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Helicopter Noise - what is important from a community prospective?

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ABSTRACT

Social surveys indicate that helicopters are 10-15dBA more annoying than other aircraft (for the same or lower measured sound level) suggesting that there is something either about helicopters or the noise they produce that is more objectionable than other more common sources of noise. The characteristics of rotor noise are well understood and much effort continues to be expended in reducing noise exposure, both by reducing noise levels at source and by developing low noise flight procedures. The designer's principal objective is to ensure compliance with relevant statutory noise limits, i.e. *objective* noise metrics such as Leq, EPNL etc.. However, the *subjective* response to helicopter noise in the context of public acceptance is less well understood and, in the opinion of the author, is not properly rated by conventional measurement techniques.

From an industry perspective it is important to understand the scale of the problem created by helicopter operations and what can be done to improve perception and thus public acceptance. For example a recent survey carried out by the Environmental Committee of the London Assembly claims that helicopter noise is having a negative impact on the life of many people in London and concludes "*The time has come for the Department of Transport and Civil Aviation Authority to take action in reducing the environmental impact of helicopter noise and thus improve the quality of life of Londoners"* These are strong words but do they reflect the opinion of the wider population? This paper sets out the author's view of what should be done to address public acceptance of helicopters.

This paper is based on papers published jointly by the author with J. W. Leverton in 1998[1], 1999[2] and 2007[3].

1. INTRODUCTION

The development of helicopter operations in Europe, the United Sates and other parts of the world is being restricted by objections about noise. The commissioning of new heliports, and changes to services at existing facilities, tend to be controversial and are often rejected as a result of public opposition. From an objective viewpoint, opposition to helicopters and helicopter operations purely as a result of excessive noise is difficult to understand because most helicopters generate noise levels considerably below the internationally agreed certification limits and comfortably satisfy established community noise rating criteria and guidelines. The inference is that even relatively sophisticated noise rating methods based on complex objective measurements fail to account for the disturbance caused by helicopters. Nevertheless, as a result of concerted opposition to helicopter operations it has been suggested that maximum noise levels for noise certification and criteria associated with community rating procedures should be lowered. There is no doubt that in general "lower is better". However, in view of the engineering implications of reducing helicopter noise, statutory limits must be chosen with care and any increase in stringency must result in a *noticeable* reduction in noise level. Moreover, an extensive survey of the effect of operations in the environs of a military establishment in the UK[4] concluded there was a poor correlation between helicopter noise level and subjective annoyance and that the study confirmed for helicopters the weak relationship between objective noise measures and subjective annoyance levels.

In fact, as shown on Figure 1, social surveys[5] indicate that helicopters operating in the London area are considered to be 10 – 15 dB(A) more annoying than fixed wing aircraft, suggesting there is something either about helicopters or the noise they produce that is more objectionable than other more common sources of noise. However, the figure also shows that in Aberdeen helicopters are not regarded differently to other aircraft, so that, perhaps, negative reaction to helicopter operations is not always directly attributable to noise.

From an industry perspective it is important to understand the scale of the problem created by helicopter operations and what can be done to improve perception and thus public acceptance. For example a recent survey carried out by the Environmental Committee of the London Assembly[6, 7] claims that helicopter noise is having a negative impact on the life of many people in London and concludes "*The time has come for the Department of Transport and Civil Aviation Authority to take action in reducing the environmental impact of helicopter noise and thus improve the quality of life of Londoners"* These are emotive words. However, the very limited response to the widely advertised survey makes it impossible to determine the opinion of the wider population. The fundamental questions addressed by this paper are why is the reaction to helicopters different to that of other forms of transport? and what can be done to improve the level of public acceptance?

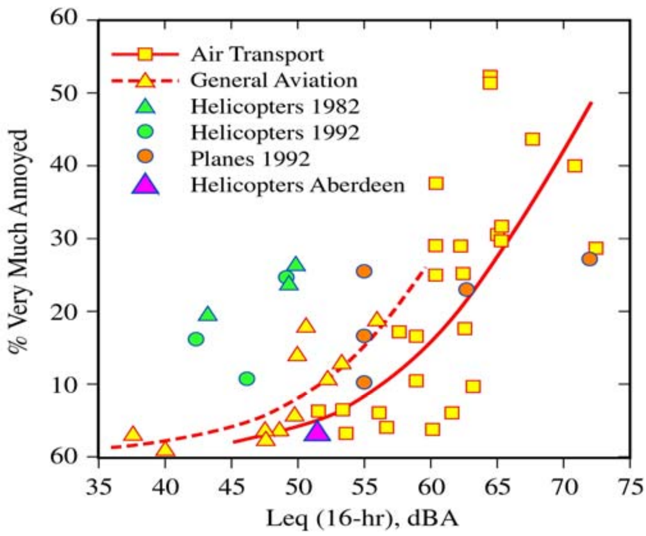

Figure 1: CAA social survey results

2. RATING OF COMMUNITY RESPONSE

Most community rating procedures are based on the use of A-weighted sound pressure level integrated over a relatively long period (16 hours in the UK between 7:00 and 23:00) to account for the noise level of individual events and the number of occurrences in a specified period. This type of analysis may be applicable to the large number of operations that occur at a major airport where sound levels are relatively constant. However, the effectiveness of methods based on long term averaging is questionable in those cases where the duration of the event is very much shorter than the evaluation period and the number of events in that period is such that noise levels are subject to large variations. For example, the duration of typical helicopter overflights is such that the maximum A-weighted noise level in any single event can be almost 20 dB(A) above ambient up to 64 times per day before the noise level recorded by community rating methods exceeds acceptable values. Even larger differences between the maximum noise level and the local background level would be rated as acceptable when the number of flights per day is lower. In this respect, noise evaluations based on long term averaging fail to properly forecast public reaction to a limited number of moderately 'noisy' events.

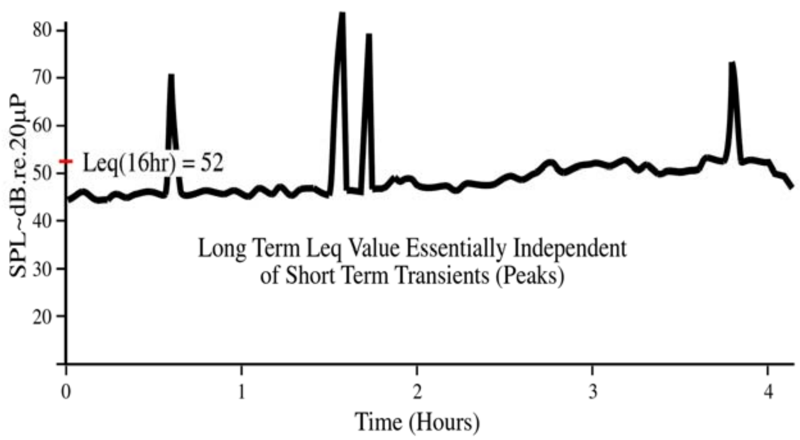

Figure 2: Community/helicopter noise levels

Figure 2 shows a section of A-weighted time history with four helicopter flights over a 4-hour period. Expressed in terms of $L_{Aeq\ 16\ hour}$, the noise level is virtually independent of the short duration helicopter noise events even though individual occurrences would be noticeable and probably considered annoying. Therefore, in the opinion of the author, current community rating methods are deficient in two respects. First, the subjective effect of the more intrusive helicopter noise sources is underrated. Second, evaluation over a period of several hours fails to properly account for the disturbance caused by relatively short duration events. Coupled together, these two deficiencies help to explain why helicopters attract special attention.

3. HELICOPTER NOISE CHARACTERISTICS

The external noise signature of helicopters is the result of several complex sources. Most of the acoustically dominant sources are aerodynamic in origin so that the relative strength of each and, therefore, the noise heard on the ground depends on a number of factors. Despite a high degree of variability, helicopter noise exhibits certain characteristics peculiar to this type of vehicle which make rotorcraft readily identifiable even at quite low sound levels – *this is a helicopter!* It is these peculiar characteristics that not only make helicopters potentially more annoying than vehicles with less distinctive signatures but also impose special demands on the techniques used to rate the level of annoyance.

The dominant sources are aerodynamic noise generated by the main and tail rotors as a direct result of providing lift and directional control and additionally by interactions between the main rotor and its own wake - blade/vortex interaction noise (BVI) and between the main rotor wake and the tail rotor - tail rotor interaction noise. BVI noise will be generated by all helicopters during banked turns and landing but the effects can be minimized by noise abatement techniques. Tail rotor interaction noise can and should be avoided as much as possible during the design of the aircraft by careful placement of the tail rotor relative to the main rotor disc.

Rotor noise appears in the time domain as a sequence of regularly spaced pressure pulses which produces a frequency spectrum comprising a series of harmonically related tones the fundamental frequency of which is determined by the rotational speed of the rotor and the number of blades. The way in which rotor noise is *perceived* depends on the repetition rate of the pulses. When the rate is sufficiently low, individual pulses can be resolved. As the rate is increased, this becomes more difficult and eventually the sound is perceived as a continuous complex tone. For all but the smallest aircraft, the repetition rate of main rotor noise is such that the noise is perceived as distinct pulses or ‘thumps’ whereas tail rotor noise generally appears as a continuous frequency or ‘whine’. The noise produced by both forms of interactions is rather more complex and is at the same time both highly characteristic and potentially annoying.

The most important feature of helicopter noise in terms of community response is that although in principal, significant reductions in noise level can be achieved by the correct choice of aircraft design parameters, the basic characteristics described above cannot be eliminated entirely.

3. NOISE CONTROL

Considerable effort continues to be expended in reducing noise exposure, both by reducing noise levels at source and by developing low noise flight procedures. The helicopter designer’s principal objective is to ensure compliance with relevant statutory noise limits, i.e. *objective* noise metrics such as Leq, EPNL etc. However, the *subjective* response to helicopter noise in the context of public acceptance is less well understood and, in the opinion of the author, is not properly rated by conventional measurement techniques.

Any objective criteria used to regulate helicopter noise must satisfy certain conditions if reductions in helicopter noise are to be realized by the introduction of less noisy aircraft rather than by severely restricting operations. First, and perhaps most importantly, noise limits must be a compromise between what is acceptable to the majority of those exposed to the noise and what can be achieved within technological and commercial limits. Secondly, the units in which noise levels are expressed must reflect subjective response if regulatory processes are to achieve noticeable reductions in noise level. The latter point is particularly relevant in the case of helicopters because of significant variations in both the character (*timbre*) and level of the noise with aircraft type and flight condition.

The principal regulatory process for controlling the noise level of civil aircraft is noise type certification whereby aircraft are subject to rigorous flight test evaluation against a set of maximum noise levels. The object of noise certification is to reduce noise at source by encouraging the design of less noisy aircraft. The operation of aircraft which fail to comply with internationally agreed limits is prohibited, providing manufacturers with a powerful incentive to incorporate acoustic technology into the design. In order to appreciate the implications of statutory limits on helicopters it is necessary to understand clearly how noise control interrelates with other design considerations. Before describing the effect of noise rules on rotary wing aircraft, it is worth summarizing the history of noise certification and the essential differences between fixed and rotary wing aircraft.

Noise first became a major issue in the arena of aircraft certification in 1969 – 70 because of environmental pressure resulting from the shatteringly high noise levels of turbojet aircraft powered by low by-pass ratio engines. Fortunately, timely development of turbofan engines resulted in the introduction of much less noisy civil transport aircraft. Significantly, these engines are both less noisy and much more fuel efficient so that lower noise levels have been accompanied by improved performance and lower operating costs. In complete contrast, design changes to improve helicopter performance tend to increase noise and *vice versa*. For example, the change from piston engines to turbo-shaft engines, although enabling improvements in helicopter performance, has not resulted in noise reductions. The availability of higher installed power, particularly in the case of multi-engine configurations, has allowed designers to exploit the performance benefits of increased rotor blade loading and tip speed, both of which increase noise levels.

4. DESIGN CONSIDERATIONS

The helicopter, with the possible exception of those powered by reciprocating piston engines, is unique amongst powered lift aircraft insofar as the primary lift and control surfaces are almost invariably the dominant source of external noise *in all modes of flight*. Consequently, the noise characteristics of a specific helicopter type are established almost completely once the main and tail rotor configurations and their position relative to one another has been decided. It is for this reason that significant reductions in noise level after the first flight of a new helicopter type are most unlikely without:

(a) Escalation of development costs which may ultimately include major redesign work

and/or

(b) Flight limitations to avoid regions noisy regions of the flight envelope.

In today's financial climate, bearing in mind the enormous costs associated with any new aircraft programme, the first option may not be commercially viable. The alternative solution will probably result in the aircraft failing to meet customer operational requirements. Clearly, major aircraft programmes will be jeopardized by design philosophy that does not attempt to virtually guarantee compliance with statutory limits.

The realization of the quiet helicopter concept is, therefore, not one of post flight modifications to a noisy aircraft but a carefully planned compromise, made at the design stage, between several conflicting requirements. Unfortunately, simple physical considerations show that the design parameters most effective in reducing rotor noise also have the greatest influence on performance. Indeed, although purely acoustic considerations point towards low rotor blade tip speed, the aerodynamicist seeks the highest possible rotor speed commensurate with compressibility effects in order to save weight and to maximize rotor inertia in the event of autorotation. Genuine reductions in noise at source cannot, therefore, be achieved unless noise is treated as a design requirement and given the same priority as other attributes such as payload, range etc. all of which contribute to the overall effectiveness of the vehicle. Lower noise levels will come at the expense of either performance, operating costs or research activity (none of which may be palatable). Nevertheless penalties incurred in the pursuit of low noise should not be isolated for special attention. They are simply a legitimate part of the design process and must be accepted as such.

The close relationship between the various helicopter design parameters is illustrated in Figure 3. The Figure illustrates the consequences of reducing the main rotor tip speed to reduce noise. The first consequence is that blade area must be increased to recover thrust capability, either by adding more blades of the same type or by changing the dimension of the blade. In either case, further alterations to the helicopter will be necessary to accommodate the changes. For example, reducing the rotational speed of the rotor will increase the torque required, possibly requiring a new, heavier transmission system and a new tail rotor to provide additional yaw control. Additional blades will require a more complex rotor hub while increasing the rotor radius may involve a longer tail boom to avoid interference with the tail rotor and so on. The way in which each parameter change necessitates others can be linked to an *explosion* radiating outwards from the initial modification as more factors come into play.

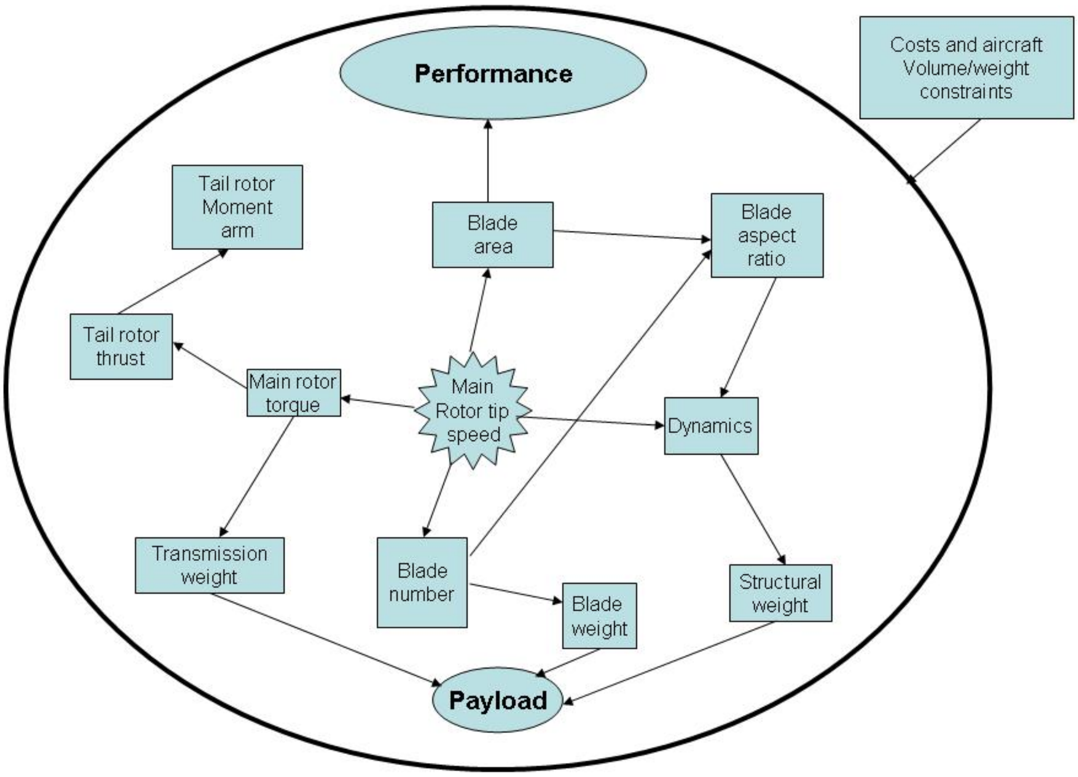

Figure 3: Effect of design changes

For a completely *new* design the process of optimizing the balance between various attributes can continue until it is constrained either by technological boundaries or by cost and vehicle weight/volume limits. For *derived versions* of existing aircraft the freedom of choice before costs-to-change become prohibitive is more restricted. Inevitably this means that the level of noise reduction achievable without penalizing some of the other aircraft attributes is significantly smaller in the case of derived versions than that achievable by completely new designs.

Practical design improvements to reduce noise are currently directed towards BVI and tail rotor noise. These sources (arguably) are the biggest cause of complaint about helicopter noise and they also provide a powerful *acoustic cue* that might stimulate responses to non-acoustic issues such as privacy, envy, fear of crashes on so on – the so-called *virtual noise*. The problem of BVI noise is being addressed both by passive rotor blade tip planform modifications and by active blade control systems such as higher harmonic control (HHC), individual blade control (IBC) and, more recently, active flaps, controllable twist and aerofoil section changes. All of these devices have been tested at model or full scale with varying degrees of success so, given sufficient development funds, it is possible to foresee improvements of perhaps 6 dB(A) during landing. In the light of these undoubted benefits it is, however, easy to overlook the fact that if the aircraft is not operating under BVI conditions, i.e. during noise abatement approaches, take-off or in level flight, little or no reduction in noise will actually occur so the *operational* advantages of active systems may be small. Perhaps a more effective use of active systems is to reduce or even eliminate the penalties traditionally associated with low rotor speed so that lower noise levels are obtained during all modes of flight. Thus, the real benefit of technologies being developed will come in terms of expanding the area of the aircraft flight envelope in which noise is considered to be acceptable.

The importance of tail rotor noise, not only in terms of overall noise level but also as a function of subjective response, has been appreciated by some manufacturers for over 20 years. Westland Helicopters developed a quiet tail rotor for the Lynx (which initially suffered from severe tail rotor interaction noise) and Westland 30 in the late 1970's. The basic design methodology is illustrated in Figure 4.

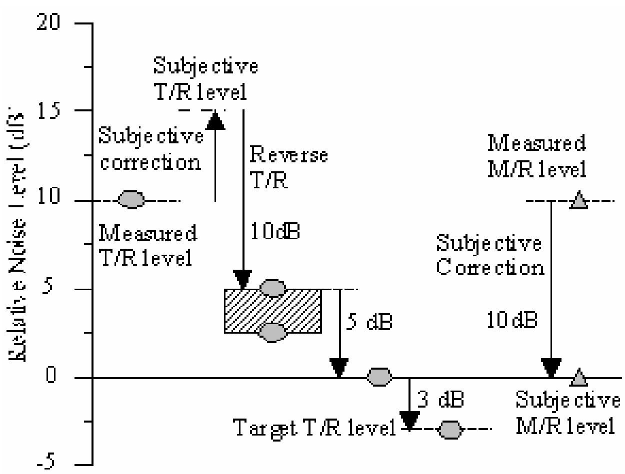

Figure 4: Tail rotor balanced noise source concept

The concept of balancing the perceived *noisiness* of the main and tail rotors has been applied subsequently to the EH101[8]. The development by McDonnell Douglas of the NOTAR (NO TAil Rotor) series of helicopters was based on the desire by the U.S. Army to reduce the detectability of small helicopters. The solution was to remove the tail rotor source completely[9]. This technique cannot be applied to large helicopters for a number of design and operational reasons. However, with careful attention to detail the acoustic characteristics of a conventional quiet tail rotor can be as acceptable as NOTAR[8]. The *fenestron* fan-in-fin solution adopted by Eurocopter, is also noteworthy in this context. Although early applications of this technology introduced a high frequency whine, recent modifications using unequal spacing of the rotor blades and non-radial stators have reduced this problem and under most flight conditions, it offers improvements comparable to NOTAR and conventional quiet tail rotor technology[10]. Again, however, structural, dynamic and aerodynamic limitations restrict fan-in-fin technology to low and medium weight helicopters.

5. "LONDON IN A SPIN"

One of the most high profile surveys of helicopter noise in the UK was carried out by the Environmental Committee of the London Assembly in 2006[6, 7]. The forward to the final report "London in a Spin"[6] states that "helicopter noise is having a negative impact on the quality of life for many people". The report makes 14 recommendations for alleviating the problems created by helicopters operating over London.

The report is based on written evidence[7] received by the committee following advertisements in local media encouraging members of the public to submit their views and experience of helicopter noise. An analysis of the written evidence shows that of the 195 submissions, 132 were received from London residents, 14 from London boroughs with the balance coming from public interest groups. The total of 195 responses represents less than 0.01% of Inner London (population 2.766 million according to the 2001 census) and merely 0.003% of Greater London (population 7.172 million). Taking into account that the London Boroughs reported only limited problems with helicopter operations, the level of public nuisance created in London by helicopters as reported in reference 6 is questionable. This is not to imply that those people who submitted negative comments did not feel genuinely aggrieved but simply that the views of the vast majority are unknown. Assuming at least 99.9% of the population of London was not sufficiently motivated to respond to the survey, an alternative view to that expressed by the London Assembly is that, for the majority, helicopter noise is not a problem. However, a more sensible conclusion is that the true impact of helicopters operating over the city remains unknown.

6. SUBJECTIVE CONSIDERATIONS

Ultimately, despite the considerable effort being directed towards reducing noise levels, there is a need for more research into the subjective response to helicopter noise - the main activity in this area was over 20 years ago. From the industry point of view (operators and manufacturers) it is essential to establish what *really* needs to be done to improve public acceptance and indeed, whether or not helicopter noise is a genuine problem, affecting a significant percentage of the population rather than just a small but nonetheless sincere minority prepared to respond to surveys. Accordingly a listening trial is being planned to investigate:

(i) The subjective rating of helicopter noise relative to other common noise sources.

In this case the test participants will be subjected to a selection of noise sources at the correct absolute SPL, most conveniently maximum dB(A) but may be open to review. The most obvious sources include helicopters, fixed wing aircraft, road transport vehicles and some non-transport related sources such as lawn mowers, barking dogs etc. The objective will be to select recordings that present each source in a realistic environment. This may be quite difficult.

(ii) The relative importance of major helicopter sources

Here the objective is to establish which of the significant sources are responsible for the (supposed) high levels of intrusion attributed to helicopter noise. The goal is to determine what needs to be done to the noise signature in order to achieve a significant improvement in public acceptance.

7. CONCLUSIONS

The characteristics of helicopter noise are well understood and significant reductions in noise level have been made in the last 20 years. Further reductions in noise level resulting from improvements in both technology and operational techniques developed under the EU supported research programmes FRIENDCOPTER and Clean Sky JTI can be expected. For example, one of the stated aims of FRIENDCOPTER is a 50% reduction in noise footprint area while Clean Sky aims for a 10 EPNdB reduction. These are both significant and worthwhile objectives. However, the true effect of helicopter noise on the general public remains unclear so that the designer does not have a clear target at which to aim future designs and specific areas of technological development. Moreover, without a much better understanding of the subjective effect of helicopter noise, there is no guarantee that further reductions in noise level will result in a significant improvement in public perception. The subjective trial described in this paper to be carried out under FRIENDCOPTER is a first step towards that goal.

The response to surveys carried out thus far reveals a strong negative reaction against helicopter operations amongst small groups of respondents but invariably fails to make clear the true scale of the problem in the wider population. It is also apparent that non-acoustic issues such as the invasion of privacy, fear of crashes and the feeling that many helicopter flights do not perform a useful function cannot be solved by reducing noise levels. These factors should be addressed by a determined effort by the helicopter industry and regulators to improve public relations.

ACKNOWLDEGEMENTS

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