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DETERMINATION OF HELICOPTER NOISE DIRECTIVITY - THE NATO/CCMS WORKING GROUP'S APPROACH

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ABSTRACT

The total noise signature of a helicopter consists of several characteristic sounds. Aerodynamic flow phenomena occur around the rotor blades and fuselage, resulting in a number of noise sources. Since air flow velocity and direction will vary during different kinds of operation, so will the directivity and characteristics of these sources. Helicopters in flight emit noise which is highly directional and can vary widely depending on flight mode, airspeed and rate of climb/descent. The noise associated with landing at a heliport may be quite different than that of a level flyover, take-off or hover. All this adds up to a very complex three dimensional directivity pattern of the total noise from a helicopter. This directivity pattern will differ from one type of helicopter to another and also will differ from one type of operation to another for each helicopter type. These differences must be taken into account in order to make useful predictions of the noise associated with each flight condition at heliports or airfields. The NATO/CCMS Working Group on "Helicopter Noise Prediction Modelling" developed and evaluated a helicopter noise directivity measurement method consisting of microphones mounted on cranes and on the ground.

1 - INTRODUCTION

In 1985 the NATO Committee on the Challenges of Modern Society (CCMS) established a pilot study group to investigate the problems associated with civil and military aircraft noise. The pilot studýs aim was to make a contribution to reduce aircraft noise, especially noise from low-altitude flights with military jet aircraft. These flights caused numerous complaints in all NATO countries. But helicopter operations around helicopter landing sites and helicopter training at low-altitudes (50 ft) have also had a tremendous effect on public annoyance. The Pilot Study Final Report [1] contains a number of recommendations for further work and proposed a "Follow-Up Programme". Among the recommendations were a proposal for the creation of a common helicopter noise database and the evaluation of helicopter noise prediction models.

The helicopter follow-up working group was established in 1992 with the aim to collect and exchange data on helicopter noise as well as to evaluate helicopter noise prediction models. In the first report of the working group [2] the necessity of measurements of helicopter noise directivity was emphasized. It was recommended to develop a common helicopter directivity measurement and data acquisition procedure and to create a common helicopter noise database.

During a meeting of the working group at Ft. Drum, USA in 1995 a helicopter noise directivity measurement procedure was developed. A first evaluation of this procedure was successful carried out at the UK Test Range at West Freugh in 1996.

The Canadian member of the NATO/CCMS working group then offered to host a joint helicopter noise directivity trial in Moose Jaw in Saskatchewan in the western central region of Canada in May 1998. The aim of the trial was to prove a recognized international standard for measuring and analysing the noise directivity of helicopters.

2 - HELICOPTER NOISE DIRECTIVITY MEASUREMENTS

In principal, one can measure a three-dimensional directivity pattern in one-third-octave-bands by considering the total sound power together with a directivity index. Measurements could be made at selected three-dimensional microphone positions in a similar fashion to those positions employed for standard sound power measurements in a free-field. Alternatively, one could select equal steer-radian positions and determine the directivity function by employing a two-dimensional spacial Fourier transform. However, there are several key problems to this approach. Firstly, unlike the case of a factory machine where microphones can surround the stationary source, a helicopter is a moving noise source. Secondly, helicopter noise varies significantly over time, and finally, measurements with moving microphones and aircraft in flight are extremely expensive and not very accurate. For a standard helicopter noise directivity procedure this seems to be impracticable.

For accurate helicopter noise predictions the knowledge of the 3D noise directivity of the helicopter is necessary. The horizontal directivity is important for a helicopter at large distances from an observer when the noise will emanate from close to the plane of the rotor. To obtain the acoustic directivity in the plane of the rotor microphones need to be placed in this plane. It is normal practice to measure noise from helicopters using microphones which are either mounted flush with the ground or are elevated but close to the ground. For an elevated microphone the interference between the direct and reflected waves can lead to difficulties of interpretation when they are out of phase. If the microphone is high off the ground there may be added complication that the direct and reflected waves of the moving helicopter may be emitted at different times and at different angles to the receiver. Therefore, some assumptions need to be made about the 3 D noise directivity, which is the characteristics we are trying to measure. Microphones mounted close to the ground are adequate for measuring the directivity of a helicopter out to approximately $\Theta = \pm 60°$, where Θ is the angle to the vertical as shown in figure 1.

To obtain the acoustic directivity patterns in the region $60° < |\Theta| < 90°$ using a ground microphone, the propagation distances would become very large or the helicopter need to be flown even closer to the ground. In either case the measurements are influenced by refraction through the atmosphere, as well as interference with the ground, and this can lead to large errors in interpreting the data. These effects are also changing throughout the measurement period. In principle given enough meteorological information it may be possible to account for these effects but this is a complex and complicated calculation which itself may be subject to uncertainty, especially in the upwind condition.

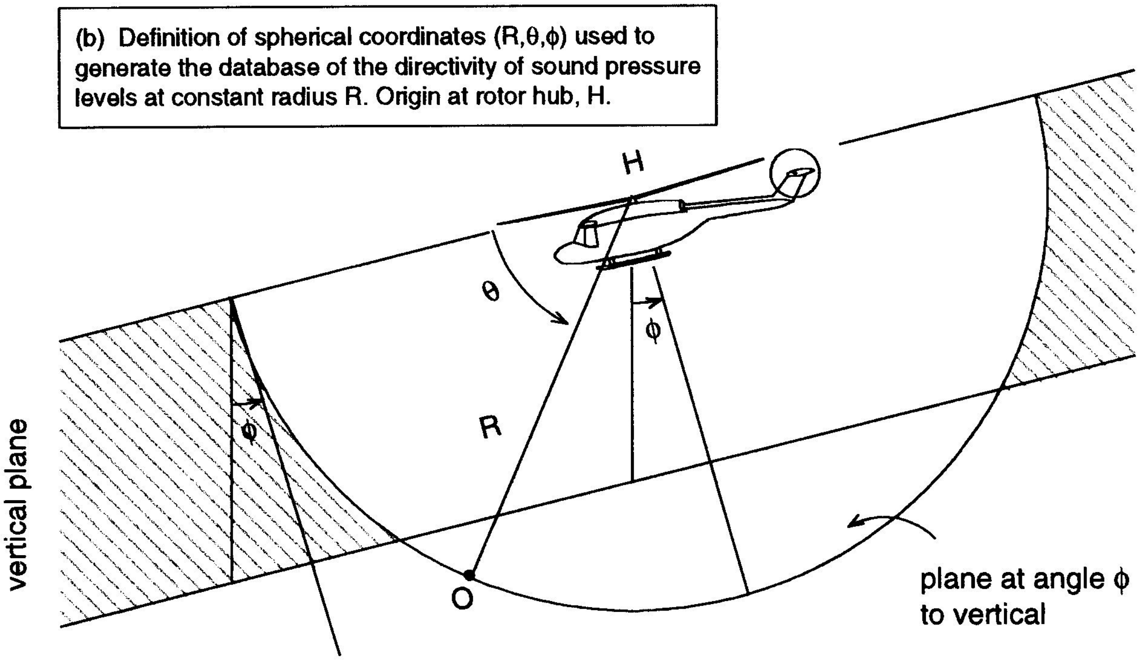

Figure 1: Helicopter co-ordinate system for acoustic directivity.

Helicopters – especially military ones – were usually flown at very low altitudes. Therefore the helicopter can be seen from the receiver's location at very low elevation angles with nearly grazing incidents. Due to the agility of the helicopter which allows sharp banking angles it is necessary to know the vertical noise directivity at least up to the rotor plane. For a measurement of the vertical directivity up to the rotor plane with ground based microphones one need to measure the noise at extremely far distances. Due to noise measurement problems at large distances the working group have had the idea to fly the helicopter through a U-shaped microphone array. Perfectly all microphones should have the same distance to the noise source which is for simplicity assumed to be in the helicopter's rotor plane. Additionally, with this microphone arrangement the vertical noise directivity could be measured even above the helicopter's rotor plane.

The idea developed by the working group was to approximate the U-shape microphone arrangement with a vertical and a horizontal microphone array which was erected at a line perpendicular to the helicopter flight path. The trial methodology uses repeated overflights of a helicopter across a number of microphone arrays, under stringent trial conditions, to eliminate or quantify the independent variables. The helicopter type used during the test was a Bell 412 EP (Canadian Forces designation: CH-146 "Griffon"). The analysis of the trial data in a common data format was essential for the trial. It was also necessary for the exchange of data between the participating institutions. The following nations and organizations had participated in the trial: Canada (Department of Defence), Denmark (Delta Acoustics & Vibration), Germany (Federal Environment Agency), Norway (SINTEF), Switzerland (EMPA), UK (RAF, University of Salford and Defence Evaluation and Research Agency (DERA)) and USA (USAF, NASA Langley and Wyle Labs).

The helicopter had accurately follow a defined flight track using the onboard GPS (Global Positioning System) and visual aids (markers) on the airfield. Engine power settings were kept constant for each run. Details of engine power settings and blade conditions for each combination of run condition were specified prior to the onset of each run. The conditions were monitored by a passenger on board the helicopter. The passenger also had to control the attitude sensor (Motion Reference Unit, MRU) and GPS sensors and record the positional data. For later analysis of the data there is a requirement to locate the helicopters position with respect to time. Therefore, the helicopter tracking data needs to be logged during the trial. Multiple GPS-systems were used to provide accurate position data due to the use of differential GPS-receivers. Each of the GPS-receivers provided a standard GPS-signal; the differential GPS-signal was post processed. Additionally, a master GPS unit provided an accurate time signal to all other recording systems.

For the determination of meteorological conditions a weather station was used which recorded constantly air pressure, wet and dry bulb temperatures, wind speed and direction. The vertical wind profile was determined prior and after the measurements. A tethered weather balloon was used to assess the vertical wind profiles between 100 ft and 1000 ft. An additional portable weather monitoring station at a height of 2 m was positioned near the base of one of the cranes.

Two 54 m cranes with additional pole extension to 200 ft were used. The cranes were erected on the runway surface with a 150 m separation between the cranes. Steel cabling, onto which microphones were mounted, were suspended from the crane down to the ground. A large weighted drum was suspended from the cable. The cable was lowered until the drums were just in contact with the ground, ensuring that the cable is both tough and anchored at the base. The microphones were mounted perpendicular to the steel cable and parallel to the flight track at predetermined heights. Between the cranes and as far as 1000 m to both sides of the cranes there were several microphones (on ground and at 1.50 m height). On one crane a beam-forming array consisting of 14 microphones distributed over 30 m were used by DERA. The beam-forming technique was used to steer the microphones to different points during the fly-by of the helicopter. The Bell 412 EP helicopter has main rotor harmonics spaced at approx. 22 Hz and tail rotor harmonics spaced at approx. 56 Hz. Therefore, the array was designed to cover the frequency range from 20 Hz up as high as possible. The technique used by DERA is in greater detail described in [3].

NASA Langley used a large ground based microphone array consisting of 30 ground plane microphones distributed over an area of 1219 m x 1067 m. The spacing of the microphones were varying from 75 m to 150 m in three linear arrays with a distance of 305 m between the linear arrays. The NASA layout was primarily used for the measurement of noise footprints. The specific purpose of the NASA Langley participation was the acquirement of an acoustic database for the validation of the Rotorcraft Noise Model (RNM). This database should be the standard database with the public release of RNM version L1.0.

When conducting level flight conditions the aircrew aimed to maintain a constant heading along the centerline of the microphone array. The flight path was extended 3000 m before and after the microphone array. Within the first 1000 m the aircrew was aiming to settle at the desired height and airspeed. Once within 2000 m of the microphone array airspeed, engine power and rotor setting should be constant. Figure 2 shows details of all level flights at an airspeed of 90 kts. In the upper half of the figure the horizontal distribution of all flights is shown whereas in the lower half of the figure the vertical spread of the flight tracks is shown.

For each ascent and descent the aircrew climbed or descended at a rate so as to cross the microphone array at an altitude of 50 m. For a 12° descent the helicopter began a steady descent at an altitude of 100 m aiming to land at a distinguished marker behind the microphone array. The hover conditions (in-ground-effect and out-of-ground effect) were measured at a point in the middle of the cranes to one side of the cranes.

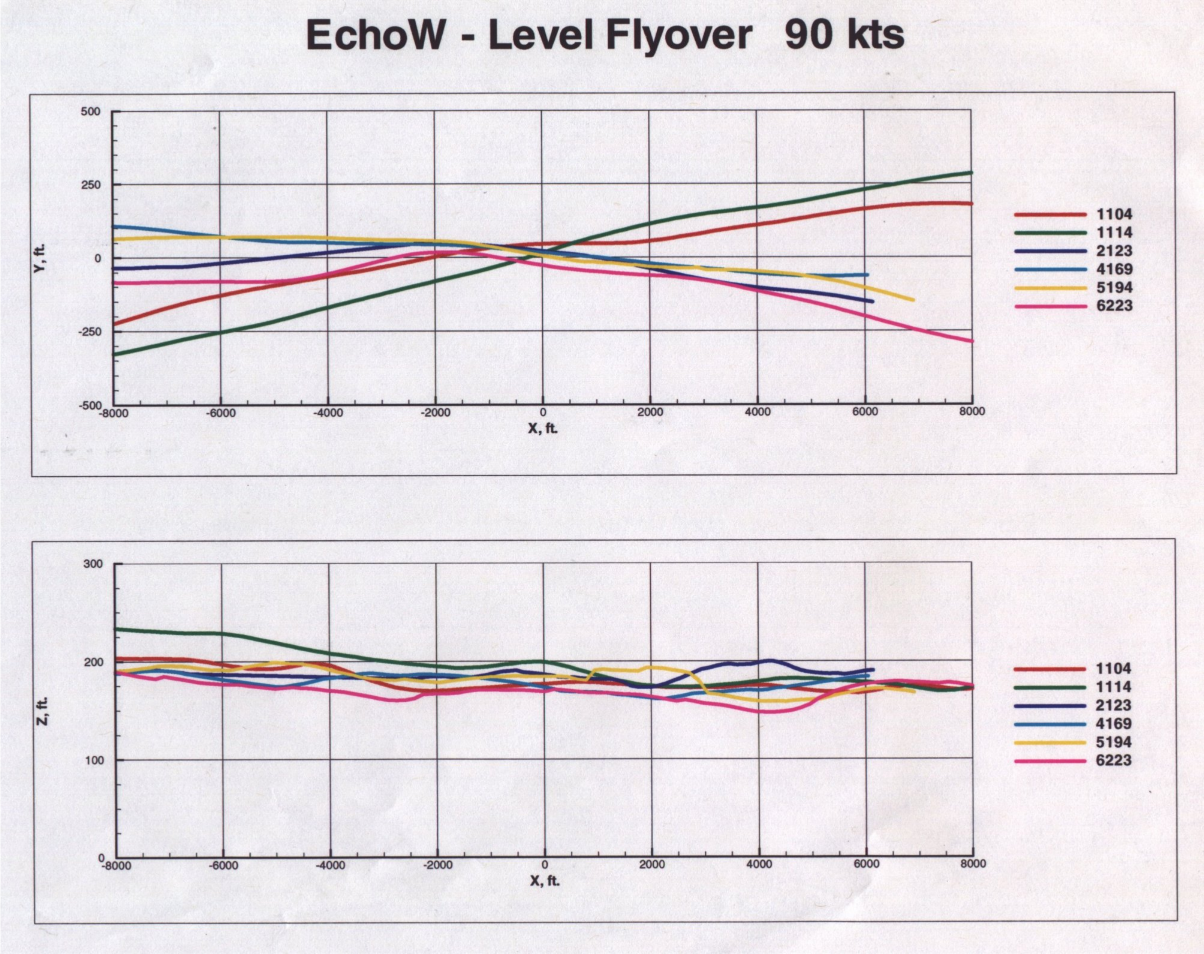

Figure 2: Horizontal and vertical distribution of all flight tracks for level flights with 90 kts in 50 m AGL (above ground level).

The main aim of the Moose Jaw trial was to evaluate the advantages and disadvantages of the four helicopter noise directivity measurement methods: a large flush mounted microphone array (used by NASA), a linear ground based microphone array on a line perpendicular to the flight track and the U-shaped crane array with (used by DERA) and without beam-forming measurement technique.

3 - RESULTS

The analysis of the data and therefore the evaluation of the four helicopter noise directivity measurement methods is still an ongoing task. Only the hover flights and the level fly-over with 90 kts in 35 m AGL (above ground level) are yet analysed. Only one example of the results received until now will be shown. The directivity pattern in the plane of the rotor during hover was measured by DEAR using the beam-forming array. The helicopter was performing an out-of-ground effect (OGE) hover at 35 m AGL, at a distance of 213.6 m from the array. The array remained stationary while the helicopter moved through 360° in 30° increments hovering at each position for 1 minute to allow sufficient data to be collected. Figure 3 shows the directivity pattern for the first five main rotor harmonics (left) and the first three harmonics of the tail rotor (right). The main rotor harmonics are reasonably omni-directional whereas the tail rotor harmonics are distinctly directional in nature. For further details of the beam-forming technique and the first results of the Moose Jaw trial obtained with the beam-forming array see [3].

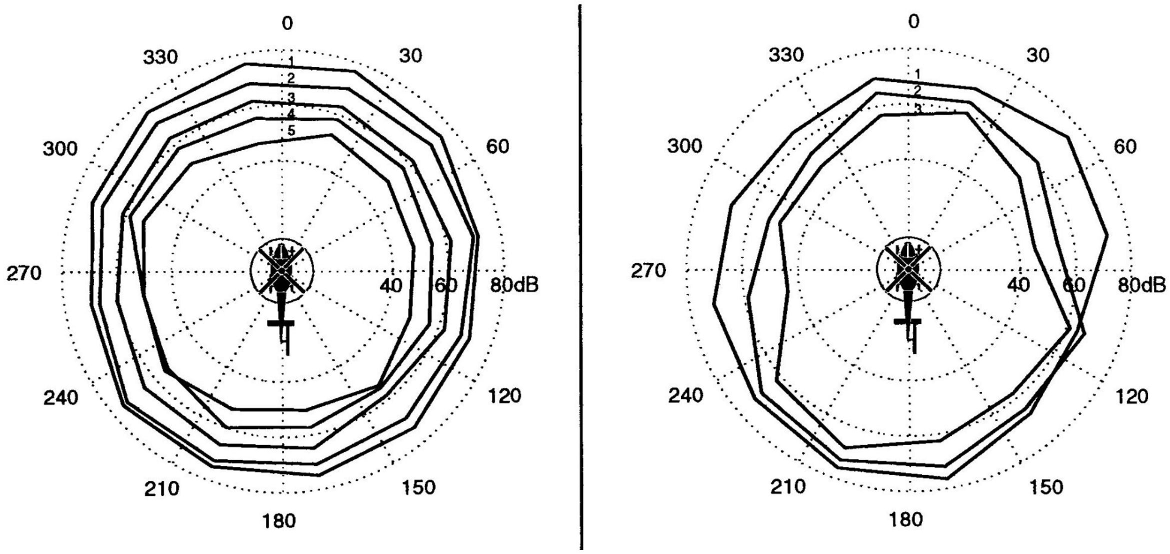

Figure 3: Directivity pattern of the first five main rotor tones (left) and of the first three tail rotor tones of a Bell 412 EP helicopter measured and analysed by DERA [3].

4 - CONCLUSIONS

Ground microphones have been the accepted method used for measuring noise from helicopters during fly-by manœuvrers. They are useful for measuring the vertical noise directivity out to $\Theta = \pm 60°$. However if the noise directivity of the helicopter near to the plane of the rotor is required then propagation distances become too large for accurate measurements due to meteorological effects. Simply raising the microphone above the ground to obtain the directivity at the higher values of Θ is not straightforward due to interference between the direct and the reflected wave. These problems could be solved with a beam-forming microphone array.

Another lesson learned in the Moose Jaw trial was that during nearly 25 % of all flights the GPS sensor onboard the helicopter was not working correctly due to bad weather conditions (mainly due to buildup of electricity between the main rotor and the GPS-antenna). Therefore, a check of the tracking data is necessary after every flight day. A backup system as used during the test is absolutely mandatory. An MRU system seemed to be a good alternative for the attitude measurements. It was clearly demonstrated that improved pilot guidance is required to improve acoustic data quality. Better flight track queues could be provided easily and cheaply with bright focussed lights along the flight path for good lateral flight path guidance and VASI lights for good flight path approach angle queues.

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