24th EUROPEAN ROTORCRAFT FORUM
Marseilles, France - 15th-17th September 1998

Acoustics AC03

UNDERSTANDING HELICOPTER NOISE - IMPLICATIONS ON DESIGN AND OPERATION

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The impact of helicopter noise on the public at large has become more important in recent years and is one of the main attributes of this type of aircraft inhibiting the expansion of helicopter operations and the development of heliports. There appears to be a marked disparity between public acceptance of helicopter operations and the level of intrusion inferred from the most common methods for rating noise disturbance in the community. The peculiar characteristics of rotor noise which might explain why helicopters are singled out for special attention and ways in which the problem may be resolved by design and operational techniques are discussed in detail.

1. INTRODUCTION

The development of helicopter operations both in Europe and North America is being restricted by objections about noise. The commissioning of new heliports, and changes to services at existing facilities, tends to be controversial and is often rejected as a result of public opposition. Prime examples include operations at the Issy-les-Moülineaux heliport in Paris, the continuing debate about helicopter operations and heliport development in London, the use of heliports in New York and sightseeing tours of the Grand Canyon. The problem of helicopter noise in connection with heliport operation and community response has been reported recently in Rotor & Wing (1) and Helicopter World (2). At first glance such opposition is difficult to understand because most helicopters generate noise levels considerably below the internationally agreed certification limits and comfortably meet established community noise rating criteria and guidelines. The inference here is that even relatively sophisticated noise rating methods based on complex objective measurements fail to account adequately for the disturbance caused by helicopters. It has been suggested that the noise criteria or limits associated with the community rating procedures should be lowered. Although some minor adjustments to the assessment criteria may be helpful, careful analysis of the problem suggests such action will have little or no direct effect on the level of public acceptance. This point is significant because various national authorities and some industry observers believe a reduction in absolute noise levels should be the main focus in finding a solution to the problem of making helicopters more acceptable to society in general. Indeed, it is clear that public acceptance of helicopter noise is not wholly reflected either in conventional community rating procedures or helicopter noise certification. This may seem odd because these same rating methods are used successfully for controlling the environmental impact of large commercial aircraft and other forms of transportation such as road and rail traffic. The fundamental question addressed by this paper is what is different about helicopters and what should be done to improve the level of public acceptance? In reality the problem is two-fold. First, what singles out helicopters for special attention? Second, by what means can helicopter noise levels observed on the ground be made more acceptable?

2. SOCIAL SURVEY RESULTS

From a review of case histories, press reports and information collected by industry associations, it is fairly clear that helicopters and heliports in many locations enjoy only a low level of public acceptance. This was put into perspective when the results from a number of studies connected with the operation of helicopters in the United Kingdom was reported in 1993 by the Civil Aviation Authority (CAA) (3). Figure 1, reproduced from that study, shows annoyance as a function of *noise level* expressed in terms of Leq (16hr) dB(A). Data were obtained by the CAA in the 1982 survey along the route of the Gatwick-Heathrow Airlink service (no longer operating) and at Aberdeen, Scotland, the major base for offshore oil industry helicopter operations in the North Sea.

Figure 1 shows that, relative to air transport (fixed wing) aircraft, helicopters within the London area are considered up to 15dB(A) more annoying at the 10% and 20% *Very Much Annoyed Level.* It will also be observed that general aviation aircraft are rated approximately 5dB(A) more annoying than larger aircraft. The helicopter results contrast with those obtained in Aberdeen which show no difference to fixed-wing aircraft. Ollerhead (3) has suggested this disparity in reaction can be explained in socio-economic terms: "better off people tend to be more annoyed". Moreover it was believed that residents under the Airlink were disposed less favorably towards a helicopter shuttle service which was being used largely by first class passenger, whilst in the Aberdeen area, North Sea oil operations contribute significantly to the local economy. In drawing such conclusions it is important for there to be no difference in the source of annoyance. The Gatwick-Heathrow Airlink measurements would have been dominated by the noise of the Sikorsky S61 used for the service, although other helicopters used the same route. In the Aberdeen

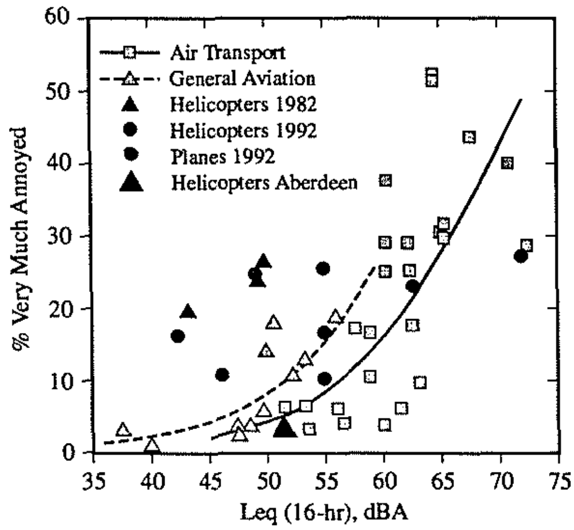


Figure 1
CAA Social Survey Results

region, operations include large numbers of the Sikorsky S61, and Eurocopter Super Puma aircraft (65%), together with Sikorsky S76, Eurocopter AS365 Dauphins and other types. Thus in both cases the characteristics of the acoustic environment were influenced heavily by large, acoustically non-impulsive helicopters. In 1992 a small scale study was performed by the CAA in London at Fulham, Putney and along the River Thames in the vicinity of Battersea and near the London Helicopter Routes: these locations are affected to some extent by overflights of aircraft landing at Heathrow. To a first order the results are similar to those for the Gatwick-Heathrow Airlink evaluated 10 years earlier (see Figure 1). The London flights were largely dominated by the corporate market using light/medium helicopters with a large proportion of Bell Jet Ranger and Long Rangers and Eurocopter Dauphins with some Sikorsky S76s and a few larger helicopters. Studies carried out by the Greater London Council some time ago confirmed an underlying concern from many of the residents about noise and safety of helicopters.

Comments similar to those made in London are a common thread whenever helicopter complaints are examined and are clearly a significant factor when attempting to quantify a *quiet helicopter.* The implications are that helicopter noise levels need to be much lower than those for fixed wing aircraft for a similar level of annoyance or acceptance. An alternative view would be that annoyance caused by main rotor/tip vortex interaction (BVI), main rotor wake/tail rotor interaction (TRI), and tail rotor noise is largely ignored by conventional rating procedures. In fact, an underlying dislike of helicopters and the additional annoyance due to certain transient characteristics of rotor noise are both important as discussed in this paper.

With reference to safety, it should be noted that members of the public may be generally unaware of the helicopters ability to land safely in the event of engine failure and do not realize that many helicopters - particularly those used in Europe over city environments - are twin engine and can fly with one engine inoperative. The connection between noise and safety is perhaps not immediately obvious but studies have shown that concerns about safety play a significant part in people's attitude towards helicopters which, of course, has a direct bearing on the level of acceptance.

Another common theme expressed by the public is that helicopters generally fly in an uncontrolled manner and the national authorities have little or no power over the flight paths/heights used. This is not true, particularly in metropolitan environments, but such misconceptions seem to be routed deeply. This was confirmed in a 1987 study for the American Helicopter Society (AHS) (4) which stated that the *"perceived intrusion of the helicopter into one's living space as evident by low flying is a significant negative factor"*. Another important issue is that of the low flyover height used by many helicopters, particularly in the USA. In this context, a study made in Hawaii a few years ago as a result of the anti-tour helicopter lobby (5) states that people in rural areas feel that *"their home's privacy was invaded by helicopter flyovers"*. From these and other statements there appears to be a strong commonality in the response to helicopter noise irrespective of location or county being considered. Such assessments also suggest that there is a strong relationship between the number of flights and the level of annoyance with Reference 5 suggesting an upper limit of just four or five flights per day before the annoyance becomes unacceptable.

The situation is further complicated in practice because the general public in many areas experience helicopter noise both from military and civil vehicles and in some areas, particularly the larger cities, helicopters used by the police. Military helicopters and those used by law enforcement agencies are not subjected to the same constraints as those operated by the civil sector. From a public viewpoint annoyance is a combined effect so that they simply place all helicopters in one category, although there is some evidence that people are more tolerant to helicopters used by the police. Some locations are also exposed to Helicopter Emergency Medical Service (HEMS/EMS) operations and while there is normally less resistance to such use, noise at hospital heliports is still a significant issue in the U.S.. Indeed it was reported at the HAI Heliexpo 1996 meeting, that development of a hospital heliport in California was abandoned because of objections by the public on noise grounds. In this context it is worth noting that although EMS operations involve life threatening conditions, the majority of such flights are hospital-to-hospital transfers, etc. which do not have the same level of public acceptance.

4. RATING OF COMMUNITY RESPONSE

The external noise signature of helicopters is the result of a number of complex sources acting together. Most of the acoustically dominant sources are aerodynamic in origin so that the relative strength of each and, therefore, the overall signature heard on the ground depends on a number of factors. Despite a high degree of variability, helicopter noise exhibits certain characteristics peculiar to the vehicle which make it readily identifiable even at quite low levels. It is these characteristics which, 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. In order to be truly effective, any form of noise assessment must be based on units which in some way reflect subjective response to the noise being controlled.

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) to account for both the noise level of individual events and the number of occurrences in a specified period. The length of the integration period in relation to the duration of typical helicopter overflights means that the maximum A-weighted noise level of the helicopter can be nearly 20dB(A) above ambient 64 times per day before there will be any real public concern forecast by the rating method. Even higher differences between maximum noise level and ambient would be rated as acceptable if the number of flights was lower. This type of analysis may be applicable to the large number of operations which occur at a major airport. The authors suggest it is less satisfactory when the number of flights per day is relatively low and/or the difference between the background level and the maximum noise level of the helicopter is large. This effect is illustrated in Figure 2 which shows a section of a A-weighted time history over a 4-hour period with four helicopter flights. Based on the Leq (16hr) analysis, the integrated value is virtually independent of the short term transient helicopter noise peaks even though such occurrences would be noticeable and probably considered to be annoying. It is the opinion of the authors that the failure of exisitng rating methods to properly account for the most intrusive types of helicopter noise explains, at least in part, why rotary wing aircraft seem to attract special attention.

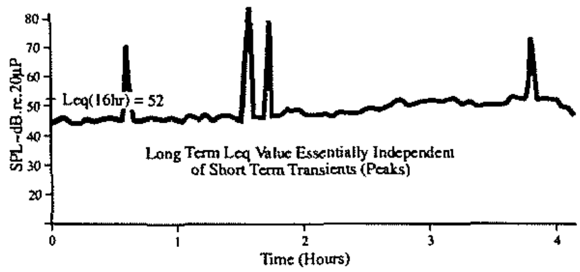


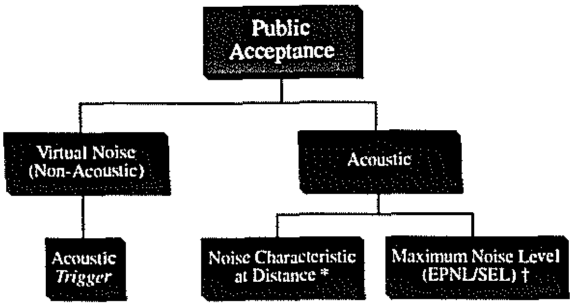
Figure 2
Community Noise Levels

5. PUBLIC ACCEPTANCE

Community noise rating procedures predict the impact of fixed-wing aircraft noise around airports and within local communities relatively well. This is not the case for helicopters and heliports which appear to be treated very differently by the general public. The question is why should this be so? Clues can be found by considering the differences between aircraft types. Fixed-wing aircraft operations typically involve a large number of flights per day and, because the noise characteristics of most of the large jets are similar, the noise climate is relatively uniform. Away from airports aircraft overfly at high altitude and there is little general concern over aircraft safety. Helicopter operations are very different. In general, the number of operations per day even near a busy heliport is relatively low and very variable in nature. Flight paths, unlike those used by fixed-wing aircraft, vary widely and so at any one location the noise pattern is much less consistent. There is also a very large difference in both level and, more importantly, the character of noise created by different helicopters with some small helicopters *sounding* noisier than larger ones. Overflights are generally made at relatively low altitudes so that any concerns over safety are heightened.

5.1 Annoyance Stimuli

From a study of the various factors involved, the level of public acceptance can be considered to be a function of both acoustic (direct) noise and a non-acoustic element, termed *virtual noise,* as illustrated in Figure 3. The acoustic noise response is a function of maximum noise level as defined by objective measurements and, more importantly in this context, the subjective characteristics of the noise as it first becomes audible. The magnitude of the non-acoustic component is not related directly either to the absolute level or to the character of the noise generated by helicopters, but it is *triggered* by the acoustic signal. In addition, the annoyance or level of public acceptance is usually quantified using measured noise levels as illustrated in Figure 1. Consequently the *virtual noise* element is treated, for all practical purposes, in the same way as noise radiated by the helicopter. *Virtual noise* is dependent on a wide range of inputs but is triggerd initially by any peculiar characteristic of the acoustic noise and, to a lesser extent, the absolute noise level.



* Trigger for Non-Acoustic
† Certification Value

Figure 3
Elements of Public Acceptance

It cannot be stressed highly enough that whenever adverse reaction to helicopter operations results from *virtual noise*, attempts to address the problem by reducing *acoustic noise* at source will be largely ineffectual.

5.2 Acoustic (Direct Noise) Stimulation

A generalized sound pressure level time history of a helicopter flyover expressed in subjective units such as dB(A) or PNdB is illustrated in Figure 4. The figure shows the effect of high levels of tail rotor noise, main rotor wake/tail rotor interaction noise (TRI) and main rotor/blade vortex interaction noise (BVI) on overall noise levels. It will be noted that when measured in conventional subjective units, the form of the time history will be similar whichever of these sources is predominant. Moreover, since all three generate similar noise levels, there will be little change in the time history even if one or two of the sources is pronounced at the same time. The directional characteristics of BVI are such that it has little influence on the maximum noise level which occurs close to the overhead position. TRI or high levels of tail rotor noise can affect the maximum level, but experience suggests the influence is no more than 5dB(A) as shown in Figure 4. More importantly, it can be seen that the greatest effect of the intrusive sources on measured noise level occurs more

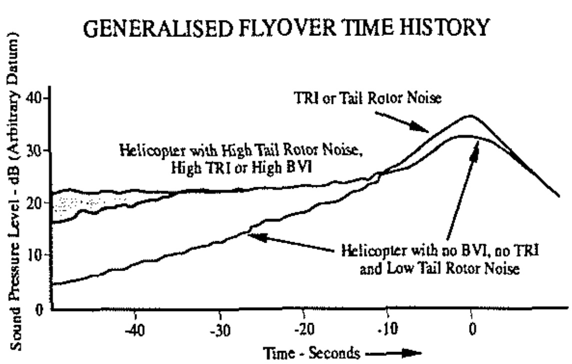


Figure 4

than 10dB(A) below the maximum value so they will have little or no influence on time integrated units such as SEL and EPNL.

Assessments conducted in London and Los Angeles by GKN Westland Helicopters together with information in the files of the Helicopter Association International (HAI) and general experience and knowledge in the industry makes it clear that the subjective impression created by these additional sounds is very important when considering public acceptance. It is not simply that levels of sound at distance on approach to the observer are higher than on designs with no noticeable tail rotor, TRI or BVI noise. Rather it is that the *tonal* and *impulsive* characteristics of these sources are in themselves more annoying and draw attention to the helicopter. If a tone or whine - akin to the sound generated by the tail rotor - is present in a noise signal, some rating criteria apply a +5dB or +10dB penalty to account for the extra disturbance. Many researchers argue that EPNL - and by implication the SEL or Leq. units - give a realistic measure of both the source level and public response, implying that any increase in the sound associated with BVI, TRI and tail rotor noise is accounted for in full.

The topic of subjective rating was researched heavily in the late 1970s and early 1980s (References 6 to 11). One objective was to develop an impulsive correction which could be added to more conventional metrics to account for the subjective effect of BVI and tail rotor noise. Despite the considerable effort expended, the results of these studies in combination were largely inconclusive. After an extensive review of all the issues, ICAO chose in 1983 to use EPNL (Effective Perceived Noise Level) for helicopter certification, with the proviso that manufacturers *strive to eliminate intrusive noise sources*. This decision was based largely on the assumption that the presence of impulsive components in the signal would increase the duration of the noise, thus automatically increasing EPNL.

Whilst this argument is at least partly valid, it is apparent that both the level and character of sound audible at distances greater than those involved in EPNL calculations play a major part in the rating or acceptance of helicopter noise. The tonal and impulsive quality of sound 15 to 25dB(A) below the maximum noise level observed during any single event can influence the subjective response. It would appear that when the degree of blade vortex interaction, tail rotor interaction and/or tail rotor tonal noise is pronounced these distinctive sources act as an audible cue, increasing the negative response to helicopter noise. These low level *triggers* are not accounted for in EPNL or SEL calculations which account for acoustic energy only within 10 dB of the peak value.

5.3 Non-acoustic (*Virtual Noise*) Stimulation

The studies based on U.K. data, supplemented by information from other locations including that associated with the Airspur operations in the Los Angeles, California area in the early 1980's, show that the *noise characteristics* and *virtual noise* are equally or more important than the measured noise level. It is difficult to ascertain precise values for each because they are partly interrelated. For example, a helicopter generating BVI noise may cause annoyance directly, while at the same time acting as a trigger to highlight public opposition to some other aspect of the operation. The data suggests that sounds such as tail rotor 'whine' or BVI noise also exacerbate concern over safety because either may signal (falsely) mechanical failure. Taking this argument to extremes, a helicopter which generates low but perceivable levels of tonal or impulsive noise, flying over an area where the public have major concerns on helicopter safety could create the same negative response as one with high levels of tail rotor, TRI or BVI operating over communities which are generally more tolerant of helicopters.

In the context of this evaluation it has been found that general aviation light propeller driven aircraft create a similar impact - at least in Europe. Research reported to ICAO (12) based on studies conducted at the University of Southampton Institute of Sound and Vibration Research (ISVR), (13) has shown that a number of complaints attributed to light aeroplane noise are, in fact, related to other causes. This research attempted to classify complaints and to quantify the effect in terms of the equivalent A-weighted sound pressure level with the following results:

a)	negative reaction to leisure flying	5dB(A)
b)	poor community/airfield relations	10dB(A)
c)	fear of crashes	10dB(A)
d)	nobody acts on complaints	20dB(A)
e)	aircraft are flying too low	20dB(A)

It should be noted that these equivalences are not reversible, so that, for example, a reduction in noise level of 10 dB(A) will not remove the fear of crashes.

While it has not yet been possible to determine similar equivalence factors in such a precise manner, the concept appears equally applicable to helicopters. The main difference being that the first of the non-acoustical factors - negative reaction to *helicopter* flying - appears to be stronger than for GA aircraft and may be as high as 15dB(A) at particularly sensitive locations. This is because helicopters are often perceived by the public to be engaged either in leisure flying or operating for no justifiable reason. As explained previously, however, if it is believed that helicopters provide a worthwhile service, as in the North Sea, the *virtual noise* factor can be very low or zero. Similarly, the concern over safety and fear of crashes in areas where flights are conducted over precise routes under air traffic control may be much less. Experience from Aberdeen, Scotland, where helicopters have become accepted much in the manner of large fixed-wing transport aircraft, tends to support this view.

Amongst the non-acoustic sources associated with airfield related disturbance, the work reported in Reference 13 found that fear of crashes was the most significant factor. Low flying, changes in the engine noise signature, and previous crashes increased anxiety. At one airfield where an accident had occurred shortly before the survey, concern was almost three times greater.

It is also interesting that while the ISVR study (13) was made at general aviation airfields dominated by light propeller driven aircraft, there was some helicopter traffic at one of the airfield sites. Examination of the results obtained indicates similar trends for both general aviation fixed-wing aircraft and helicopters, but it is difficult to be specific because the survey did not set out to highlight differences between helicopters and other forms of air traffic. A review of other evidence however, suggests these light aeroplane findings are generally applicable to helicopter operations.

5.4 Subjective Considerations

The study reported this paper has shown there is a need to consider the *character* of the sound heard by an observer, as well as the absolute noise levels. It is extremely difficult to quantify the effect of particular sounds on individuals in terms of a subjective weighting, but studies by Westland Helicopters suggested values of 4 to 6dB(A) and 6 to 9dB(A) should be added to measured levels to account for signals with high levels of tail rotor noise and high levels of impulsive (BVI) noise respectively (8,9). These values compare well with the quantitative results determined from the review reported here.

When the information available was examined initially, a number of observations could not be explained. Further analysis shows that if an operation involves a mixture of helicopters with high levels of BVI, TRI and/or tail rotor noise and those without such sources, the least acceptable will tend to drive the level of public acceptance. Thus a few *noisy* aircraft can create adverse response which will then affect all helicopters. If the number of operations of noisy helicopters is very low, however, this may not always be the case. In Aberdeen, Scotland one type of helicopter which generates high levels of impulsive noise (BVI) is known to provoke adverse public response, but because of the small number of daily flights associated with this vehicle and the careful selection of routes, it does not appear to influence the overall positive level of public acceptance.

6. PUBLIC AWARENESS

The level of helicopter noise relative to the ambient or background value is an important factor when addressing public acceptance, because it determines the significance of the *acoustic trigger* heard by the observer. This is illustrated in Figure 5 which shows the generalized dB(A) flyover time history (Figure 4) with various background noise levels. In this context the ambient noise level is that actually being experienced by the observer and not the general value associated with the locale. If a residence is located in a busy urban area, for example, near a major road it is often assumed that the ambient noise levels will be relatively high. This may be the case at the part of the property facing the road, but as illustrated diagrammatically in Figure 6, the area facing away from the direct path of the traffic noise will be shielded and relatively low levels can exist. As a result, even in urban and city areas, many residential properties are located where ambient noise levels are low and it is this environment that is relevant. Conversely, the acoustic

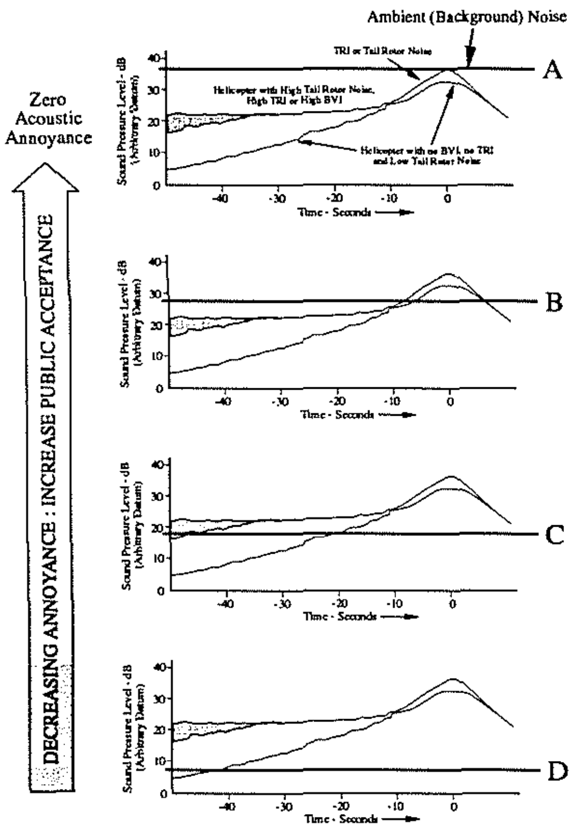


Figure 5
Effect of Background Noise Level

signal from the helicopter is unshielded and radiates directly on to the property. This is particularly significant for low altitude level flyovers where the impulsive BVI and tail rotor noise are both radiated forward and can be at such a level that for a significant period of time only these intrusive sounds are audible.

There appear to be some situations where the relative levels of the helicopter and ambient noise are such that the helicopter cannot be heard and yet there is some resistance to operations. It would seem that in these situations the trigger for the *virtual noise* is visual. The surprise of suddenly seeing a helicopter has been

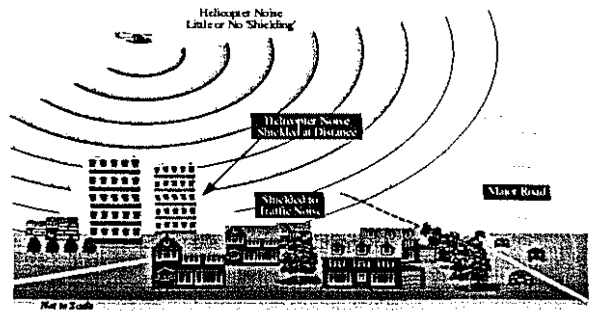


Figure 6
Effect of Shielding on Community Noise Exposure

commented on a number of times by the general public. The number of occurrences when the *visual trigger* is significant, however, appears to extremely small and it is not addressed further in this paper

7. NOISE REDUCTION AT SOURCE

The helicopter 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*. The only exception being piston engined aircraft in which case noise from a poorly muffled engine may be a nuisance. The inevitable consequences are that the noise characteristics of a given type are established almost completely once the main and tail rotor configurations and their relative position has been decided. 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 a number of conflicting requirements. Unfortunately, simple physical considerations show that the design parameters which are most effective in reducing rotor noise also have the greatest influence on performance. Indeed, while purely acoustic considerations suggest low blade tip speed, conversely 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. Thus, although reducing noise will come at the expense of either performance, operating costs or research activity (none of which may be palatable), 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 interrelationship between the various helicopter design parameters is illustrated in figure 7. The rationale behind the figure starts by assuming main rotor tip speed has been reduced to improve noise. To maintain performance, blade area has been increased to recover rotor thrust capability, either by adding more blades of the same type or by changing the dimensions of the blade. In either case, further alterations to the aircraft will be necessary to accommodate the changes. Additional blades, for example, will require a more complex rotor hub while increasing 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 likened to an explosion radiating outwards from the initial modification as more and more factors come into play.

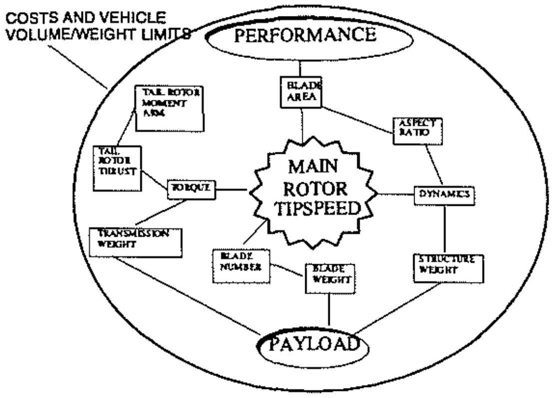


Figure 7
Effect of Design Changes

For a completely *new* design this process of optimization can continue until it is constrained either by technological boundaries or by cost and vehicle volume/weight limits. For *derived versions* of existing aircraft the freedom of choice before costs become prohibitive is more restricted so that the level of noise reduction achievable without penalties is significantly smaller.

Practical design improvements to reduce noise are centred currently on BVI noise during descent and tail rotor noise which, arguably, are the biggest sources of complaint about helicopter noise directly and also the main triggers for *virtual noise*. The problem of BVI noise is being addressed both by passive tip planform modifications including the GKN Westland Vane Tip (14) and by active blade control systems such as active flaps, higher harmonic control (HHC) and individual blade control (IBC). 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 6dB(A) in this area. In the light of these undoubted benefits it is, however, easy to overlook the fact that if an aircraft is not operating under BVI conditions, i.e. during noise abatement approaches or in level flight, little or no reduction in noise will actually occur. In cases when the approach technique avoids BVI, *operational* advantages may therefore be small.

At this point it should be remembered that the noise certification approach flight condition (6° descent at minimum power airspeed, Vy) was adopted because it captures the maximum BVI noise levels. Consequently, much of the research on passive palliatives, higher harmonic control and individual blade control will be most effective at 6°/Vy. This combination of rigidly stabilized airspeed and fixed glide slope is not used in *normal* descents which commonly employ varying descent angle and decelerating airspeed. Tests flights have shown that noise levels encountered during normal approach procedures are, depending on aircraft type, between 1 and 10dB(A) lower than those measured at 6°/Vy (15). Thus, although contemporary research will probably lead to lower *certification* levels, noise levels on the ground under normal operating conditions may show little or no improvement over the quieter helicopters of the present generation. The real benefit comes in terms of expanding the area of the operating envelope in which noise levels are acceptable.

The importance of tail rotor noise, in terms of both overall noise level and subjective character has been appreciated by some manufacturers for over 20 years. Westland Helicopters developed a quiet tail rotor (Q.T/R) for the Lynx and Westland 30 in the late 1970's. The basic methodology is illustrated in Figure 8 while the effect of the revised tail rotor on a Lynx narrow band spectrum is shown in Figure 9. The concept of balancing the perceived *noisiness* of the main and tail rotors has been applied subsequently to the EH101 (16). The development of the NOTAR series of helicopters by McDonnell Douglas was based on the U.S. Army desire to reduce the detectability of small helicopters. Here the solution has been to remove the tail rotor source completely (17). This technique cannot be applied to large helicopters for a number of design and operational reasons. It should also be noted that with careful attention to detail the acoustic characteristics of a conventional quiet tail rotor can be just as acceptable as NOTAR (16). The *fenestron* fan-in-fin solution adopted by Eurocopter, has also reduced the impact of tail rotor noise. Although early applications of this technology introduced a high frequency whine, recent modifications using unequal spacing of the rotor blades

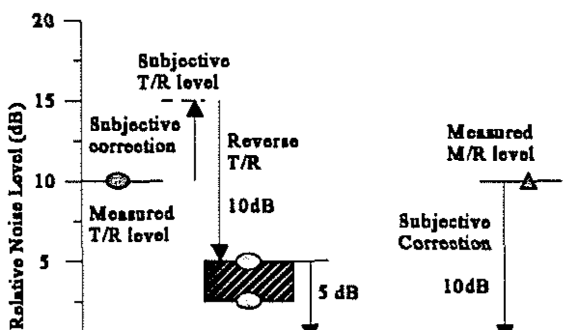


Figure 8
Tail Rotor Balanced Source Concept

and non-radial stators have reduced this problem and under most flight conditions, it offers improvements comparable to NOTAR and Q.T/R (18). Again, however, structural, dynamic and aerodynamic limitations restrict fan-in-fin technology to low and medium weight helicopters.

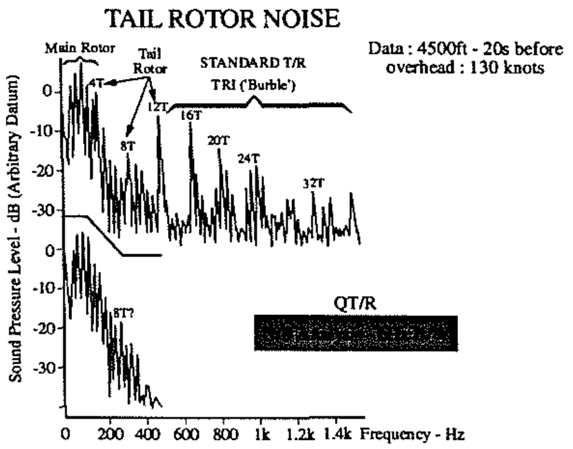


Figure 9
Lynx Tail Rotor Noise Spectra

It is interesting that the majority of papers dealing with noise reduction associated with the various NOTAR, Fenestron and conventional low noise tail rotor solutions such as that applied to the Sikorsky S76 (17,18,19) concentrate on overhead noise levels and reductions expressed in EPNL and SEL metrics. In fact, the main acoustic advantage of these anti-torque systems is the change in the character of the sound as the aircraft flies towards an observer which explains much of the perceived noise improvement achieved by NOTAR.

8. INCREASING PUBLIC ACCEPTANCE

8.1 Operational Impact

The helicopter industry often assumes that because BVI is generated primarily in descending flight and because it is the noisiest of the noise certification test conditions, approach to landing is the main problem with public acceptance. It is for this reason that much of the noise research undertaken currently is directed at eliminating, or reducing BVI. The level and character of noise generated during this condition is undoubtedly important and is a major aspect to be addressed when considering operations at a heliport. An examination of noise complaints in mainland Europe, the United Kingdom and the USA, however, shows that overflight or flyby noise causes the most problems because far more people are exposed to the noise.

The level of noise *en route* can be controlled simply and effectively by operating at greater heights above the ground. There is less flexibility in the control of noise during approaches to landing sites, although noise abatement techniques are effective and should be employed. Takeoff is much less of a problem because the main rotor is climbing away from its own wake so BVI does not occur and tail rotor noise (and TRI if it is present) is less pronounced than in cruise flight due to lower flight speeds. Consequently, flyover and approach are the areas of greatest concern from a public acceptance perspective, with the former being the more important of the two.

The *virtual noise* element must be minimized or eliminated to gain public acceptance. To this end, flights should be conducted whenever possible so that the acoustic level of the helicopter never exceeds the typical background level (Figure 5A). If this cannot be achieved fully, the flight procedures and operating height above the ground should be chosen so that the helicopter noise exceeds the ambient level by no more than 10dB(A). This will lessen the subjective impact of BVI, TRI or tail rotor noise thereby reducing the level of *virtual noise* associated with the character of the sound. It should, however, not be overlooked that simply hearing the helicopter can still stimulate a significant reaction regardless of whether the sound is unpleasant or not.

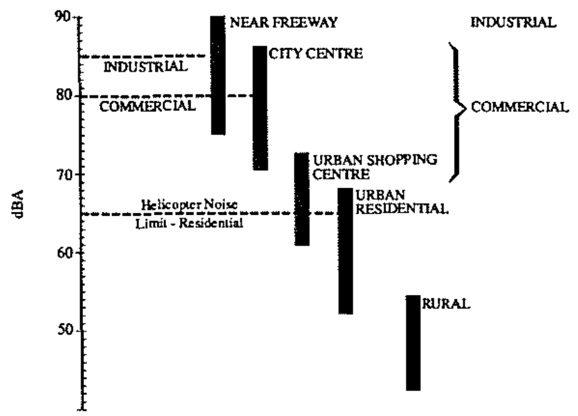


Figure 10
Typical Background Noise Levels

Typical ambient noise levels, expressed in terms of A-weighted sound pressure level are illustrated in Figure 10. Accepting that even within industrial and commercial areas relatively quiet areas exist, the authors suggest that in city environments noise levels from helicopters should not exceed 65dB(A) on the ground to minimize disturbance. The subjective characteristics of current helicopters have been taken into account in making this judgement. Nevertheless, it has to be a generalization because the actual level of perceived intrusion at a specific location is clearly a function of the helicopter to ambient noise ratio as shown in Figure 5.

8.1.1 Flyover

The level of *virtual noise* is dependent on the relative levels of helicopter and ambient noise so the flyover height above the ground must be increased as the background noise decreases as shown in Figure 11.

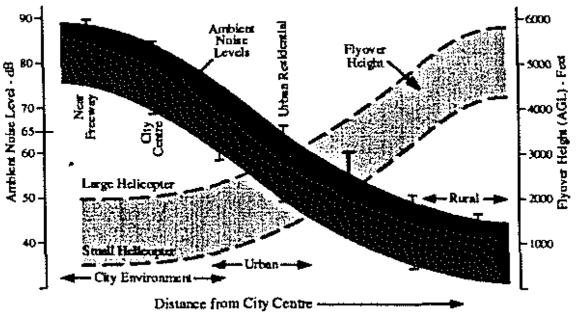


Figure 11
Flyover Heights and Background Noise Levels

Overall noise levels are, in general, a function of all up mass so that large helicopters need to fly higher than small ones to obtain the same level of public acceptance. In city areas this suggests flyover heights between 500ft and 2000ft while for flights over communities in quieter rural areas, heights of 4000ft to 6000ft are required for small and large helicopters respectively. If the typical area background noise level or community noise limit is known, the height can be estimated from charts such as those for the Robinson R22 (1370lb/621kg) and the larger E.H. Industries EH101 (32,188lb/14,600kg) shown in Figure 12. Also indicated is the 65dB(A) target noise level recommended by the authors. To achieve the desired public acceptance, flyover heights of 800ft and 3000ft respectively for the R22 and EH101 are required. In this context it is worth noting that the reduction in noise level is approximately 7dB(A) per doubling of distance so that noise levels on the ground will decrease by 14dB(A) if the flyover height is increased from 500ft to 2000ft. This compares with a potential 6dB(A) source noise reduction from noise research and a 6dB(A) reduction from flight procedures. Thus, increasing operating height, or slant range distance, is a powerful method for controlling noise. Moreover, except for the small increases in both flight duration and fuel consumed in climbing to the higher altitude, noise reduction obtained in this way is virtually *free of charge.*

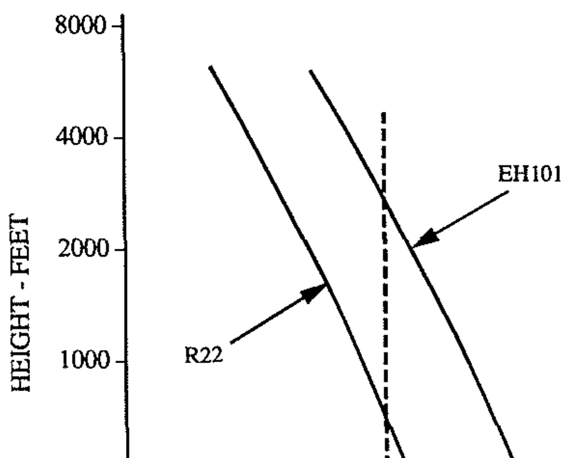


Figure 12
Effect of Flyover Height

The heights recommended by the manufacturers for various aircraft types and associated with specific operations, are indicated in Figure 13. It will be noted that although U.S. operations are typically flown at 500ft or below and many flights in Europe between 500 and 1000ft, most manufacturers recommend at least 1000ft, with the exception of Robinson and Hiller for the R22 and RH1100 respectively, who suggest use of 500ft.

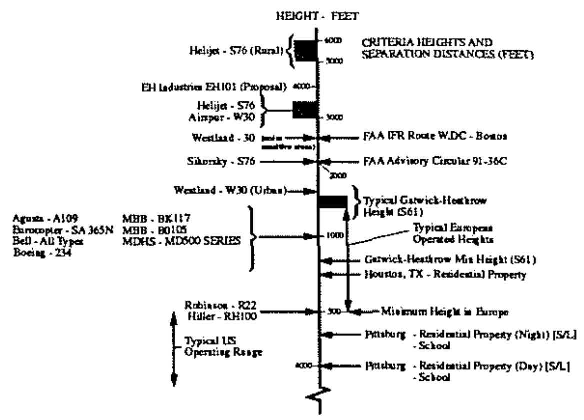


Figure 13
Recommended Flyover Heights

The flyover height recommended for the Westland 30 scheduled airline service operated by Airspur in the early 1980's for flights over noise sensitive areas was 2500ft. In this context it is worth noting that any residential property is essentially a noise sensitive area. This was true particularly in the Los Angeles area of California where Airspur operated, because many people have outside swimming pools, decks for sitting etc. Early Airspur operations conducted at approximately 1500ft provoked a strong public outcry. Subsequently, an increase to between 3000 and 3500ft was effectively forced on Airspur due to public pressure and as a result, opposition on noise grounds essentially ceased. Interestingly, there was evidence of residual *virtual noise* which some will say has continued to today even though the service ceased operations in 1984. It is also worth noting that the W30 was equipped with a Q.T/R and so there was little or no tail rotor, TRI or BVI noise during cruise flight.

Helijet Airways, who operate a schedule service between Vancouver, Vancouver International Airport and Victoria, British Columbia, Canada, have also found it necessary to fly high to obtain public acceptance. The service began by operating a Bell 412 at between 4500 to 5000ft in the summer months. This aircraft was soon replaced with a Sikorsky S76 and although 3500ft was adequate for flights over the city, the operators had to increase the heights to 5000 to 6000ft because of lower background noise levels over the rural areas in order, as Helijet states, *"for the complaints to go away"*, These heights agree well with those indicated in Figure 10. Obviously Helijet have limitations placed on the height both by air traffic control around Vancouver Airport, and as a result of adverse weather. The operators have therefore established a family of routes at different heights. During the winter months flights are made at much lower altitude - in the order of 2000ft to 3000ft, reducing to 1500ft under IFR. This does not cause too many complaints because few people are outside or have windows open during periods of cold or adverse weather. Ken Glaze, V.P. of Operations, has also stated publicly that for any scheduled helicopter operation to succeed it must have public acceptance and this means flying high whenever possible.

8.1.2 Approach/Landing

The work carried out in preparation of this paper has shown that the problem of heliport noise is not simply one of making judgements based on conventional noise metrics. Heliport location and routes into and out of the facility are critical. The flight paths should include areas having the highest levels of background noise or which are not noise sensitive such as rivers, major highways and railways. The importance of BVI, not only as a direct noise source but also because of the way in which it can influence the magnitude of *virtual noise*, is confirmed. It has already been established that the degree of BVI can be controlled by descent procedure (15). Variable segment approaches which increase the separation distance between the helicopter and observer, while at the same time decreasing the levels of the BVI, are essential.

The findings given in Reference 15 are supported by the results of flight tests carried out on the Sikorsky S76 and the MDHS Explorer reported more recently (20,21). The new data indicate that in the case of the S76, reductions in SEL measured under the flight path at a point 7000ft (2135m) before the helipad of up to 7.8dB(A) are possible (relative to the noise certification 6°, Vy approach condition). Similar studies using the MDHS Explorer have shown that the use of noise abatement approach flight profiles produces reductions in SEL averaging 3.5dB(A) over large areas located between 3000ft (914m) and 7000ft (2134m) from the helipad. The changes to the character of the noise are not stated in the report but it is reasonable to expect that BVI would decrease significantly. As a result, a substantial reduction in the *virtual noise* associated with such operations would be expected in addition to the reduction in the acoustic noise levels.

It follows that the location and layout of heliports should be chosen such that noise abatement procedures can be exploited to the full. Moreover, because public opinion can be influenced to a large extent by even a small number of noisy helicopters, it is essential that noise abatement procedures are employed by <u>all</u> aircraft using the facility. This applies equally to small, lightweight helicopters because although absolute noise levels are generally a function of all-up-mass, the characteristics of the sound and, therefore, intrusion can be somewhat independent of size.

8.2 Reduction of *Virtual Noise*

Virtual noise can be eliminated by removing completely the stimuli by which it is triggered. This ideal is normally not achievable at heliports so the aim should be to minimize the effect as far as possible. The study reported here has confirmed that the public have major concerns over safety issues and often do not always understand the need for helicopter operations. Equally, the helicopter industry often underestimates the level of public apprehension and fear of accidents. Difficult situations are compounded if the community regard responses to complaints as either unsympathetic or dismissive. Problems exacerbated by a lack of diplomacy or tact mean that this *virtual noise* element can be equivalent to 15dB(A) or more.

Even with action to understand complaints and associated concerns, the industry will still be faced with two major issues. Firstly the fear of accidents and secondly, a lack of appreciation by large sections of the population of why helicopters are required. These *virtual noise* elements, which evidence suggests can amount to 15- 20dB(A), can be resolved only by publicity campaigns. It is unlikely that these two issues can be tackled piece meal by individual operators so that the combined efforts of the European Helicopter Association (EHA), the American Helicopter Society, HAI and other associations and societies worldwide are required. The HAI Fly Neighborly programme, targeted at reducing nuisance by encouraging the use of noise abatement procedures, has shown that such concerted action can be very effective. Publicity aimed at highlighting the actual high levels of in-flight safety is also required if *virtual noise* is to be reduced. To achieve the desired reduction of non-acoustic sources the industry may, however, have to accept tighter operational control particularly in city environments.

Since it is such a strong component of public acceptance, there is great potential for improving the current situation if *virtual noise* can be reduced or eliminated by better public relations. A satisfactory situation in the broadest sense cannot be achieved until both sides appreciate and understand the concerns and needs of each other. The industry for its' part must identify noise sensitive sites and alleviate problems by re-routing, increasing flyover heights, and revising operational procedures to resolve local noise issues.

If a concerted effort is made by the manufacturers and the industry associations, the non-acoustic component could be reduced dramatically over a 2 to 3 year period. Conversely, if no action is taken, evidence suggests *virtual noise* will remain a very significant factor in determining the level public acceptance to helicopter operations.

9. CONCLUDING REMARKS

The reaction to helicopters and heliports is dependent on several factors, some of which are completely unrelated to helicopter noise. These non-acoustic phenomena described collectively as *virtual noise* are usually triggered by acoustic noise although there is some evidence of a visual trigger. The non-acoustic component can dictate the level of public response to helicopters under certain circumstances.

Public acceptance of helicopters can undoubtedly be improved by reducing the level of tail rotor noise, tail rotor interaction noise and BVI as demonstrated by the latest advanced technology rotorcraft. A reduction of these sources decreases annoyance, not only by reducing the noise nuisance directly but also by alleviating the level of *virtual noise*. Nevertheless, the only sure way to increase public acceptance to a level which will allow industry to expand operations is to operate helicopters when ever possible in a manner which either reduces noise to the point at which it is inaudible or minimizes the annoyance factors This can be achieved *en route* by flying (subject to air traffic or other limitations) at heights much greater than those employed currently. Typical route heights in the region of 2000ft to 3000ft above city areas and up to 5500ft over rural areas, where ambient noise levels are much lower, are desirable.

The problem of heliports is more difficult to solve but if locations are chosen carefully and routes directed over high noise corridors such as railway tracks and highways or over non-noise sensitive areas, considerable improvements in public acceptance can be achieved. The use of noise abatement procedures such as multi-segment steep approaches to reduce the level of BVI and minimize footprint areas is essential. In this context it should be remembered that non-acoustic effects are also very important. *Virtual noise* can be decreased by increasing public confidence in helicopter operations, showing the need for such operations and resolving concerns over helicopter safety.

If the actions outlined in this paper to address the perceived environmental impact are implemented, public acceptance of helicopters should reach the levels enjoyed by other forms of transport permitting expansion rather than contraction in usage of this most versatile flight vehicle.

ACKNOWLEDGMENTS

Some of the work reported in the paper was conducted as part of the GKN Westland contribution to the HELISHAPE research project funded by the EC under the BRITE/EURAM aeronautics programme. The views expressed in this paper are, however, those of the authors and do not necessarily reflect those of GKN Westland Helicopters Ltd., GKN Westland Helicopters Inc., E.H. Industries Ltd., or E.H. Industries Inc.

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