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ACTIVE CONTROL OF HELICOPTER CABIN NOISE

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1. INTRODUCTION

Helicopter cabin noise levels are in excess of noise levels in the cabins of other passenger aircraft and often necessitate the wearing of ear defenders. The main source of noise is often the meshing of gears in the gearbox. Other sources include the main rotor, the tail rotor and the turbine blades. One common feature of the sources is that they are all periodic.

There are three methods for reducing cabin noise:

- i) Redesign of the noisy components, including the cabin itself;
- ii) Passive silencing, including acoustic linings and vibration isolation, for example at the gearbox mounting points; and
- iii) Active control, including active isolation and active cancellation.

The first method, even if it is practicable, is inevitably expensive and is often unsuitable as a retrofit. However, it is likely to be the best solution.

Passive silencing techniques are abundant. One strategy is to try and absorb sound at the cabin walls, and much work has been done on the use of tuned panels for this purpose [1], [2]. However, it is difficult to design panels which are sufficiently effective over a wide enough range of frequencies. Acoustic linings are commonly used to reduce cabin noise because of their simplicity and effectiveness at high frequencies. However, much of the noise is at frequencies below a kilohertz where the space and weight requirements for effective linings are prohibitive [1]. Another passive strategy is to isolate the cabin from the sources of vibration which cause the noise, for example, through the use of passive isolation mountings for the gearbox. Of course, such measures would only be acceptable if the safety requirements could be met. Even then passive vibration isolation is unlikely to be suitable for retro-fitting.

The third technique for reducing cabin noise is the main subject of this paper: active control.

All of the above techniques can be used together and the optimal mix of passive and active control techniques will be discussed in some detail.

2. ACTIVE CONTROL

Active control techniques have been developing rapidly over the last decade and active control of rotor vibration is the first area where the techniques have entered into helicopter design [3]. Most of the development has been in the area of control of periodic sound and vibration. The main requirements for implementing periodic control are:

- i) The noise must be coherent with a tachometer signal, to which the control signals can be phase-locked;
- ii) Powerful computers capable of implementing the complex multichannel control algorithms;
- iii) Reliable transducers to produce the cancelling sound or vibration and to sense the residual signals. The residual signals are used

to adapt the levels of the cancelling sources in order to maintain optimal performance under transient conditions; and

- iv) Space for control sources and sensors and the control system itself.

For the helicopter cabin noise problem, it should be possible to meet conditions (i) and (ii) above.

Loudspeakers can be used as transducers for active noise cancellation, the performance, characteristics and reliability of loudspeakers have been widely studied. The reliability of suitable actuators for active vibration control at acoustic frequencies is an area of current research [4].

Space is of course at a premium in a helicopter, but loudspeakers can be fitted in the cabin trim and microphones can be placed on the seatbacks - provided they exist! The degree to which electronics can be miniaturised is largely determined by cost.

Active control of cabin-noise is very likely to be technologically feasible, so its implementation will be governed largely by costs. The factors which determine the cost of a system are:

- i) The size and complexity of the system;
- ii) Power requirements;
- iii) Weight;
- iv) Performance;
- v) Maintenance.

Some of these are system costs whilst others are operating costs and more difficult to quantify. In the remainder of this paper we consider items (i)-(iv) and the relationship between them.

3. SYSTEM COMPLEXITY

This depends upon the details of the acoustic characteristics of a particular cabin and the noise source. There are, however, a couple of rough estimates that may be used. Firstly, in a resonant enclosure approximately one loudspeaker is required for each resonance mode in the frequency range of interest. This allows the system to cancel the modes which dominate the structure of the sound field. This approach is known as modal matching [5]. The second approach is known as source matching. This technique involves locating the areas of the cabin structure which are vibrating most, and consequently are responsible for radiating most of the noise into the cabin. These areas are then covered with loudspeakers on a half-wavelength scale. This loudspeaker arrangement can then mimic the effect of the surface vibration in anti-phase [6]. The lower of these two numbers provides an estimate of the system complexity. Generally more microphones than loudspeakers are used to monitor the performance, and ideally should be at less than half-wavelength spacing throughout the volume which is to be controlled.

The complexity of the field to be cancelled is best estimated from experimental measurements. Figures 1 and 2 show plots of reductions in

noise levels for given numbers of loudspeakers in two different situations. Figure 1 was produced for a machine whose whole surface constituted the source region and so the number of loudspeakers for a given performance increases with the square of the frequency. Figure 2 was produced for a situation which is closer to the helicopter environment and so gives an idea of the likely complexity of the control system required for suppressing gearmeshing noise.

4. POWER REQUIREMENTS

The power requirements for the loudspeakers are important both for the design of the system and for operating costs. It is determined by

- i) The loudness of the unwanted noise;
- ii) the loudspeaker and power amplifier efficiencies;
- iii) the distribution of loudspeakers.

The last factor is important because the loudspeakers can attempt to cancel the noise produced by one another. This effect is illustrated in figure 3. The noise level falls rapidly once the system has sufficient power to cancel most of the noise, but the power can be increased by a factor of 100 just to get another 2dBs of reduction. This law of diminishing returns is unavoidable.

5. WEIGHT REQUIREMENTS

The relationship between the weight and power handling and capability of some commercially available loudspeakers is shown in figure 4. This figure is taken from reference [7]. This is an approximate band which represents the maximum power to weight ratio using conventional loudspeaker materials. Using this relationship the performance versus weight graph looks similar to figure 3.

6. THE RELATIONSHIP BETWEEN POWER AND SYSTEM COMPLEXITY

Having determined the number of loudspeakers and the power required to achieve a given performance it is interesting to see how the power requirement changes if we introduce more loudspeakers. An example is shown in figure 5. Interestingly, as the number of loudspeakers increases, less total power is required to maintain a 10 dB reduction.

7. THE OPTIMAL MIX OF ACTIVE AND PASSIVE CONTROL

We have described above how the performance of an active control system depends upon the power available and hence on the weight of loudspeakers. It is therefore possible to compare active and passive techniques on this basis and to look at the performance of combined systems. An example is shown in figure 6. The assumptions are that the cabin structure has a minimum mass M and that the noise reduction is dominated by the added mass m so that the noise reduces in proportion to $M/(M+m)$.

The dashed lines show the results of adding a fixed amount of 'passive mass' and then introducing an increasing amount of 'active mass' in the form of loudspeakers. In the regions where the dotted lines lie totally

above the passive mass curve the best solution is to add passive mass alone. In the other regions there is an optimal mix which can be found by considering the envelope of the family of dashed lines. It should be possible to produce graphs such as these for the helicopter environment, and they will provide an essential tool in designing a noise reduction package.

8. CONCLUSIONS

It is likely the active control can help to provide useful reductions in helicopter cabin noise. The balancing of cost and weight penalties will probably lead to a mixture of active and passive techniques providing the best solution.

The design tools and the technology for active control systems are already in existence, and the next steps will be to develop the electronics and the transducers to meet the requirements of the helicopter environment.

9. ACKNOWLEDGEMENT

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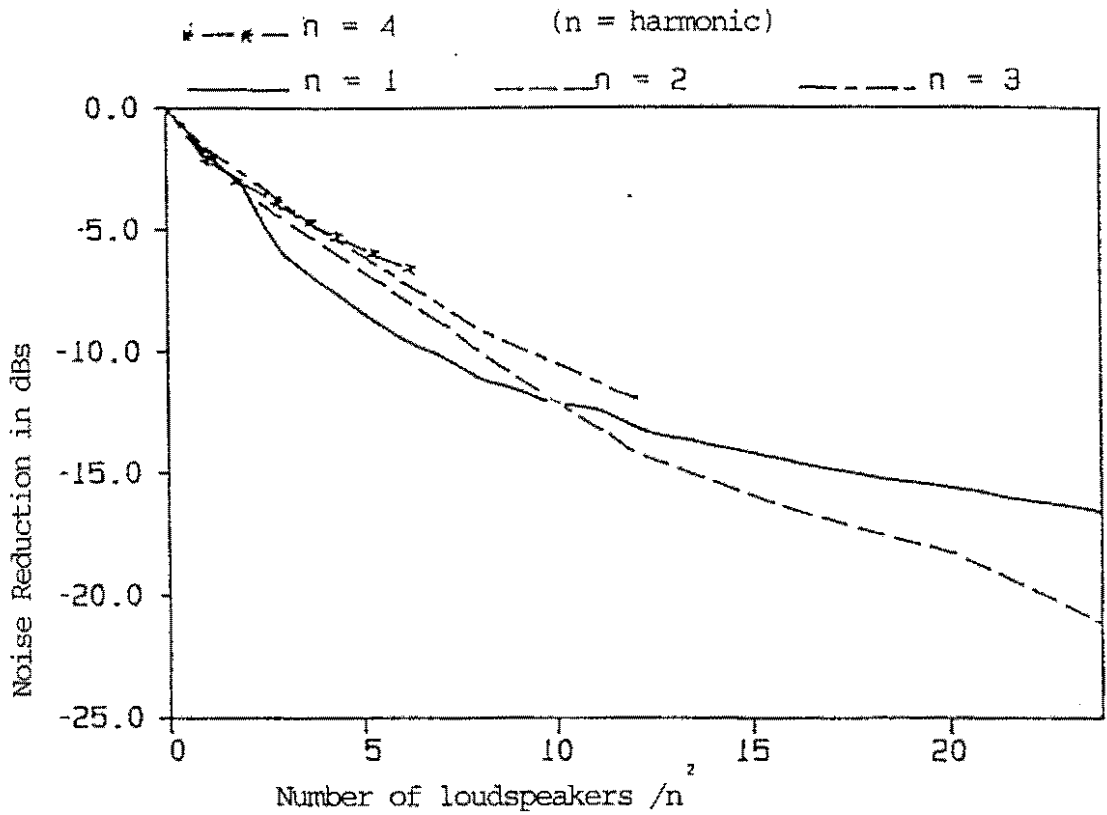


Figure 1: The performance of an active control system at different harmonics plotted as a function of the number of loudspeakers. The control system is for a machine whose whole surface was radiating sound.

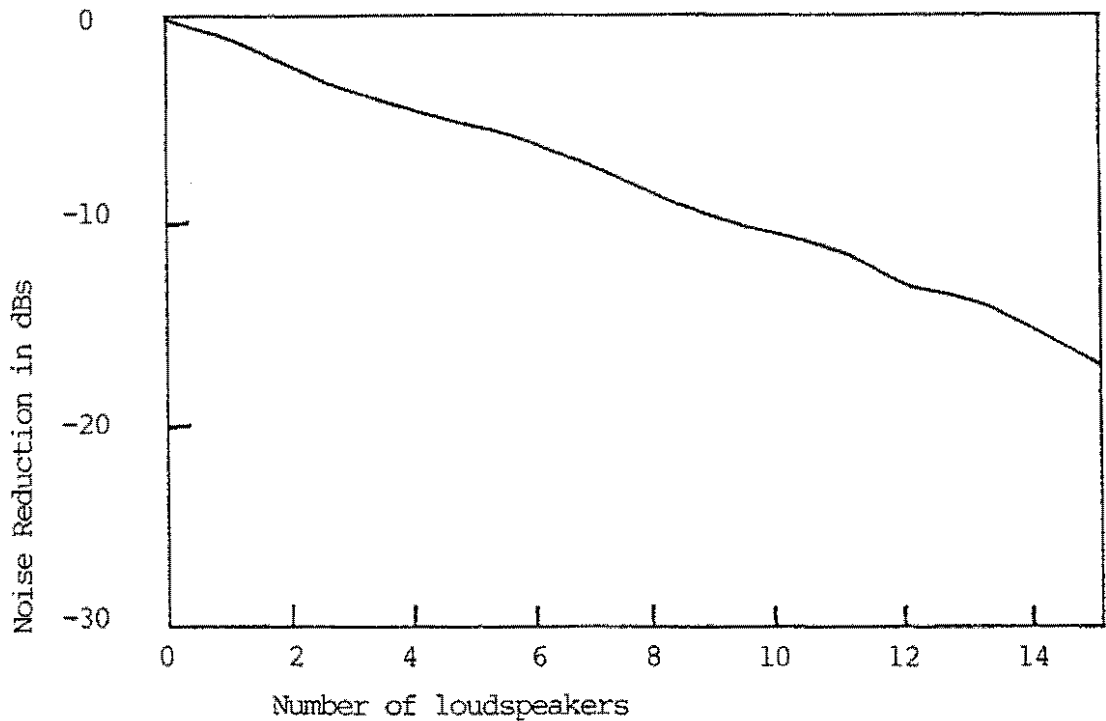


Figure 2: As figure 1 but for a situation which resembles the helicopter cabin noise problem.

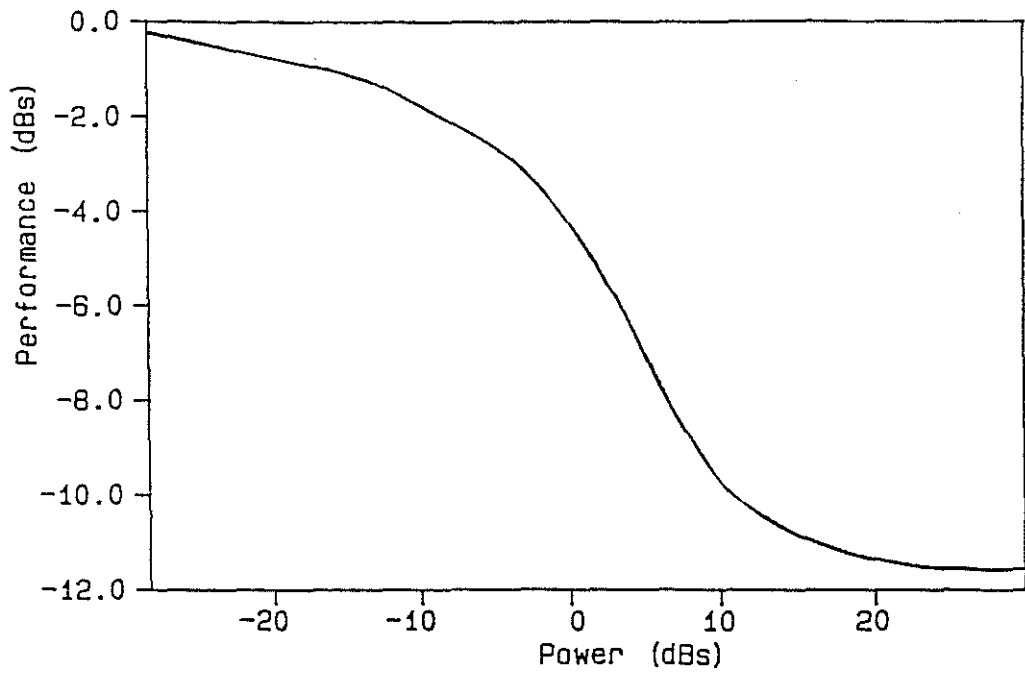


Figure 3: The performance of an active control system as a function of the power applied to the loudspeakers.

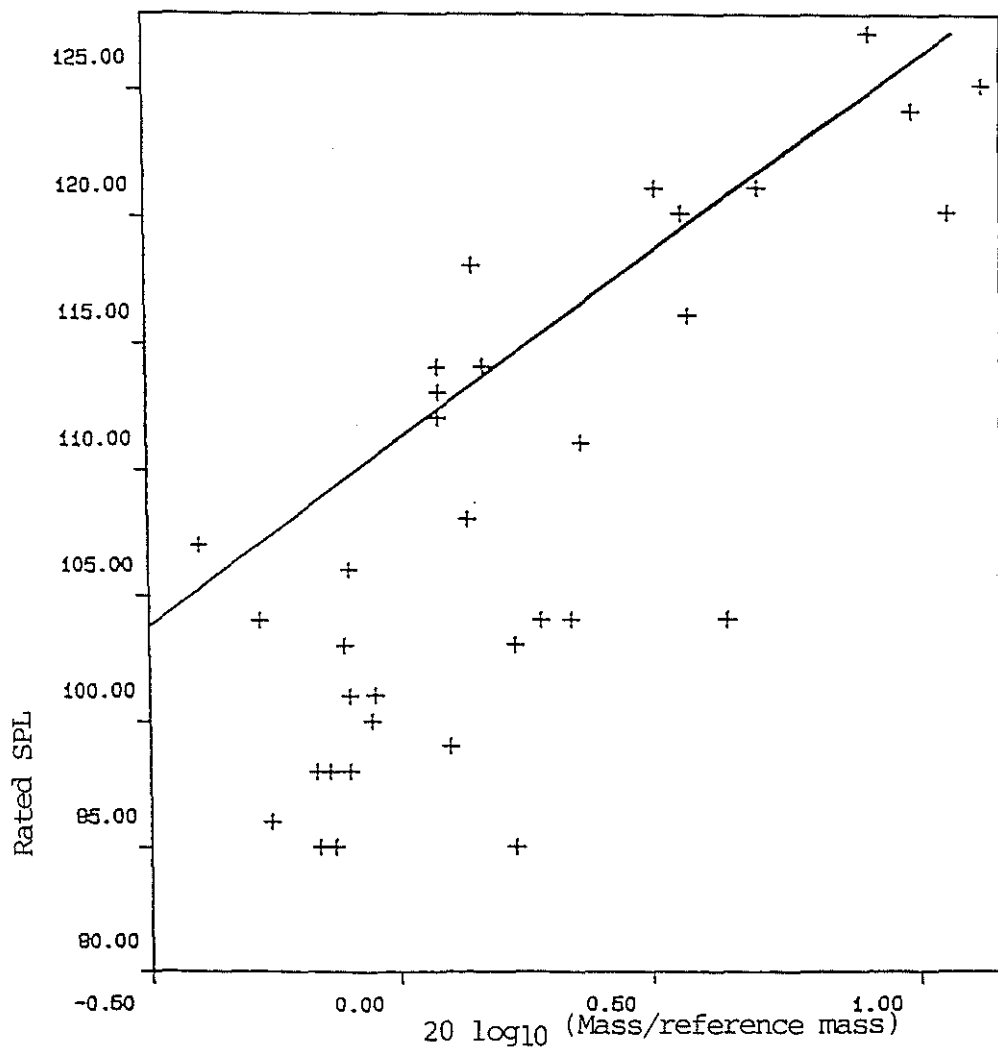


Figure 4: Loudspeakers' powers plotted as a function of their mass.

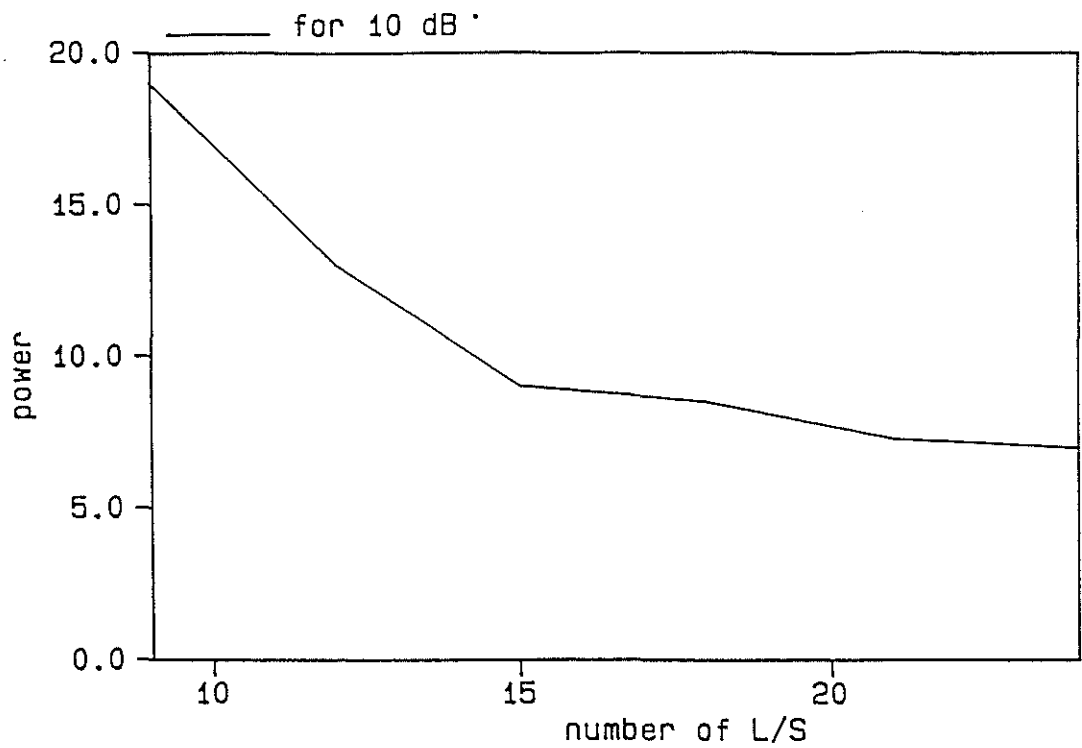


Figure 5: The power supplied to achieve a noise reduction of 10dB as a function of the number of loudspeakers.

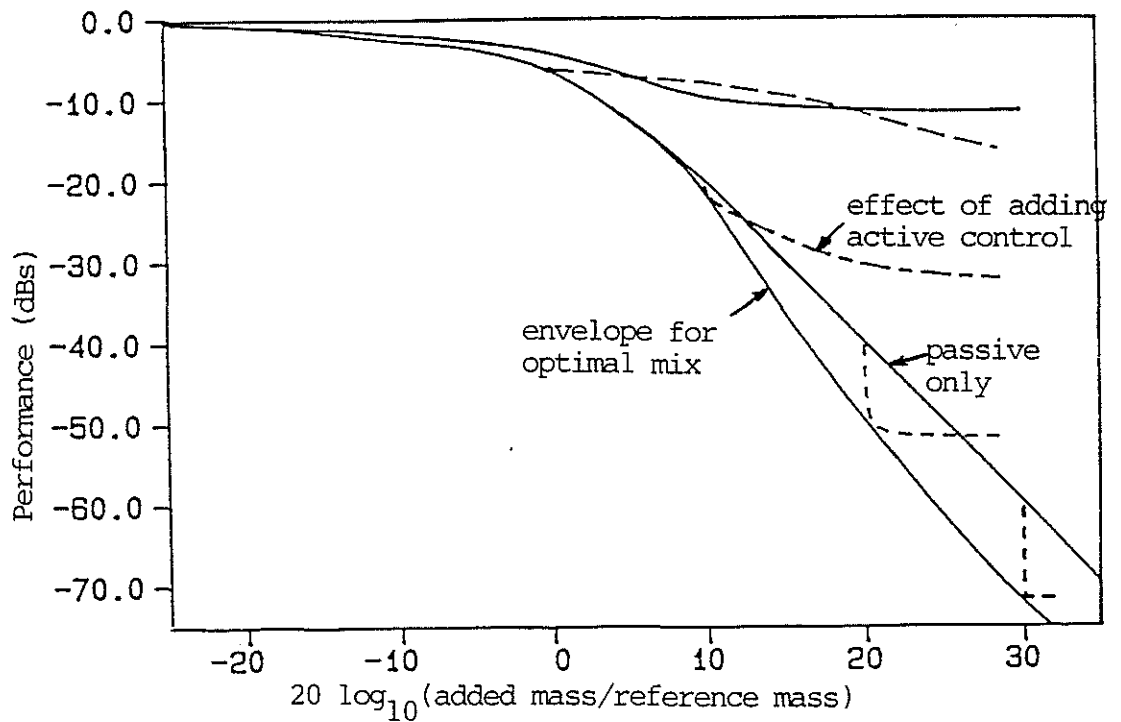


Figure 6: Noise reduction plotted as a function of added mass for combinations of active and passive noise control measures.