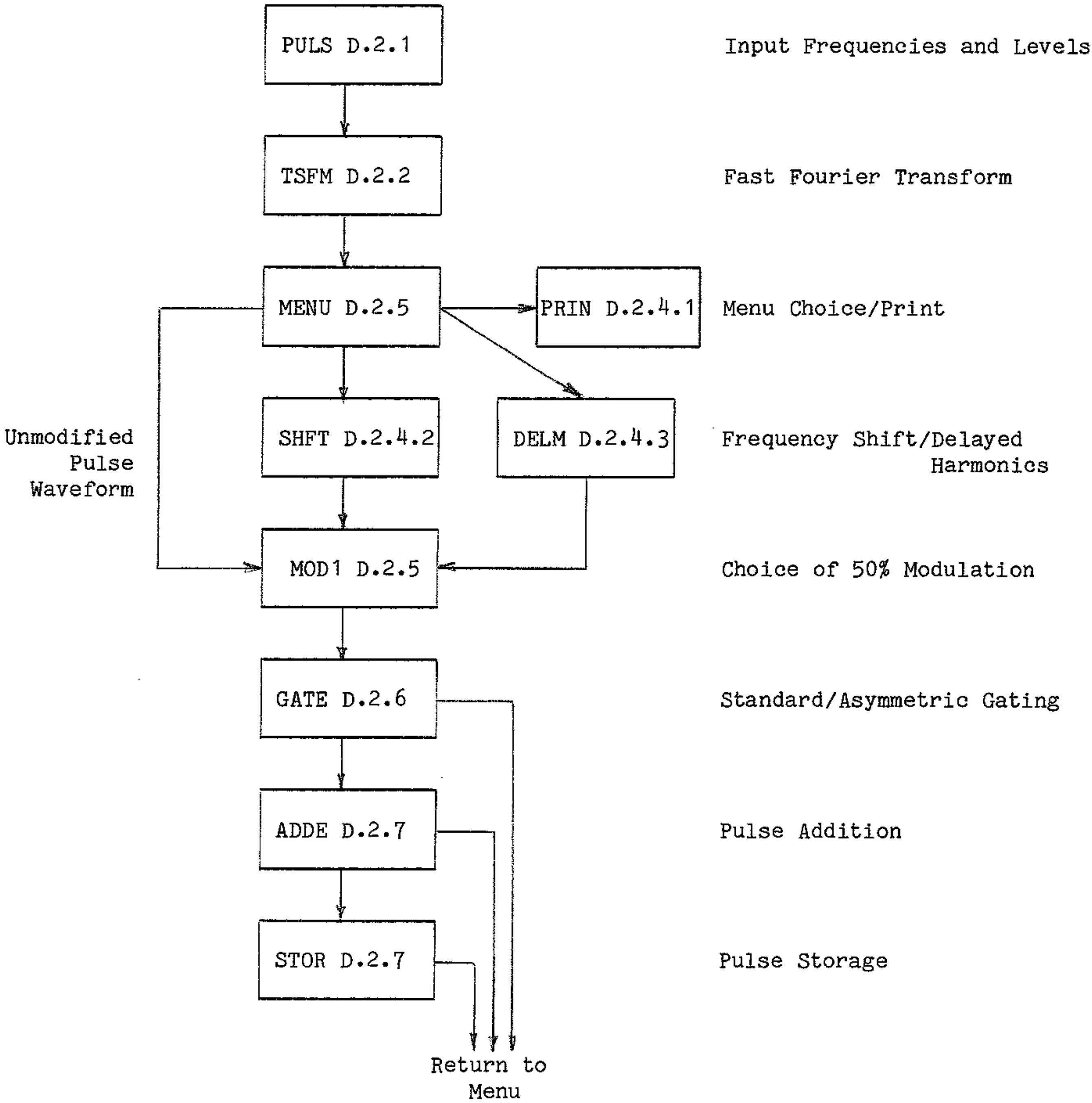

Figure D.1: Simplified block diagram of overall program

TABLE D.1 Organization of the Direct Memory Address (DMA)

Block	Memory allocation
1/2	Basic spectrum
2/4	Basic waveform
4/6	Basic waveform (gated)
6/8	Frequencyshift waveform
8/10	Frequencyshift (gated)
10/12	Delayed harmonics waveform
12/14	Delayed harmonics (gated)
14/16	Modulation
16/18	DIY frequency shift
18/20	Storage of added pulses
20/28	General workspace
28/30	Pulse addition and display
30/32	Check for pulse duration

APPENDIX E

GENERATING AND AUDITORY WARNING FROM A SOUND PULSE

E.1 Introduction

This is a guide to a suite of programs for warning construction. It enables the user to generate a complete auditory warning from a single pulse of sound. The sound pulse can either be generated using a parallel program suite for pulse construction, or selected from a battery of pulses stored on the hard disk.

Warning construction occurs in three stages. The product of each stage is a set of parameter values specifying an entire burst of sound. The values act progressively on the pulse in real-time in groups of three. Within each group of three values, the first determines the pitch at which the current pulse is to be played, the second determines the attenuation of the pulse, and the third determines the time interval between the start of the current pulse and the start of the next. The parameter values are printed out in the form shown in Table E.1.

The meaning of these values will be given in the following pages.

In the first stage, a matrix of values is generated in order to create an original burst of sound. The set of values specifying this burst is printed out on completion. The pitch, attenuation and spacing of each sound pulse can be altered independently.

The original set of values is scaled as a single unit (a burst of sound). In the second stage, the original burst is rescaled in pitch, attenuation and/or pulse spacing as desired. Pulses cannot be altered individually; the user specifies the scaler which acts on each of the burst parameters. The end product of this stage is a set of variables specifying a rescaled burst. A burst matrix, in the form of Table E.1 is printed out on completion.

In the third stage, three versions of the burst are set up from the rescaled burst, for the final warning. They are initial, urgent and background forms of the burst. Three burst tables are printed out. For the three burst types, three new sets of parameter values are created and stored on-line, in addition to the set for the rescaled burst which is itself not part of the final warning.

The range of possible values for each of the parameters is large and only minimally constrained by the sound system itself; however, ergonomic considerations make only a subset of these values appropriate for an auditory warning. Familiarity with CAA paper 82017 is assumed, and some ergonomic considerations are presented fin the text that accompanies the programs described here.

E.2 Sound generation

The auditory warning is played through the analogue sound-rig at APU. The pitch, attenuation and pulse spacing values act successively on the single pulse, to generate burst of sound.

The pitch, level and length of the pulse are specified during the pulse-construction, or pulse-selection, stage. The pitch of the pulse can be altered, attenuation can be added and time intervals can be placed between pulses in order to construct appropriate auditory warnings.

E.2.1 Pitch

The pitch and fundamental of the pulse is already specified. Changes of pitch are achieved by modifying the sampling rate of the sound-system, on-line, as each pulse in the warning is played. Ergonomic considerations restrict the range of possible values, and details of these constraints are given in the programs.

E.2.2 Attenuation

The sound pulse is set at maximum DAC output. In the complete warning, changes in level are achieved by altering the attenuation of the pulse as the warning is played. This is achieved by modifying the programmable attenuators on-line. The minimum attenuation value is 0 dB, and ergonomic considerations restrict the attenuation to approximately 20 dB.

E.2.3 Pulse spacing

The length of the pulse is already specified. Pulse spacing refers to the amount of time, in milliseconds, between the start of one pulse and the start of the next. The pulse spacing value for any pulse specifies the time interval, in milliseconds, between it and the next pulse; it refers to the first, rather than the second of two, pulses. Pulse spacing is achieved by waiting the required amount of time whilst playing the pulse within this period. If the length of the pulse exceeds the time required between pulses (as it will in some urgent burst forms), the system waits for the specified amount of time and then continues to the next pulse, irrespective of whether the full pulse has been played.

E.3 Description of programs

E.3.1 Stage 1: The Original Burst of Sound

The product of Stage 1 is a set of parameter values specifying an original burst of sound. The user specifies pitch, attenuation, and pulse spacing values for each pulse in the burst. Later in this stage each pulse can be independently altered. The programs for this stage are as follows.

E.3.1.1 AWPS:

Some text is presented describing the purpose of the program suite. The sound-system is set up by turning off the VDU and text, by setting an initial sampling rate of 10240 Hz and by setting the programmable attenuators to minimum attenuation. This program automatically fetches program PSEL.

E.3.1.2 PSEL:

Allows the user to select a pulse for use in warning construction. All the pre-made pulses are stored on the hard disk, in files with a size of 32 blocks. Starting at block 2, the pulses are stored progressively in 2-block units. There are 15 pulses per file.

The file required is placed into a buffer file of the same size (RAEP01). The user requests a number of pulses (maximum of 15); each pulse is shown on the screen, played 4 times, and its number displayed on the VDU. When all of the pulses have been presented, the user specifies the pulse required. The location of this pulse in the buffer file is stored ifn a variable, and the pulse is placed at location 0 in memory, where it stays throughout the entire warning construction process.

If the pulse has just been constructed, it should be placed in the buffer file and its location specified. This program automatically fetches program TEXF.

E.3.1.3 TEXF:

Explains how the original burst is specified. The user enters the pitch, attenuation and pulse spacing values associated with each pulse in the burst. Pitch is specified as an integer value from 1000-1500. This gives

501 possible values, and suggests the ergonomic constraint whereby a pitch range of 1-1.5 is not exceeded within a single burst. Attenuation is specified in dB, pulse spacing is specified in milliseconds. This program automatically fetches program BCF1.

E.3.1.4 BCF1:

Enters all the variables associated with the original burst. The user first specifies the burst length (stored in variable L) and then the values of the three parameters associated with each pulse. The following questions are asked of pulse 1 to pulse L:

1. Enter pitch (1000-1500) of pulse (x) >
   (A value is entered which is muliplied by 10 to become the sampling rate for pulse x.)

2. Enter attenuation (dB) for pulse (x) >
   (A value from 0 dB upwards can be entered, but ergonomic constraints will suggest an upper limit of about 10 dB.)

3. Enter time interval from start of pulse (x) to start of pulse (x+1) (ms) >
   (A value, in milliseconds, is entered. The time interval will depend upon the urgency level of the burst.)

The parameter values are stored in N(x), V(x) and D(x) respectively, where x ranges from 1 to L. At the end of the program, all the parameter values associated with the original burst are specified in variables. This program automatically fetches program PBPF.

E.3.1.5 PBPF:

Plays the original burst as the parameter values act in groups of three on the pulse stored at 0 location in memory. The programmable attenuators are set to V(x), the sampling rate to N(x). The pulse is played and the wait period specified by D(x) is timed. The whole burst is played by incrementing x in integer steps from 1 to L. The user specifies the number of times he/she wishes to hear the burst. This program automatically fetches program MENF.

E.3.1.6 MENF:

Presents 4 options:

1. To alter a pulse (ABFQ)

2. To see the burst (CBFP)

3. To play the burst (PBPF)

4. To print out the matrix of parameter values in the form of Table 1 (OPAD)

E.3.1.7 ABFQ:

Allows the user to alter one, two or all three parameter values associated with a single pulse in the burst. The number of the pulse is specified in variable x and following questions are asked:

1. Do you wish to alter the pitch of pulse (x)?

   (If No, question 2 is asked)
   (If Yes, the previous value of N(x) is shown on the screen and a new value is entered by the user)

2. Do you wish to alter the attenuation of pulse (x)?

   (If No, question 3 is asked)
   (If Yes, the previous value of V(x) is shown on the screen and a new value is entered by the user)

3. Do you wish to alter the time between pulse (x) and the next pulse?

   (If No, the program returns to program MENF)
   (If Yes, the previous value of D(x) is shown on the screen and a new value is entered by the user; the program then returns to program MENF)

The MENF-ABFQ-MENF loop can be implemented any number of times. This program automatically fetches program MENF.

E.3.1.8 CBPF:

Constructs a picture of the burst in memory, showing it on the VDU. The original pulse is copies in memory location 2. It is then attenuated in memory by the variable V(1). The value of D(1) is converted to its approximate value in block sectors, and the pulse size, in block sectors, is subtracted from this value and placed in variable N. Zeros are entered in memory for N blocks immediately after the first copy. The pulse is then copied again at the new memory location and the second set of variables (V(2) and D(20) operate on it in the same way. This is done for all values of V(x) and D(x). Values of N(x) are not involved. The whole of the burst is then viewed.

If the total number of blocks required exceeds 30, the burst will not be available on the screen. This program automatically fetches program MENF.

E.3.1.9 OPAD:

Prints out the matrix of parameter values associated with the original burst in the format shown in Table E.1. The column under 'Pitch' prints out the pitch parameter values of N from N(1) - N(L); the column under 'Attenuation' prints out the values of the attenuation parameter V from V(1) - V(L); the column under 'Spacing' prints out the values of the spacing parameter D from D(1) - D(L).

This program is the only exit route from program MENF. This program automatically fetches program TBSC.

E.3.2 Stage 2: The Rescaled Burst

The original burst is rescaled to produce a rescaled burst and table of parameter values in the form shown in Table 1. Pitch, attenuation and/or pulse spacing can be rescaled, or the original burst can remain unaltered. Individual pulses cannot be independently altered as any change is applied to an entire parameter. The user is successively asked whether he/she wishes to change the pitch, attenuation and/or pulse spacing of the original burst. When alterations are required, variables act on the appropriate set of parameter values (N(x), V(x) or D(x)).

When any change occurs the user has the option of either storing the new parameter values, or of resetting them back to their original values. The rescaled burst is heard before this decision is made.

E.3.2.1 TBSC:

Presents the user with text explaining that the original burst can be rescaled. The scaling procedures are explained in later programs. The program asks three questions:

1. Do you wish to rescale the pitch of the burst?
   (If No, question 2 is asked)
   (If Yes, program SCP2 is fetched)

2. Do you wish to rescale the attenuation of the burst?
   (If No, program OPAR is fetched)
   (If Yes, program SCA2 is fetched)

3. Do you wish to rescale the pulse spacing of the burst?
   (If No, program OPAR is fetched)
   (If Yes, program SCD2 is fetched)

E.3.2.2 SCP2:

Allows the user to rescale the pitch of the burst. Text describes the method of rescaling. An integer value of between -10 and +15 is entered, where each integer approximates to a semitone in the musical scale. This integer is multiplied by 500 and is added to all pitch parameter values (N). This results in a drop in pitch for a negative value, and a rise in pitch for a positive value. A range of -10 to +15 can therefore result in a sampling rate of 5000 Hz for the lowest pulse in a low-pitched burst (10000 - 5000 to 15000 + 7500). This allows any rescaled burst to be further rescaled by the same range, which may take place in the warning construction stage. Ergonomic considerations will restrict the range of appropriate values, and a pitch range of 1 to 1.5 within a burst will generally not be exceeded. This program automatically fetches program PPS2.

E.3.2.3 PPS2:

Plays the rescaled burst with its new pitch parameter values a specified number of times. The burst is played in exactly the same way as in program PBPF (Section E.3.1.5). The new pitch values can either be stored or reset back to their original values. If the user chooses to reset, all original pitch values are reinstated and program SCP2 is fetched, allowing a different pitch scaler to be entered (a value of 0 is acceptable, resulting in no pitch change from the original pitch values). This loop can be initiated any number of times.

When the new pitch is determined, 2 further questions are asked:

1. Do you wish to rescale the attenuation of the burst?
   (If No, question 2 is asked)
   (If Yes, program SCA2 is fetched)

2. Do you wish to rescale the pulse spacing of the burst?
   (If No, program OPAR is fetched)
   (If Yes, program SCD2 is fetched)

E.3.2.4 SCA2:

Allows the user to alter the attenuation of the burst. An integer value of dB is to be entered, which is then added to all attenuation values in the original burst. A negative value can be entered, provided it is no greater than the attenuation of the loudest pulse in the original burst. If a positive value is entered, it should be no greater than a value which would allow the attenuation on any pulse in the burst to exceed 20-25 dB, depending on ergonomic constraints. This program automatically fetches program PPA2.

E.3.2.5 PPA2:

Plays the burst with its new attenuation values a requested number of times. The burst is played in exactly the same way as in program PBPF. The new attenuation values can be stored or reset. If the user wishes to reset, program SCA2 is fetched, allowing the user to enter a new attenuation scaler (including 0, resulting in no attenuation change from the original burst). When the attenuation has been rescaled, the following question is asked:

> Do you wish to alter the pulse spacing of the burst?
> (If No, program OPAR is fetched)
> (If Yes, program SCD2 is fetched)

E.3.2.6 SCD2:

Allows the user to rescale the pulse spacing of the original burst. Text describes the method of rescaling. The existing pulse spacing is assumed to be 10. An integer value of from 1 to 20 is entered, with values less than 10 reducing pulse spacing (speeding up the whole burst), and values greater than 10 increasing pulse spacing (slowing down the whole burst). Each pulse spacing value is multiplied by the integer entered, and then divided by 10 to produce new values. The pulse spacing of the burst can therefore be altered by a factor ranging from 0.1 to 2, a range beyond that which will generally be appropriate in the final warning. This program automatically fetches program PPD2.

E.3.2.7 PPD2:

Plays the burst with its new pulse spacing values a requested number of times. The burst is played in exactly the same way as in program PBPF. The new pulse spacing values can be stored or reset. If the user wishes to reset these values, program SCD2 is fetched, allowing a new spacing scaler to be entered (including 10, resulting in no pulse spacing change from the original values). This program automatically fetches program OPAR.

E.3.2.8 OPAR:

Prints out the matrix of burst parameter values which specify the rescaled burst in the same way as program OPAD (Section E.3.1.9). Any new values will have overwritten those of the original bursts, as all parameter values are stored in variables N(x), V(x) and D(x). This program automatically fetches program WAT3.

E.3.3 Stage 3: The Initial, Background and Urgent Bursts

In this stage, the complete warnfing is constructed and played. For the purposes of this paper, assume that a warning with three burst forms - initial, background and urgent - is to be constructed. The appropriate pitch, attenuation and pulse spacing levels of these three burst forms are specified. The rescaled form of the burst is used as a template for each of the three bursts.

For some of the bursts, all three sets of burst parameter values do not differ from those of the rescaled burst. However, for uniformity, 3 new sets of parameter values are set up for each burst. The new burst forms are incremented by z, with z starting at 11.

The burst parameter values are generally determined in the same way as for the rescaled burst form, as can be seen from the following program descriptions. As in Stage 2, any rescaling which takes place is not final. The user is presented with the option of resetting the parameter values after hearing the new burst form. In Stage 3, this takes the form of returning to the template, the rescaled burst, the parameter values of which remain untouched throughout. When each burst type is determined, parameter matrices are printed out in the form of Table E.1.

E.3.3.1 WAT3:

Text describes how the warning is constructed. The rescaled burst is the template for constructing three burst forms: initial, background and urgent. For the initial burst, the pitch values of the rescaled burst are used and cannot be changed, although these values are copied into new variables. The pulse spacing is also that of the rescaled burst, although new variables are again set up. The user can alter the attenuation on the rescaled burst in generating an initial burst.

The pitch of the background burst can differ from that of the rescaled burst, and will generally be lower. The user determines the pitch level by entering an integer value of from -10 to +15, where 0 is the pitch of the rescaled burst. Each integer corresponds approximately to a semitone in the musical scale. Positive values raise the pitch, negative values lower the pitch. The background burst is played at a constant level (i.e. there is no attenuation envelope). The user enters this level (dB). The pulse spacing of the background burst can be different from the rescaled burst, and will generally be greater. The pulse spacing of the rescaled burst is assumed to be 10. The user enters an integer value of between 1 and 20. Values greater than 10 increase pulse spacing, values lower than 10 decrease pulse spacing.

For the urgent burst form the pitch, attenuation and pulse spacing of the rescaled burst can be altered. Pitch and pulse spacing are determined in the same way as for the background burst, although the user will generally raise the pitch and decrease the pulse spacing of the rescaled burst for this burst form. The urgent burst form has an amplitude envelope, and the user is asked to specify the number of decibels of attenuation change to be made on the envelope of the rescaled burst (probably 0, or a negative number).

A complete matrix of parameter values, specifying the entire burst, is produced for each burst form. This program automatically fetches program IBS2.

E.3.3.2 IBS2:

Enables the user to specify the form of the initial burst to be used in the complete warning. The pitch and pulse spacing values are those of the rescaled form of the burst. The rescaled values of N(x) and D(x) are placed in N(z) (pitch) and D(z) (spacing). Attenuation can be altered, and the user enters the number of dB attenuation to be placed on the attenuation envelope of the rescaled burst. It will be 0 or a positive value depending upon whether the level of the rescaled burst is set at maximum, or less than maximum, DAC output. The level of the initial burst will be lower than that of the urgent burst and so the initial burst should not be at maximum output. Each attenuation parameter value (V(x)) is altered by the attenuation change entered, and stored in V(z).

The user can then hear the initial form of the burst a requested number of times. The burst is played in the same way as in program PBPF, with the parameter values N(z), V(z) and D(z) acting progressively on the pulse.

If the new attenuation values are inappropriate, the program is re-fetched. The user can then alter the rescaled values of V(x) to a more appropriate level. If the new level is appropriate, these new attenuation values are stored. This program automatically fetches program OP12.

E.3.3.3 OPI2:

Prints out the matrix of parameter values which determine the initial form of the burst in the same way as program

OPAD. All values of N(z) are printed out in the column 'Pitch'; all values of V(z) in the column 'Attenuation'; and all values of D(z) in the column 'Spacing'. This program automatically fetches program BBS2.

E.3.3.4 BBS2:

Enables the user to specify the form of the background burst in the complete warning. The rescaled burst is used as the template. To alter the pitch of the rescaled burst to produce a background form, a value of between -10 to +15 is entered as described in program WAT3 (Section E.3.3.1). The program suggests that a negative value will probably be entered. The user enters this value, which is muliplied by 500. This value is added to all existing pitch values (N(x)) in the rescaled burst, to become the new sampling rates of the pulses in the background burst. These values are stored in B(z). The attenuation of the background burst is constant for all pulses. This value is entered in dB, which is placed in a new set of variables, J(z). To alter the pulse spacing of the rescaled burst to create a background form, an integer value of between 1 and 20 is entered. A value greater than 10 is suggested, which will slow down the burst. The rescaled spacing values (D(x)) are muliplied by this integer and are then divided by 10. These values are stored in X(z).

The background form of the burst can then be heard a specified number of times. The burst is played in the same way as in program PBPF, except that the parameter values are stored in B(z), J(z) and X(z). If one or more of the new values are inappropriate, the program can be re-fetched and new parameter values for pitch, attenuation and/or pulse spacing can be specified. If the new burst is appropriate as a background form, the new values are stored in B(z), J(z) and X(z). This program automatically fetches program OPB2.

E.3.3.5 OPB2:

Prints out the matrix of parameter values which determine the background form of the burst in the same way as program OPAD. All values of B(z) are printed out in the column 'Pitch'; the value of J(z) is printed out L times under the column 'Attenuation'; and all values of X(z) are printing out under the column 'Spacing'. This program automatically fetches program UBS2.

E.3.3.6 UBS2:

Enables the user to specify the form of the urgent burst to be used in the complete warning. To rescale the values of N(x) to an appropriate pitch, an integer value of from -10 to +15 is entered. A positive value is suggested. This value acts on the pitch values of the rescaled burst (N(x)) in the same way as in program BBS2, and the new sampling rate values are stored in M(z). The attenuation envelope of the urgent form is determined by the user entering the number of dB attenuation change required from the rescaled version of the burst. If the rescaled burst has been set at maximum level, there will be no attenution change (a value of 0 dB will be entered). If the rescaled burst is not at maximum level, a negative value will be appropriate, but cannot exceed the attenuation of the loudest pulse in the rescaled burst. All the attenuation values of the rescaled burst (V(x)) are altered by this value, and stored in L(z). To alter the pulse spacing of the urgent form, an integer value of from 1 to 20 is entered, which acts on all spacing values of the rescaled burst (D(x)) in the same way as in program BBS2. A value of less than 10 is suggested. The new pulse spacing values are stored in F(z).

The urgent form of the burst can then be heard a specified number of times. It is played in the same way as in program PBPF, with the new variables acting successively on the pulse. If any, or all, of the sets of parameter values are unsuitable, the program can be re-fetched and new values of M(z), L(z) and/or F(z) specified. If the burst is appropriate, these new values are stored. This program automatically fetches program OPU2.

E.3.3.7 OPU2:

Prints out the matrix or parameter values which determine the urgent form of the burst in the same way as program OPAD. All values of M(z) are printed out under 'Pitch', all values of L(z) are printed out under 'Attenuation', and all values of F(z) are printed out under 'Spacing'. This program automatically fetches program ITV2.

E.3.3.8 ITV2:

Enables the user to specify timing and repetition variables which operate as the warning is played in real-time. This program assumes that the warning will begin with a number of initial bursts, followed by a spoken message, followed by cycles of background burst (played a number of times), urgent burst (played a number of times) and a spoken message. Other warning forms are available (see Section 4 below). Text describes the timing and repetition variables required to construct a warning of this type. First, the number of plays of the initial burst is specified, followed by the time interval between initial bursts (end to start). The background burst-urgent burst-spoken message cycling is explained. The user specifies the number of such cycles required. For each cycle, the number of background bursts, and the time interval between each of them, is specified. The number of urgent bursts, and the time between each of them, is also specified. Finally, the amount of time required for the spoken message is entered. This program automatically fetches program PWM2.

E.3.3.9 PWM2:

Plays the complete auditory warning. Each burst is played in the same way as in program PBPF. The parameter values of the initial burst [N(z), V(z) and D(z)] act on the pulse the required number of times, waiting the time interval requested (in milliseconds) between bursts. The program then waits the time specified for the first spoken message. The background burst-urgent burst-spoken message cycles then begin. The background burst is played by all values of B(z), J(z) and X(z) acting successively on the pulse the required number of times, waiting between bursts. The urgent form of the burst is then played the required number of times by all values of M(z), L(z) and F(z) acting successively on the pulse, and then waiting the required amount of time between bursts. A time interval for the spoken message elapses, and the cycle is repeated until the required number of cycles have been played.

When the warning has been played, a different pulse can be entered into memory at 0, and the warning played again. The pulse must be in the buffer file, RAEP01, and its position in the file indicated. Alternatively, a new pulse file can be placed in the buffer.

E.4 Additional programs

E.4.1 Between stages 2 and 3

E.4.1.1 STV3

The three sets of parameter values associated with any rescaled burst can be stored in file RAEB01. Up to 16 burst forms can be stored in one block on this file, which is 100 blocks long. The required block is fetched from the hard disk and placed at location 8 in memory. The user specifies (in word mode) the location at which the burst variables are to be stored. All current values of N(x), V(x) and D(x) are stored, with x incrementing from 0 to 19. When all the parameter values have been stored, the block is stored back on the disk, at its previous location.

This program enables the user to store a complete set of parameter values without proceeding to create a warning. He/she can go on to construct the complete warning.

E.4.1.2 FEV3:

Enables the user to fetch a complete set of burst parameter values into memory, which are stored in file RAEB01 on the hard disk. The listener specifies the block on the hard disk in which the required burst parameter values are stored (facilitated by STV3 above). This block is fetched into memory at location 8. The storage location of the burst is entered (in word mode) and the length of the burst (in pulses) is entered and stored in L. The parameter values stored on disk are then progressively entered into N(x), V(x) and D(x) with x incrementing from 0 to 19. This sequence fetches program PBPF, and the burst is played the required number of times.

This option allows the user to test a number of different bursts using the same pulse.

E.4.2 Playing the warning

All three burst forms will not be required for some types of warning. Two optional programs allow the warning to be played with only two burst forms.

E.4.2.1 PWNU:

Playes the warning in the same way as program PWM2 (Section

E.3.3.9), without an urgent form of the burst. The initial burst is played the required number of times, followed by a spoken message, followed by cycles of background burst (played the required number of times) and spoken message. This will be appropriate for warnings of low-priority urgency.

E.4.2.2 PWNB:

Plays the warning, in the same way as program PWM2, without a background form of the burst. The initial burst is played the required number of times, followed by a spoken message, followed by cycles of urgent burst (played the required number of times) and spoken message. This will be appropriate for warnings of high-priority urgency.

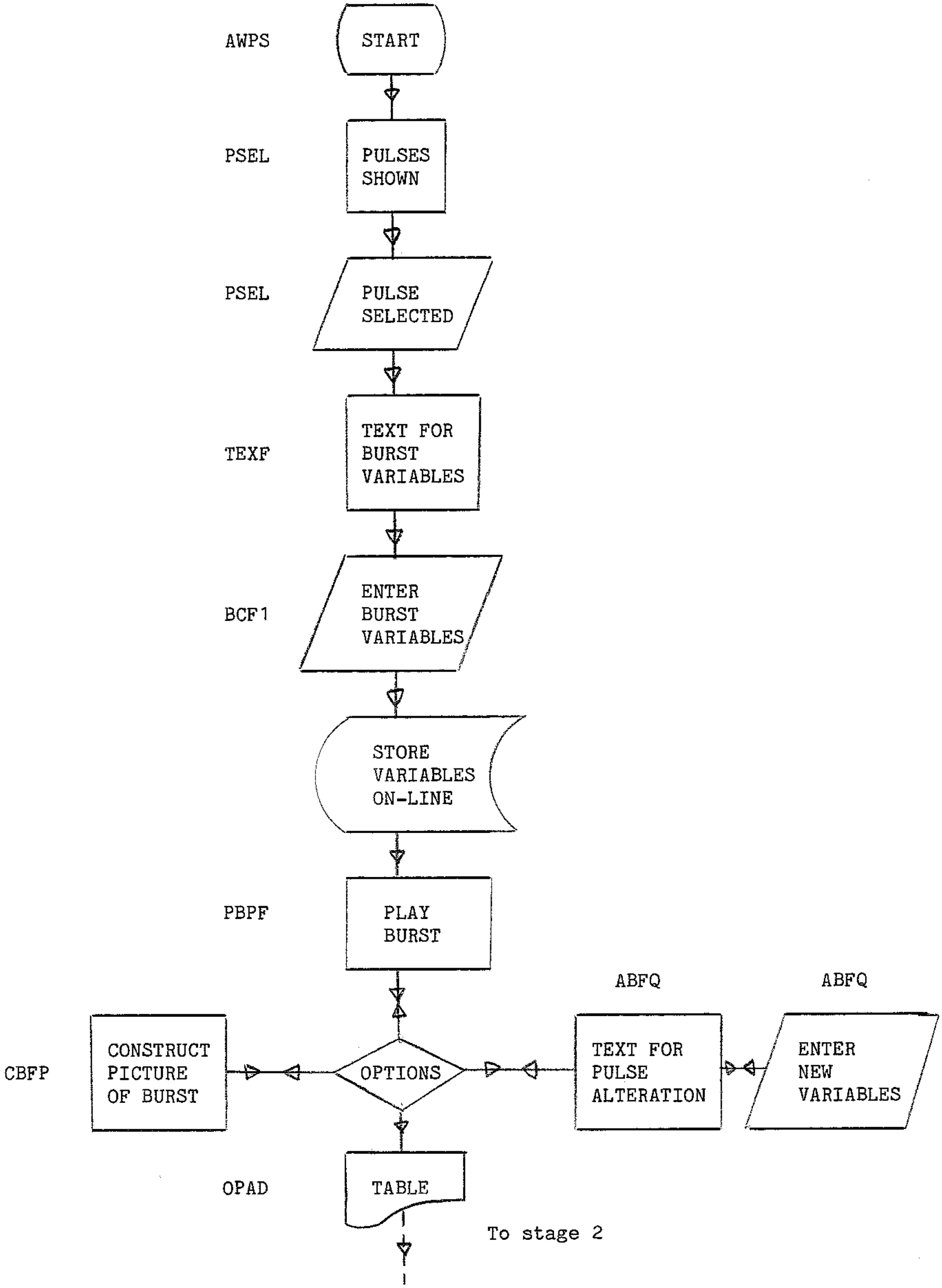

Figure E.1 Flow chart for Stage 1

COMMERCIAL-IN-CONFIDENCE

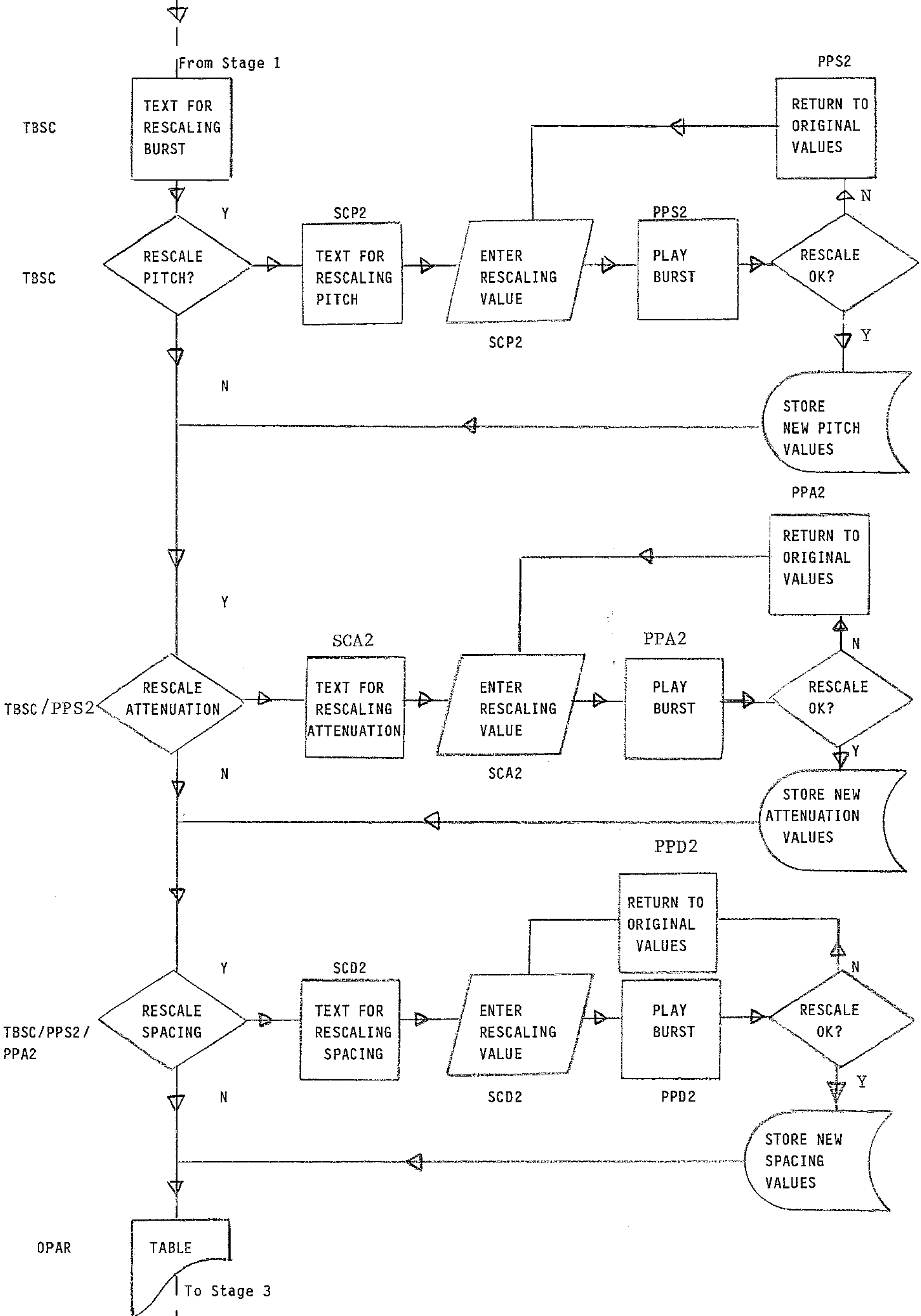

Figure E.2 Flow-chart for Stage 2

Figure E.2

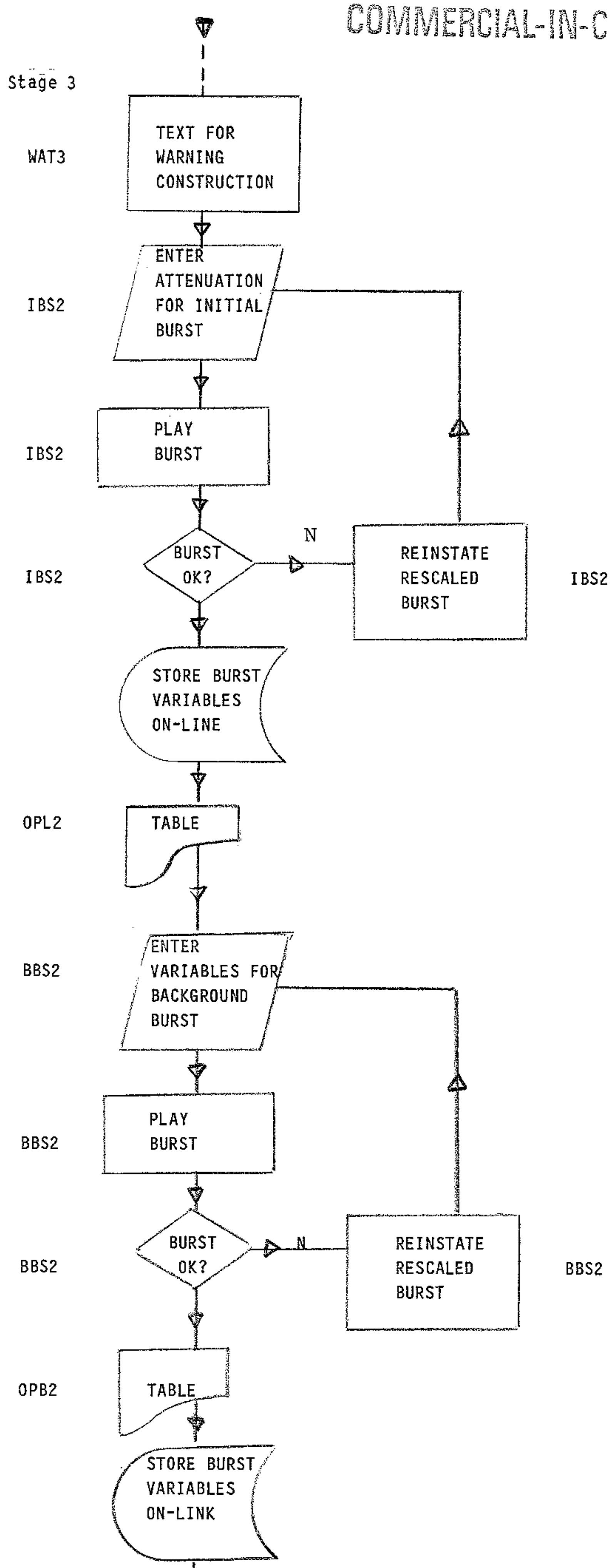

Figure E.3 Flow chart for State 3

COMMERCIAL-IN-CONFIDENCE

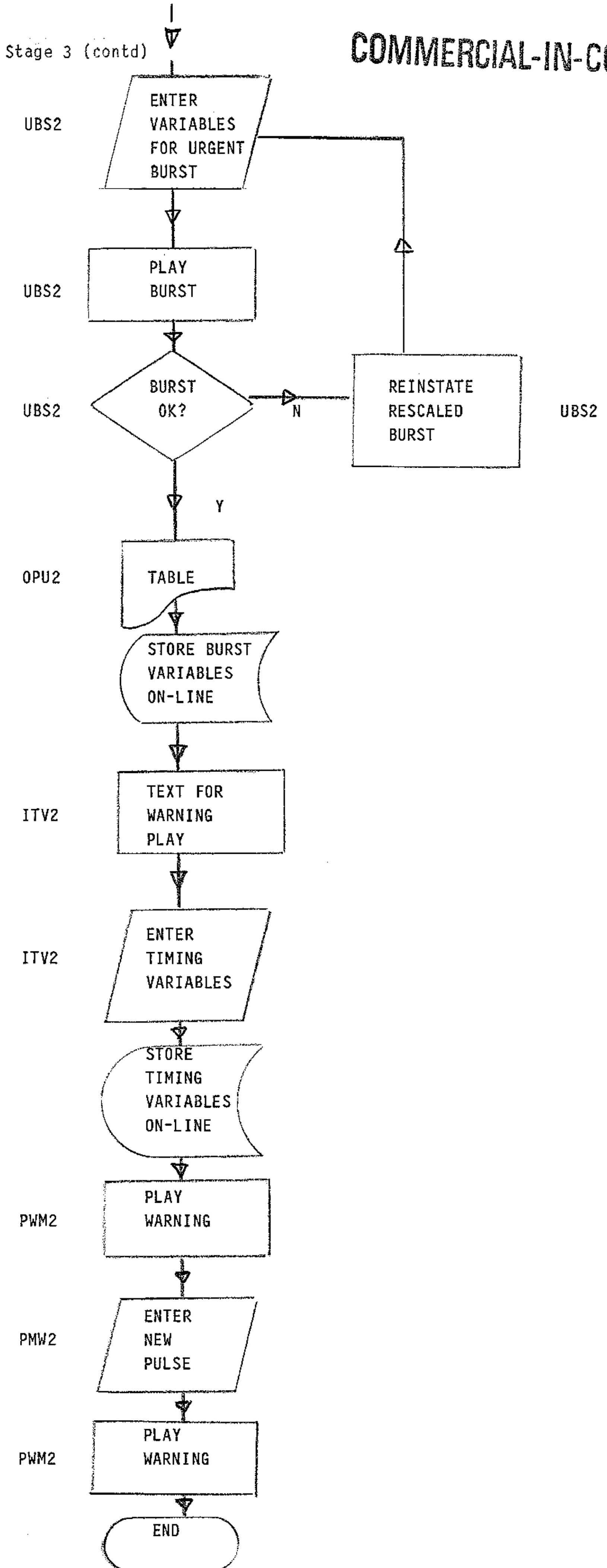

Figure E.3 (Continued)

	Pitch	Attenuation	Spacing
Pulse 1	1100	20	300
Pulse 2	1200	16	250
Pulse 3	1250	13	250
Pulse 4	1311	6	200
Pulse 5	1456	2	300
Pulse 6	1126	10	300

Table E.1: Form of table printed out for each burst form

Annex to ACHCU Report No. AC527A, October 1986.
MOD(PE) Project A94B/3593

THE DESIGN AND PRODUCTION OF AUDITORY WARNINGS FOR HELICOPTERS

1. THE SEA KING

EXECUTIVE SUMMARY

Low flying and night operations place heavy demands on a modern helicopter pilot. Night-vision goggles restrict his field of view, and his work load and concentration are high. Warning sounds are vital in this situation - they can alert the pilot immediately whereas a light on the Central Warning Panel might pass unnoticed for a few seconds. Warning sounds are not routinely fitted to military helicopters at present. But experience in civil fixed-wing aircraft has shown that warning sounds are generally ill-considered and can be counter-productive. Often sounds are too loud. They may startle. They can disrupt thought and communication when it is most necessary. There may be too many sounds which can easily be confused, and the perceived urgency of the sound may not match the real urgency of an emergency - the warning which sounds the most urgent may not be the most urgent.

These problems are avoidable. Patterson has produced a set of guidelines for warning sounds in civil airliners. He recommends a warning made up of pulses of sound grouped into bursts, in effect short melodies or tunes. Individual warnings are highly distinctive and memorable, and the urgency of the sound is matched to the urgency of the fault or potential fault by varying the pitch, tempo and rhythm. The structure has minimal interference with communication, and by matching the sound levels of the warnings to the background noise level and spectrum on the flight-deck, the warnings will be loud enough to be heard reliably, yet not so loud as to startle or distract.

This present report extends the civil, fixed-wing guidelines to military helicopters. Helicopters in general need a faster response from the pilot, and in military helicopters where the crew wear full helmets, the warning sounds need to be integrated with the Communications Control System. The frequency response of the communications telephones, the noise at the ear passing directly through the helmet, and the noise at the ear from the communication system must all be considered. A further requirement is that any warning sound should have the same meaning whenever it is heard in any UK military helicopter. This will allow pilots to convert between helicopters and should minimise confusion and reaction time in an emergency.

When all helicopter types and variants are considered there are too many warnings for each to have its own unique sound, and some rationalisation is necessary. Therefore, three categories of warning sound are proposed. These can be regarded as "emergency", "cautionary", and "information". Although the most important warnings may be assigned their own sound, usually all emergencies will be

categorised under one, "emergency", sound but each will be uniquely identified by a voice message specific to that emergency. Similarly there will be a "caution" sound with distinguishing voice messages. The "information" sound will not have any voice messages.

Since the Sea King is a first helicopter for which warning sounds have been specifically designed, the basic methods and principles are described in detail in this report.

The noise spectrum in a Sea King at the pilot's ear was measured using a miniature microphone under the standard Mk.4 helmet. From this spectrum the quietest signal level at each frequency which would be just audible above the noise was calculated, using a computer model of the human ear. Fifteen and twenty-five decibels were added to this curve of the minimum audible level against frequency, to give respectively the minimum and maximum recommended sound levels for warning sounds. The voltages needed at the telephone to produce these sound levels were calculated from the telephone frequency response.

Sound waveforms with appropriate frequency spectra were then synthesised by computer and shaped into pulses of sound. These pulses are like notes played on musical instruments. The pulses were grouped into bursts, effectively short tunes, and then complete warning sounds, in which the basic tune is repeated with some variation in speed and urgency. These sounds were tape recorded and tested in realistic levels of helicopter noise in a helicopter noise simulator.

The simulator trials showed that the sounds were quickly and easily recognised even without their voice messages, provided there were not too many. A few sounds were rejected and improved at this stage. Six sounds are easily memorised and retained, ten are distinguishable but proportionately far more time and effort is required to learn this many.

The warning sounds are now ready for flight testing.