ENVIRONMENTAL EFFECTS UPON HELICOPTER CREW

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FIFTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM
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SUMMARY

Internal vibration, noise and thermal effects can all contribute towards reducing the comfort and effectiveness of helicopter crew members. Helicopters are becoming increasingly complex systems and the crew are often the overloaded weak link in the chain. Environmental stresses tend to aggravate this situation. The measurement of cockpit and cabin conditions, their effects upon crew performance, palliatives and other ways of overcoming the problems caused by these environmental factors are currently being investigated.

The vibration and noise problems in helicopters tend to be of a different nature and rather more severe than those encountered in fixed wing aircraft. By careful basic design of the helicopter some of the effects of vibration and noise on the crew can be reduced. However, much of the noise can result from poor design and inadequate integration of the helicopters avionics and other systems. In the past little attention appears to have been paid to these aspects, with the result that the potential efficiency of the overall crew-helicopter system often has not been realised. It is hoped that by examining the shortcomings of existing helicopters and applying the findings at an early stage in the design of future helicopter systems, the next generation should be free from many, if not most, of the faults that are present today.

1 INTRODUCTION

Helicopters have progressed a long way since the Focke-Wulf 61 of 1937 and the Sikorsky VS-300 and R4 series of World War II. The steady improvement in speeds and lifting ability are clearly illustrated in Figures 1 and 2. Despite the advances in aerodynamics, structures and power plants which make these improvements possible, there have been much smaller improvements in the human factors areas of the helicopter. These areas include control, vision and displays, the vibration, noise and thermal environments and the all embracing subject of crew workload. As the helicopter has become more reliable and its performance has increased, the tasks required of it and its crew have become more varied and demanding. The stage has now been reached where although the helicopter has the theoretical mechanical or aerodynamic ability to complete a task, the pilot or crew are now the weak link in the system, being unable to fulfil the task required of them. Only by matching the helicopter's characteristics carefully to the crew members capabilities and limitations, will the full potential of the total system be realised. Helicopter control characteristics, information displays, external vision, cabin vibration, noise, heat, cold, ventilation and work space geometry can all contribute to increasing man's workload and decreasing the total efficiency of the man-helicopter system. Only by considering these aspects sufficiently early in the design of a helicopter will it be possible to integrate the man and the helicopter and thus to produce the optimum overall combination.

2 MAN AS THE CONTROLLER, HIS ADVANTAGES AND SHORTCOMINGS

Until now helicopters appear to have been designed around rotor systems and power plants, followed by airframes and systems. Finally, the crew have been added as a "necessary evil". Often, this has resulted in far from optimum cockpit and cabin layouts, as far as the crew are concerned. However, man is extremely adaptable and has usually managed to cope with the situation, albeit at some cost to himself and/or a reduction in overall system performance.

Perhaps design should begin the other way about, starting with the man and building the helicopter around him. The man has certain attributes and capabilities which are either too difficult or too costly to be provided by machine. The man also has many shortcomings, many of which can be easily or cheaply overcome by machines. Given that man has limited mental and physical capacities (which are now being used to the full in some helicopters), then obviously the best must be made of his abilities and his poorer qualities must be replaced and performed by machines.

Man's superiority over the machine is readily apparent when it comes to tasks requiring the discrimination of signals in noise, pattern recognition, especially against changing backgrounds in situations where unexpected events occur and where sensing and reporting of incidental but useful information may be made during the course of an operation having other objectives. Man can also be used effectively as a monitor of automatic and semi-automatic systems and be given emergency override authority. Man is less well suited for repetitive tasks involving numerical calculations or when large amounts of data need to be processed swiftly and precisely. Machines are far better suited to performing these types of tasks. Machines also are superior when large forces need to be applied accurately and instantly. Man can generate only relatively small forces for short times, inaccurately and usually after a delay of up to a second or so. Although machines are good at making routine decisions according to previously specified rules, man is good at inductive reasoning and despite being prone to making mistakes, is usually quick to sense errors and take remedial action.

Obviously, many of the man's and the machine's qualities are already utilised in the correct way but there are still areas where the man is required to perform tasks that a machine would do better. For example, the helicopter is basically and unstable platform which requires small but constant control inputs to maintain steady flight. A fixed wing aircraft has no such limitations and can be trimmed easily to fly "hands off". This is very difficult, if not impossible to do with most helicopters unless an auto-stabilisation system is provided. If a helicopter has no auto-stabilisation system then the pilot will be unable to remove his hands and feet from the controls for more than a few seconds during flight without losing control of the helicopter. Thus, the man is occupied for most of the time performing a task which could be done better by a machine. The man has little spare capacity to take on other tasks for which his abilities may be better suited. If the helicopter is auto-stabilised then the man merely has to monitor the control system and is free to spend the majority of his effort on other tasks.

3 VISION AND DISPLAYS

To control an inherently unstable vehicle which has 6 degrees of freedom of movement (fore and aft motion, heave, sway, yaw, pitch and roll), the pilot needs good visual cues. These cues enable him to detect deviations from the intended flight path and then to apply control movements for correction. In general, the helicopter with its large transparent areas around the cockpit has provided a usually more than adequate external visual field for this purpose. However, there is a constant danger that these transparent areas may be reduced due, for example, to the need for extra panel space in the roof or to the addition of de-icing equipment for engines, both of which can blank off window areas over the cockpit. Also as advances in flight control systems etc improve the helicopter's manoeuvrability, the pilot requires additional transparencies through which to view the outside world.

Good visual cues are essential for the manual control of the helicopter during daylight but they become far more important for night flying or flight under imc, (instrument meteorological conditions) when the external visual references are replaced by instrument cues. Instrument flight is particularly difficult in an unstabilised helicopter and helicopter blind flying instruments have often left much to be desired. Helicopter instrument flying is far more demanding than day time flying when in visual contact with the ground. In-flight experiments, by Winn and Lewis[1] have shown that pilot effort is greatly increased during instrument flight in the helicopter. During instrument flight in cruise, control movements were found to increase by 65% over those made in cruise during normal daytime flying. It is thus essential to reduce the pilot's workload during instrument flight by providing improved information displays. The current upsurge in North Sea oil operations and the increasing need to operate military helicopters under poor weather conditions and at night have done much to spur on helicopter instrument developments in several directions.

A Sikorski S-61N operated by KLM Nordzee Helikopters has been flying since 1975 with a Kaiser electronic integrated pilot display system installed in the cockpit in place of the conventional artificial horizon[2]. This electronic display using a cathode ray tube (CRT) combines the data from all instruments which are usually scanned by the pilot during instrument take-offs and landings. The resulting CRT display is in the form of an enlarged artificial horizon. Superimposed on this are indicators of vertical speed, radio height, engine parameters (in alpha-numerical form), engine and fuel flow failure warnings and command symbols. Cyclic commands are depicted by a perspective "flight path" which converges to a point at the horizon. By incorporating all of these parameters into a single display the pilot's scanning is reduced and his visual and mental workload are improved significantly.

Once the CRT has been accepted into the helicopter cockpit for displaying flight information it can be used also to provide other types of information to the pilot. At present, crews often have to carry considerable quantities of paperwork and maps into the cockpit for navigation, radio frequency details, check lists, emergency procedures etc. These often present cockpit stowage problems. (There are rarely adequate map stowages in helicopter cockpits and papers are often stowed under the pilot's thighs.) The suitably programmed CRT display offers a solution to these problems. Check lists, navigational and radio data can all be stored in the helicopter's computer and summoned by the pilot or crew when required. In addition to these uses, a low light television or infra red view of the outside world might be presented on this CRT for night operations. Care must be taken however, not to abuse the advantages offered by the CRT display. It is always tempting to display an ever increasing amount of information to the crew. Man is effectively a single channel device with limited processing ability. If the CRT becomes cluttered and too much information is presented, the man will be unable to process it and the full potential of the display will not be realised. Only by careful matching of the display data to the man's information requirements and abilities, will the display be optimised.

4 VIBRATION

Even when a display apparently has been optimised for use by the crew, its theoretical performance may not be realised in flight if the vibration environment of the helicopter is sufficiently great.

In the past, considerable effort has been devoted to protecting equipment and instruments from vibration in aircraft. Far less effort has been spent on protecting the man from the vibration, yet if the man cannot operate the equipment due to the vibration effects on him, the advantage of vibration protection of the equipment will not be realised. However, before discussing how vibration affects man and how it may be alleviated, the main sources of vibration in helicopters must first be examined. The helicopter has been described as "a complex system of rotating out of balance masses held together by an elastic structure". The helicopter with its rotor system, certainly has more rotating parts than the equivalent fixed wing aircraft. The main sources of vibration are generated by the main rotor, tail rotor, engine, gear-box and drive shafts. As far as the man is concerned, it is the lower frequencies generated by the main rotor which cause most trouble. These contain both the greatest energy and are closest to the man's own resonant frequencies.

Figure 3 shows a typical cabin vibration spectrum of a 5 bladed medium sized helicopter. Peaks in vibration occur at 4 Hz (or 1R - the main rotor frequency), the greatest peak at 20 Hz, (or 5R, the rotor blade passage frequency), and at harmonics of this frequency 40 Hz, 60 Hz etc and also at the tail rotor frequency (1T) of 25 Hz and its harmonics, 2T, 3T etc. It should be noted these vibrations also occur in all 3 axes. (It is interesting to note that the greatest vibration levels are often to be found in the horizontal axis and not in the vertical axis as in fixed wing aircraft.)

Man is also a complex system of masses, springs and dampers with a major body resonance in the vertical axis at about 4-5 Hz and lesser resonances at 8 Hz and 11 Hz. (See Figure 4.) If he is placed in the helicopter with the vibration spectrum shown in Figure 3 his body is likely to respond to the 1R or 4 Hz vertical vibration which corresponds to his 4-5 Hz spinal resonance.

The effects of vibration at this frequency are to disturb vision, to reduce manual dexterity and to cause discomfort and fatigue, particularly if subjected to it over sustained periods.

Even where equipment has been attached by anti-vibration mounts (AVMs) it should not be assumed that the vibration reaching the equipment has been attenuated or isolated in any way. Current fixed and rotary wing AVMs tend to amplify the vibration reaching the equipment, at the frequencies and levels to be found in helicopters. This is because the AVMs have been designed to protect the equipment from very severe vibrations or shocks. AVMs have not been designed to attenuate the normal levels of vibration which are an order less in magnitude. Fig 5 shows how a ± 0.1 g vertical input vibration is transmitted through AVMs to a paper trace recorder. At the typical rotor blade passage frequencies from 15 to 22 Hz this vibration is amplified by a factor of over $2\frac{1}{2}$. In addition to this amplification, there is cross coupling with the horizontal axes and considerable amounts of sideways and fore and aft vibration are produced by the AVMs.

The helicopter crew must be protected from vibration if the system is to remain efficient. Vibration is best reduced early in the design stage of the life history of the helicopter. It is now possible, with the aid of computers, to design a helicopter so that the cabin and crew are isolated from the vibrating parts of the system. This can be achieved by mounting the rotor system, engines and gear-box etc on a "nodal beam". This beam will naturally vibrate in such a mode that there will be nodes where vibration is a minimum. If the cabin structure is attached to the beam structure at these nodes, the vibration transmission to the cabin and crew will be minimised.

If the helicopter design is beyond the stage where radical changes can be made to reduce the vibration, other, perhaps less efficient, methods must be tried to alleviate the effect of vibration on the crew. Since most of helicopter vibration is generated by fluctuating rotor blade forces much of the vibration can be reduced by mounting vibration absorbers at the rotor head. These are often of the bifilar suspension type tuned to the vibration frequency. Unfortunately these require additional masses to be added to the rotor head and tend to be effective over only a limited frequency range. Another method is to reduce the vibration reaching the crew by providing vibration attenuating seats. These seats are usually tuned to predominant vertical vibration frequencies (ie the rotor blade passage frequency). Unfortunately, as with any damped-mass-spring system, the attenuating system always has a natural frequency lower than the frequency for which it is designed to alleviate. In the case of the helicopter, the system often removes the predominant figure 4 or 5R heave vibration but amplifies the still appreciable 1R component which usually corresponds with the man's resonant frequency. In addition the vibration attenuating seat usually only reduces heave and has little or no effect upon vibration in the other axes of sway or shunt.

In the past when vibration has caused difficulties for the crew, many designers have tried to overcome the problem by giving the crew "better" more restrictive seat harness systems. Far from improving the situation, these tighter harnesses have resulted in the crew being more affected by vibration. Figure 4 illustrates the mechanism of vibration transmission to the man's head for heave. When vibration is transmitted to a seated man, the primary input is through the seat pan interface. If the man leans forward on the seat, the higher frequencies are largely attenuated through his spine and only the major body resonance affects his vision. If, however, the man leans against the seat back, or is held against the seat back by his shoulder harness, vibration input takes place at the seat back interface as well as at the seat pan. Now, some of the vibration input is much closer to the head and there is no natural attenuation of the higher frequencies through the spine.

Experiments[3] have shown that man's performance at manual control tasks is further degraded under vibration when wearing a harness. Thus where a harness must be used for safety reasons in a vibrating environment, such as a helicopter, a compromise solution may be adopted of using a tight lap harness with a loose inertia reel type shoulder harness. This would permit the crew member's back to remain free of the seat and yet provide adequate crash protection if required.

A further method of reducing helicopter vibration by active control may be available in the foreseeable future. It has been suggested[4] that the oncoming fluctuating rotor forces which are about to cause vibration could be sensed and appropriate counteracting forces generated, using the rotor control system, thus reducing the vibration at the source.

5 NOISE AT THE CREW'S EARS

Noise is yet another environmental factor to be found in helicopters, which may degrade human performance. The noise at the operator's ears may consist of aerodynamically and mechanically generated noise from the rotor system, engine, gear-box etc. It will also contain signals from radios, the intercom, audio warnings together with unwanted electrical noise and noise picked up from the crew's microphones.

Figure 6 shows a typical noise spectrum for a gas turbine driven medium sized helicopter. The lower part of the spectrum is dominated by main rotor noise. This consists of rotational noise and broad band noise. There are peaks of high energy rotational noise at specific frequencies and their harmonics, which are related to main and tail rotor blade passage frequencies. Rotor tip speed determines the rotational noise and as the tip speeds are increased so the rotational noise rises. Broad band, or vortex noise usually has a band of random noise spread over a much wider range, eg from a 100 or so Hz to 800 Hz or more. Superimposed on this will be discrete noise peaks due to certain specific components in the transmission system, such as gear-box tooth or bevel gear meshing[5]. Human speech frequencies range from about 300 Hz to 3 kHz and this gear noise is extremely unpleasant due to its interference with communications. At the other end of the noise spectrum, there may be peaks due to tooth meshing and compressor and engine noise. Although compressor and engine exhaust noise may be apparent externally, much will be attenuated by cabin structure and sound-proofing by the time it reaches the cabin occupants. Thus, most of the cabin noise in helicopters occurs at the lower end of man's audio range. The higher frequencies are further reduced if hearing protection in the form of ear muffs or protective helmets are worn. The dotted line in Figure 5 shows the noise at the ears inside a protective helmet. The vertical distance between the full and dotted lines show the noise protection given by the helmet. It can be seen that, up to about 1000 Hz, the helmet attenuation is almost non-existent, but above this figure, noise protection rapidly improves.

Speech, communications and audio signals from specific equipment, can also increase the noise dose at the crew's ears. Studies by Rood and others[6] have shown that the communications load can increase the overall noise dose by about 6 dB. Thus even if the cabin noise at the ears can be kept down to a just acceptable level, speech and other signals over the intercom can raise the overall noise level and cause temporary, or possibly over a working life, permanent hearing damage.

Another problem which can occur is illustrated in Figure 7. The noise level at an operator's ears shown in Figure 6 is shown together with an audio signal. If too low a frequency is chosen for the audio signal it is likely to be masked by gear meshing noise. To achieve an adequate signal to noise ratio for the signal to be heard its magnitude will have to be increased. This will still further add to the noise dose and also produce fatigue. However, if the audio signal's frequency is moved upward to be clear from masking, it will be both heard, yet at a much lower level, and unlikely to contribute to the noise dose of the operator.

Similarly the intercom should be designed to operate only in speech frequency range. All too often, intercom system microphones have a response from a few tens of Hz up to several thousand Hz. These will pick up the low frequency noise peaks as well as speech and transfer both to all the crews' headsets. A microphone which picks up only the middle and upper speech frequencies might be better still. Although the lower end of the speech frequencies would be clipped, the speech would still be intelligible yet free from annoying and masking noise.

In addition to the level of noise and signals, the crew of a modern helicopter often have their workload increased by the large number of different signals which are relayed over the intercom. If several signals, from for example a radio, other crew members and audio warnings, are presented simultaneously, the operator would have great difficulty in identifying each signal and making the appropriate response. Man can be considered as a single channel device capable of performing only one task at a time. Although he can perform several tasks quickly, sequentially, and give the appearance of doing several things at once, it is unlikely that he can actually process several signals simultaneously, especially when they are probably masking each other. Therefore, it is essential to present only the information that he can handle and to ensure that he is not overloaded with audio and other signals.

6 THERMAL AND OTHER ENVIRONMENTAL EFFECTS

The helicopter, being essentially a low altitude form of transport, does not have to be pressurised or (usually) have to contain oxygen breathing equipment. It does, however, have to operate in extremes of climate, from the Arctic to the Equator and from maritime to desert environemnts. With its large cockpit and window areas, it is far from ideal for hot conditions where the transparencies produce a greenhouse effect. Helicopters rarely have adequate cooling[7] or heating systems to cope with the crew's needs under this wide range of operating environments. Even where an attempt has been made to provide a helicopter with ventilating air it has not always improved the situation. For example, one electric motor driven fan produced a considerable temperature rise in the fan and the so-called ventilating air in fact contributed a 2 kW heat input to the cabin.

Occasionally, helicopters are fitted with ventilating louvres which draw in air from the outside for local cooling, but often this air is already hot and can only produce cooling by the evaporation of sweat and this can be regarded as a part solution to the thermal problem only. Sometimes in hot conditions, the helicopter is flown with doors or windows removed to achieve some reduction in thermal discomfort. This solution has some drawbacks. For example, as mentioned in Section 3, maps stowed under the pilot's thighs can prove to be a problem and sometimes a safety hazard, in the turbulent air currents coming through the open doorways. Similarly, when hovering over sandy areas or crop spraying, sand or toxic chemicals find their way into the open cockpit even more easily than usual.

The very attributes of the helicopter, such as its ability to hover and to pick up or deliver people and goods, cause its cabin environment to be degraded by dust, ground debris and its own exhaust fumes, etc. As with the reduction of cabin noise and vibration, thermal conditioning should be designed into the helicopter from the outset, rather than waiting until the final design is found to be unacceptable in the course of its operational life. At this stage, modifications to improve the cabin thermal environment are likely to be both expensive and inefficient.

7 CONCLUSIONS

Helicopters have now established themselves as capable of filling a particular gap in the transport spectrum. Their ability to manoeuvre close to the ground with great precision and to perform other tasks unique to the helicopter is now being utilised but at some cost to the human operator. Only by carefully matching the helicopter's controls, displays and cabin environment to the man's abilities and requirements, will the full potential of the system be realised.

Future helicopters should be designed from the start to accommodate the crew's requirements for information, control characteristics, freedom from discomfort due to workspace layout, vibration, noise and thermal effects.

REFERENCES

1 A L Winn and R B Lewis. Pilot Workload During Instrument Flight, 30th Annual National Forum of the American Helicopter Society 1974.

2 R J van der Harten and P G Cooper. An Electronic Integrated Pilot Display is Evaluated in North Sea Operations. Vertica, 1977, Volume 1 pages 271-279

3 E J Lovesey. An Investigation into the Effects of Dual Axis Vibration, Restraining Harness, Visual Feed-Back and Control Force on a Manual Positioning Task. RAE Technical Report 71213, November 1971

4 K W Newman. A Study of the Application of Active Control Techniques to the Reduction of Helicopter Vibration Levels. Aeronautical Research Council Paper ARC 37 614 Hel 23, January 1978

5 E J Lovesey, R Gray, G M Rood, H Howells, W F Grimster, C Holliday and D Jessop. Vibration and Other Measurements in RN Sea King Helicopters. RAE Technical Memo FS 72, February 1976

6 G M Rood and E J Lovesey. Some Aspects of Helicopter Communications. AGARD Conference Proceedings No 255, Operational Helicopter Aviation Medicine, May 1978

7 B Rebbechi. Estimation of Cabin Heat Loading in the Sea King Helicopter and Effectiveness of Possible Modifications to Improve Crew Thermal Environment. Aeronautical Research Laboratories, Melbourne, M E Note No 367, August 1977

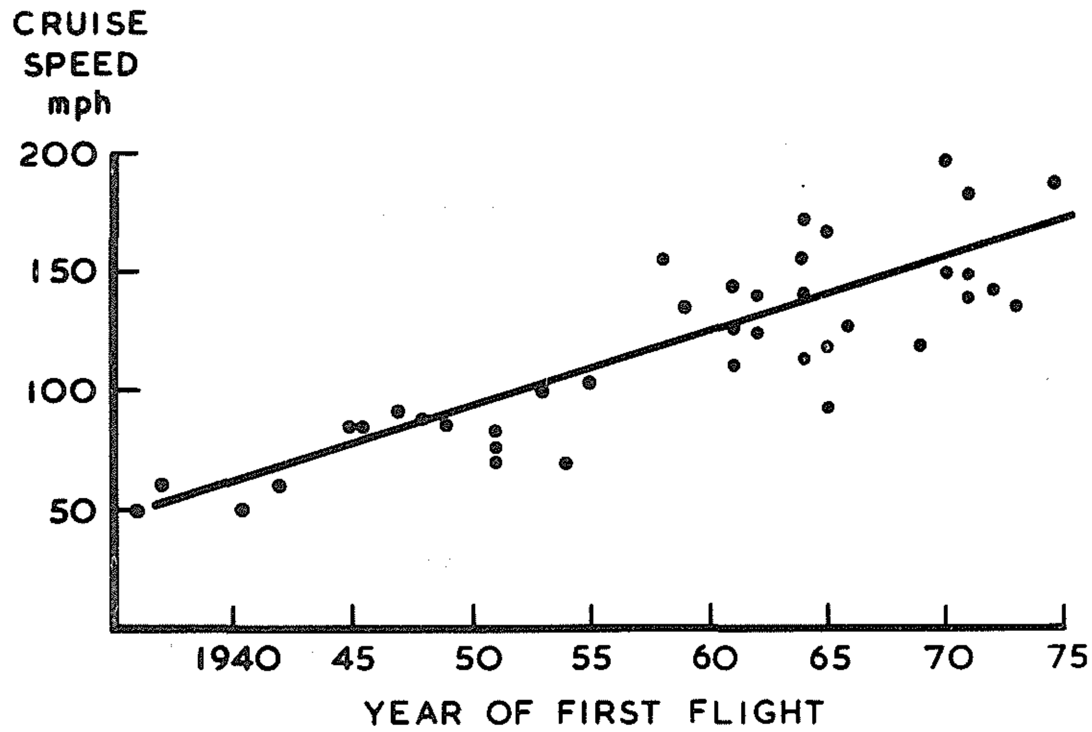

Fig 1 Speed increase with time

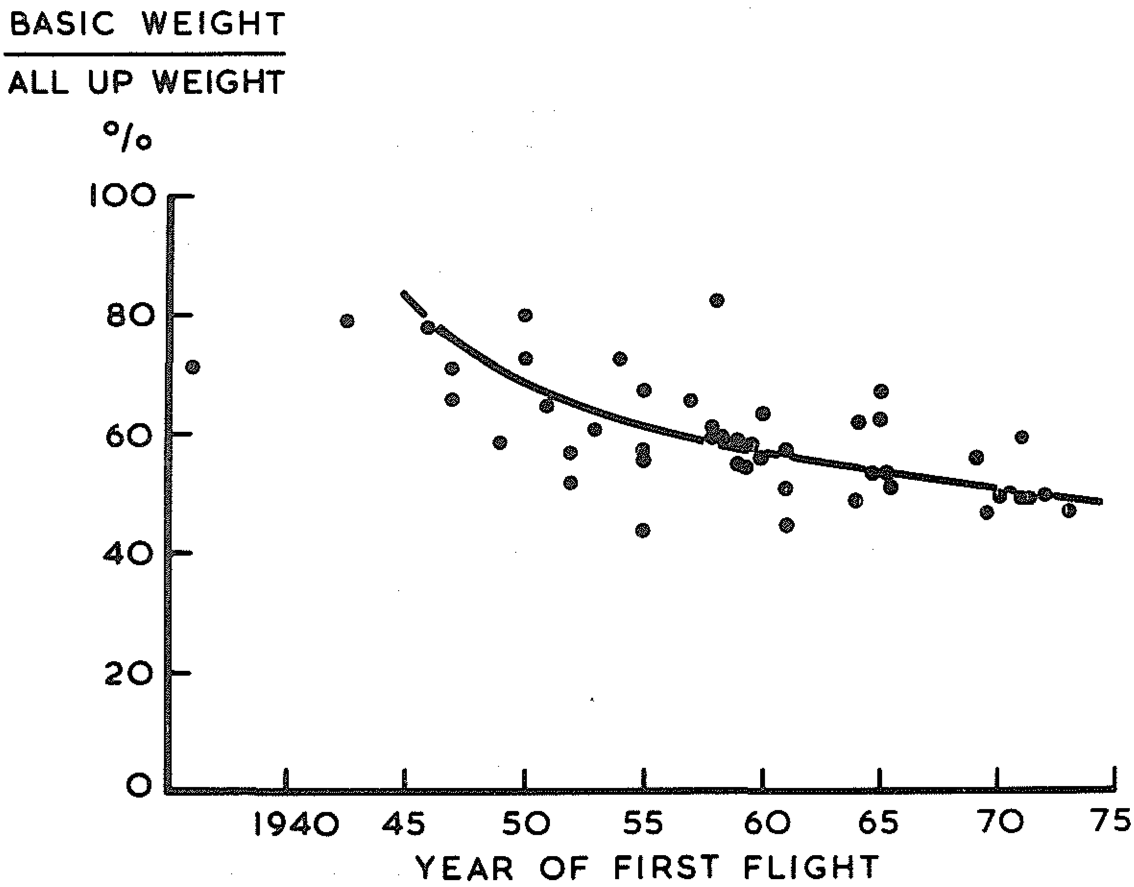

Fig 2 Improvement of lifting ability with time

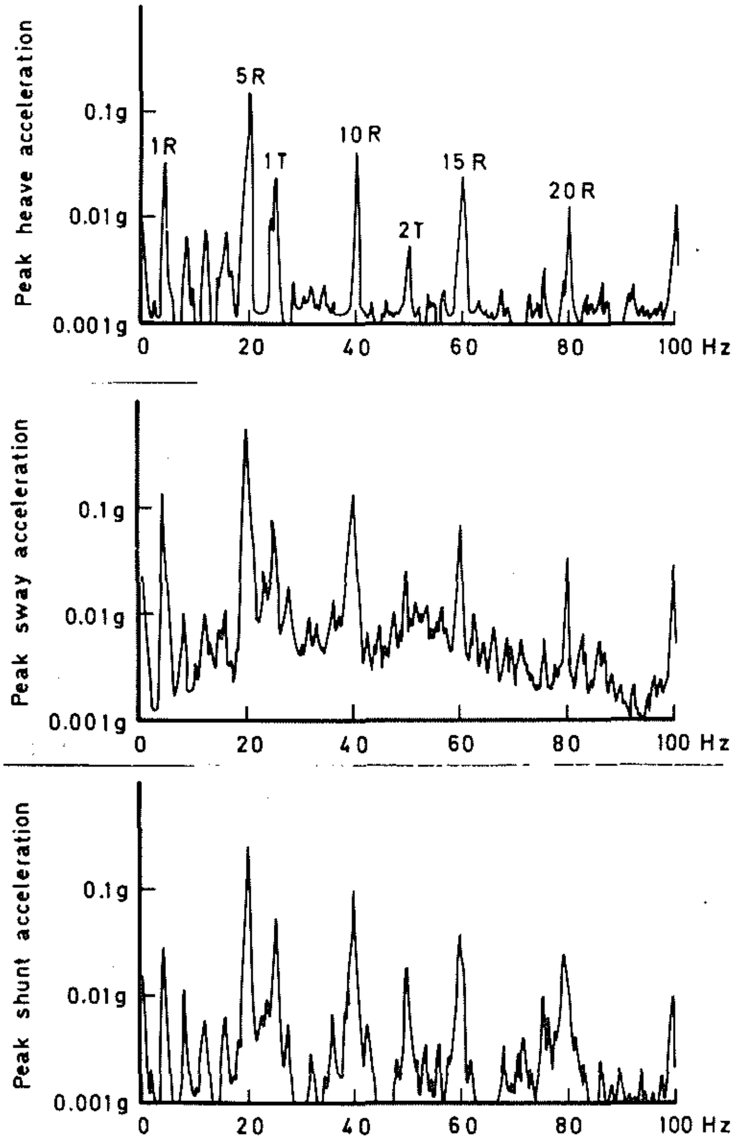

Fig 3 Vibration frequency spectra at pilot's seat position in a typical 5 bladed medium sized helicopter

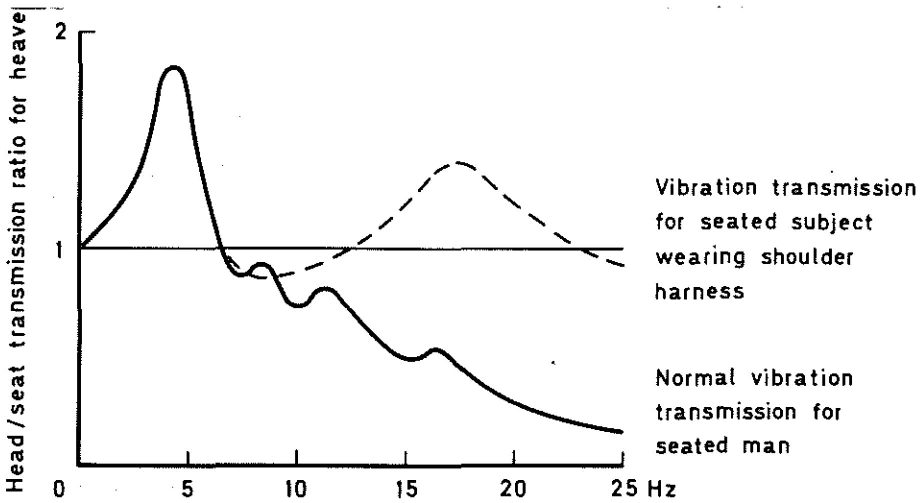

Fig 4 Heave vibration transmission from seat to head for a seated man, with and without shoulder harness

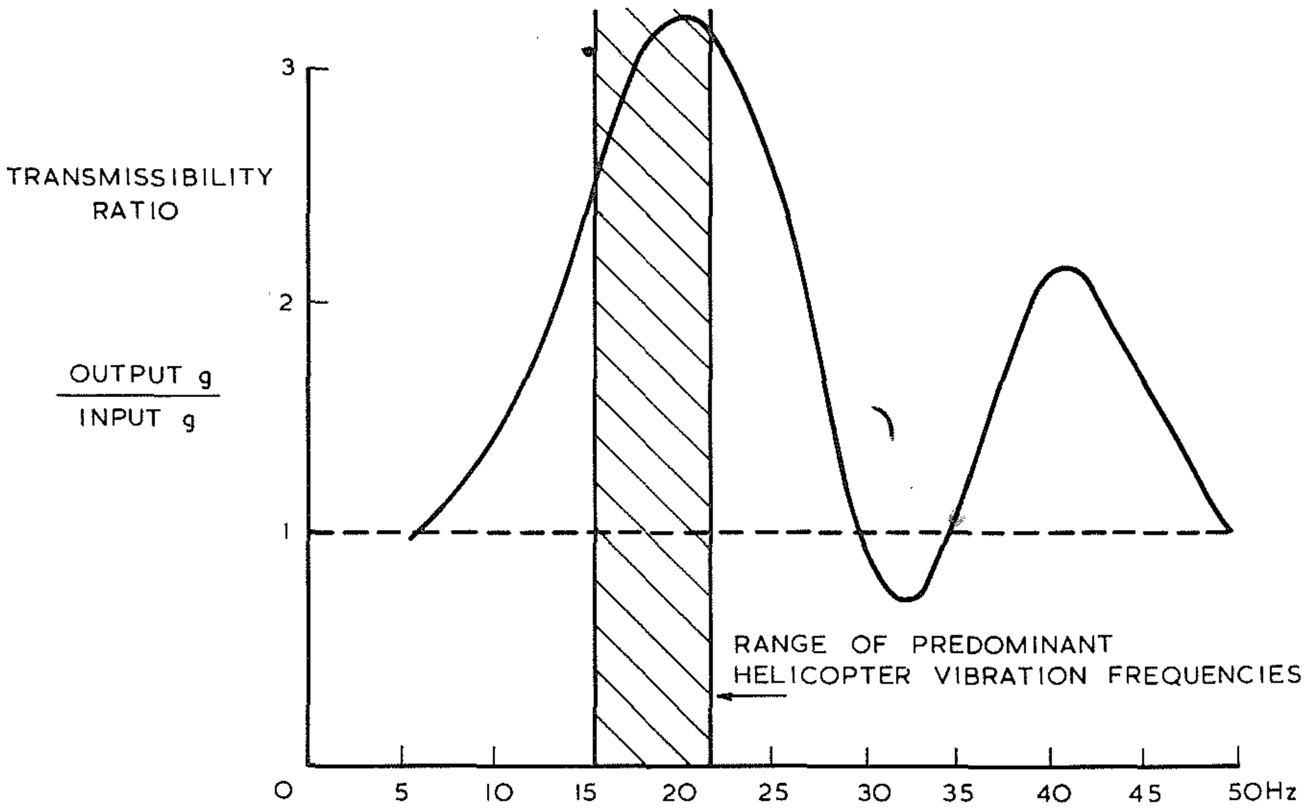

Fig 5 Transmission of vertical vibration to equipment through anti-vibration mounts

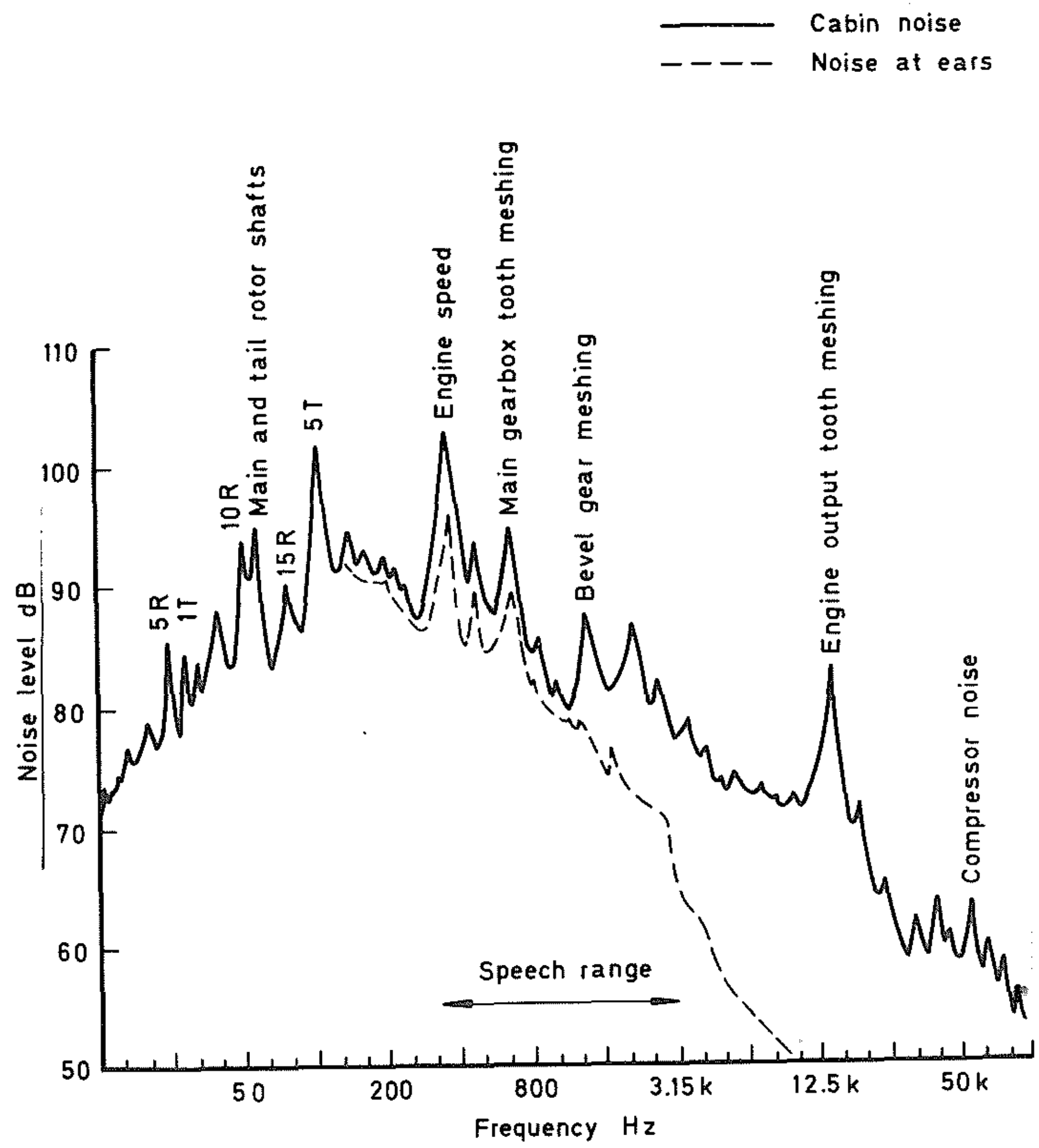

Fig 6 Typical gas turbine powered helicopter noise spectrum

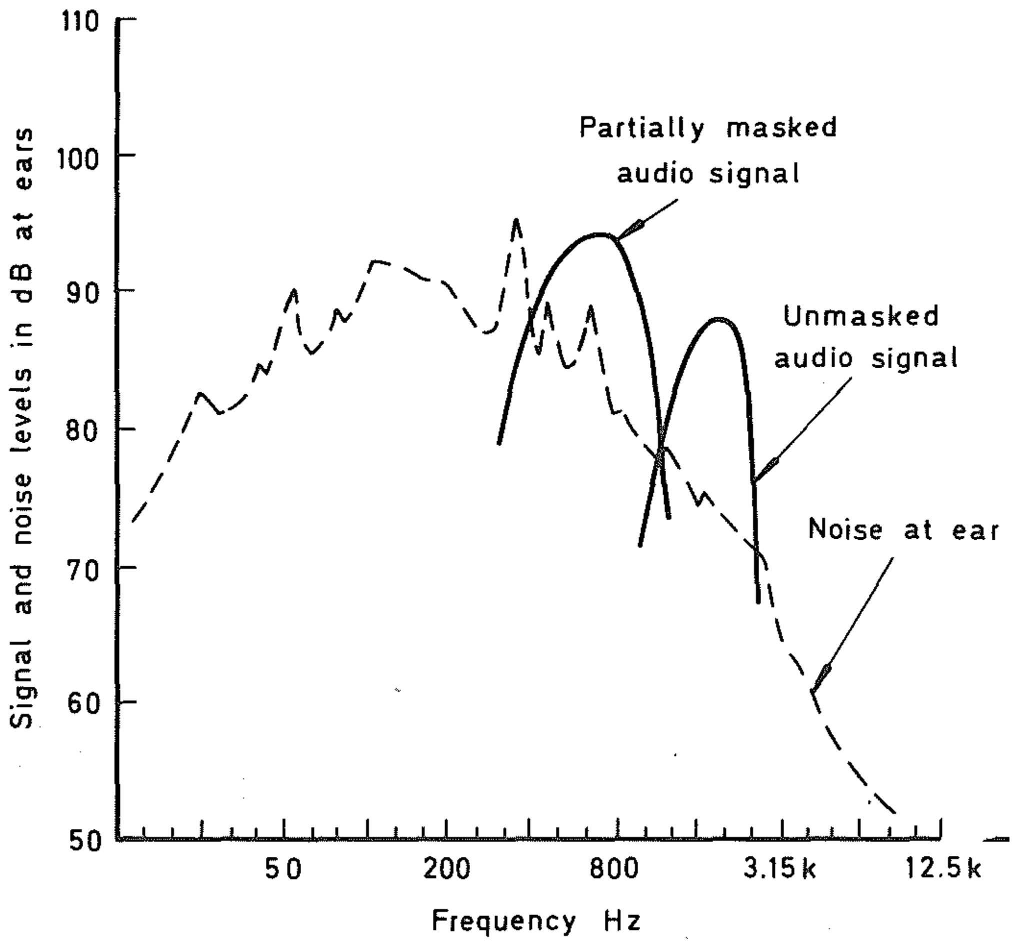

Fig 7 Noise and signals at ears of crew