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ACTIVE CONTROL OF HELICOPTER ROTOR TONES

C C Boucher, S J Elliott & K-H Baek

Institute of Sound and Vibration Research, University of Southampton, Southampton, UK

1 INTRODUCTION

The use of active control systems to minimize propeller induced cabin noise in fixed wing aircraft [1] and the engine tones inside cars [2] is well established. Some of these systems have now been developed to the point of commercial exploitation. This paper describes in-flight experiments to actively control the low-frequency blade passing tones generated by the main and tail rotors in the passenger cabin of a pre-production EH101 helicopter.

The low frequencies involved and the complex nature of the primary field greatly complicated the control task, requiring some modifications to the adaptive control algorithm previously used. Reductions of up to 12 dB were recorded in-flight and subsequent analysis of the data, which included simultaneous recordings of the time histories from all of the error microphones, was used to investigate the performance of the control system and the primary field. Natural algorithms were used to select the best sub-set of loudspeakers combinations, from the 16 used in-flight, for various secondary source strength constraints.

2 CONTROL SYSTEM

The flight trials were conducted on a prototype EH101 helicopter, a large, 30 seater aircraft made by Agusta and Westland Helicopters. The main rotor has five composite blades and is driven by three engines at a constant speed, giving a blade passing frequency of 17.5 Hz.

A control system with 32 error microphones and 16 secondary sources was based around a rack-mounted PC containing a dual TMS320C40 processor card [3]. The inputs and outputs were digitally down-sampled by an additional TMS320C25 card. The number of secondary sources was chosen to maximize the amount of transfer function data available for later analysis. Since the amount of electrical power available was finite, only 30W power amplifiers could be used on each channel.

The control system used a filtered-x LMS algorithm and was capable of controlling three frequencies simultaneously. The algorithm was modified, however, such that the individual secondary source strengths for each loudspeaker could be limited [4]. The standard effort limiting method, which includes a proportion of the sum of squared secondary source strengths in the control system cost function, was not used since it only limits the *total* power used, allowing individual outputs to overload.

3 FLIGHT TEST

The flight trial was conducted in April 1995, for which the 16 (200 mm) loudspeakers were distributed as evenly as possible throughout the aircraft, located in the overhead bins and under, or on top of, the seats. The 32 microphones were distributed at seated head height along the length of the aircraft, where possible attached to the seat head-rests. Ground based measurements of the transfer functions were made, without the engines running, at each of the frequencies of interest and were used later in-flight.

All tests were conducted under straight and level cruising conditions at a speed of 120 Knots and in good weather. Control was attempted at the fundamental blade passing frequency of the main rotor, 17.5 Hz, its first two harmonics and at the fundamental blade passing frequency of the tail rotor, 63.38 Hz and its second harmonic.

Figure 1 shows the measured reduction in the sum of the squared pressures at 35 Hz, the second harmonic of the main rotor blade passing frequency, as the control system converged. A final reduction of 6 dB was obtained. The degree of control at this frequency was limited by the secondary source power available.

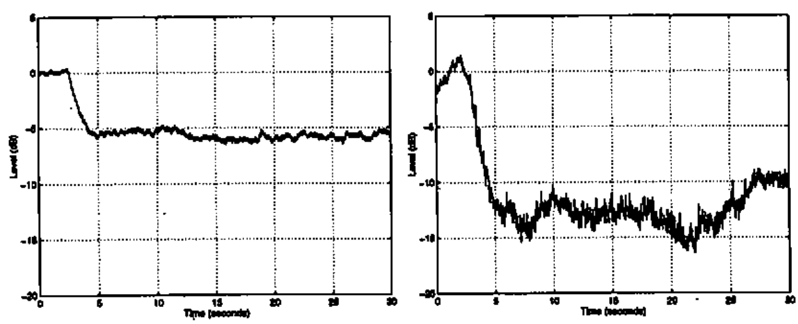

Figure 1: The convergence of the control system at 35 Hz (left) and 63.38 Hz (right) measured in-flight

At the lowest frequency of interest, 17.5 Hz, a reduction of 3 dB was measured. As at 35 Hz, the available secondary source strengths limited the degree of control obtained. At 52.5 Hz, the third harmonic of the main rotor, a reduction of 6.5 dB was recorded, secondary source strength was not a limiting factor at this frequency.

Figure 1 shows the convergence at 63.38 Hz, the fundamental blade passing frequency of the tail rotor. The system is not power limited at this frequency and a reduction of over 12 dB was recorded. At the second harmonic of the tail rotor, 126.76 Hz, a reduction of 5 dB was recorded.

4 ANALYSIS

Measurement of the EH101 passenger cabin revealed that it behaves as if it were almost acoustically transparent in the frequency range of interest. This has two main consequences for the control system. Firstly, the primary field is not a simple modal response and is, therefore, more difficult to control. Secondly, the secondary sources have difficulty in generating large sound pressure levels at these low frequencies, leading to greater power requirements. At the lowest two frequencies (17.5 Hz and 35 Hz) the available secondary source strength limited the attenuation measured in-flight.

The primary field also exhibited rapid short-term variations in sound pressure level, which limited the control systems ability to fully converge. Since the enclosure is effectively acoustically transparent at these very low frequencies, the primary field can be considered as the summation of the wave-fronts produced by the five main rotor blades. This summation will be very dependent on the exact phase of each component and, since the blades are not travelling through clean air, is subject to considerable random variation. The primary field from the tail rotor was subject to less variation than that from the main rotor, allowing the control system to more fully converge. Computer simulations, using the time history data recorded in-flight, showed that, in general, these variations in the primary field prevented the control system achieving the final 5 dB of potentially available attenuation.

Natural algorithms [5] were used to select the best sub-sets of loudspeakers from the 16 used in-flight, for various secondary source power constraints. Figure 2 shows the variation in a attenuation in the sum of squared pressures at 17.5 Hz with different numbers of optimally chosen loudspeakers, for various secondary source power constraints. It was found that, even at this frequency, at least 8 secondary sources are required to achieve over 10 dB of attenuation with reasonable secondary source strengths. This result again suggests that the primary field due to the main rotor is not dominated by simple excitation of the acoustic modes of the cabin, but rather that the sound field in the cabin is driven by the near-field of a large complex primary source.

5 CONCLUSIONS

An active control system, designed to control low-frequency helicopter rotor tones, was flight tested in an EH101 and attenuations of up to 12 dB were recorded inside the passenger cabin. The control system also recorded time histories from all of the error microphones for later analysis and computer based simulations. The primary field was found have a complex spatial distribution and was subject to rapid short-term variations in sound pressure level, which affected the control systems performance.

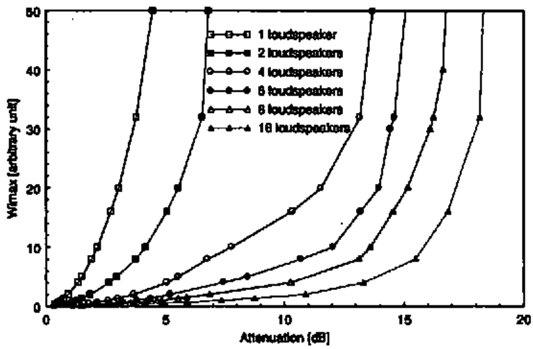

Figure 2: Attenuation in sum of squared pressures at 17.5 Hz with different numbers of optimally chosen secondary loudspeakers, which are each constrained to have a power output of less than $w_{i_{max}}$. $w_{i_{max}} = 1$ corresponds to the maximum available power for a single loudspeaker in the control system used in-flight.

Natural algorithms were used to select the best sub-set of loudspeaker combinations from the 16 used in-flight for reduced order controllers. The surprising conclusion is that even at the lowest frequency of interest (17.5 Hz) substantial attenuations in internal pressure can only be obtained with at least 8 loudspeakers, due to the complexity of the primary field and the acoustic response of the cabin.

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