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THE ENVIRONMENTAL NOISE IMPACT OF LIGHT AIRCRAFT: A METHOD FOR COMPARING DIFFERENT LIGHT AIRCRAFT TYPES

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1. INTRODUCTION

Traditionally aircraft noise annoyance is based on the comparison of noise level and the subjective response. Figure 1 is a good example and was produced for the "Wilson" report on Noise[1]. At that time the emphasis was on jet aircraft noise and therefore the annoyance scores were compared in terms of both PndB and dB(A), as shown in Figure 1. More recently, the WHO has published guidelines[2] which suggest that few people are seriously annoyed during the daytime at noise levels around 55 dB LAeq. Whilst, again, this is a level/subjective response the guidelines go on to define noise annoyance as "a feeling of displeasure evoked by a noise". This definition can include a range of physical characteristics which cannot be described directly in terms of the sound level. Light aircraft and microlight aircraft, when they can be measured above the background noise, typically produce a sound level on the ground of 50-60 dBA. However, light aircraft, and particularly microlights, generate a large number of complaints, out of all proportion to the sound level produced. The reason for this is that they tend to generate annoying tones, often being described as "lawnmowers in the sky". Military light aircraft operate at low and medium level altitudes and create a unique sound which can be present for long periods.

Internationally, the noise nuisance from light aircraft is increasingly being recognised and is likely to be included in future EC directives on environmental noise. The Royal Air Force operates a large number of light aircraft and powered gliders for preliminary and air familiarisation training, often from small grass airfields which are surrounded by village housing. This type of training involves a great deal of "circuit" flying, which can result in complaints. The effects of aircraft noise can be reduced either by reducing the level of the noise at source or by the application of operational criteria and regulations, ie management of the aircraft operations in a more sympathetic way. The Royal Air Force operates the "Good Neighbour" principle which primarily concentrates on the impact of its activities on the general public. The Royal Air Force applies this principle to the management of all aspects of light aircraft at its bases, including operational management and procurement of new aircraft. The recommended operational management of noise complaints has been described by Kerry[3] in a paper presented at Internoise '97. One of the recommendations[4] was that aircraft procurement procedures should include noise specifications as well as the more usual parameters, such as performance. This paper describes a method used by the RAF Institute of Health to select a "quiet" aircraft as part of a procurement procedure.

2. EFFECTS OF AIRCRAFT NOISE

The environmental impact of aircraft operations is mainly due to noise intrusion. Noise affects people in many ways, eg annoyance (displeasure or resentment), aggravation, loss of concentration and sleep disturbance. These effects are subjective, especially at sound levels which are just above the threshold of noise annoyance. The four factors which contribute to these effects are listed below:

a. Noise level produced by the aircraft, ie loudness.
b. Number of flights per day over any one particular area.
c. Time of the day when flights occur, ie daytime or night time.
d. The frequency content of the received noise; whether low, high, broadband or tonal.

3. ASSESSMENT PROCEDURE

Since the assessment procedure was to be used in a light aircraft procurement trial, selection was not based purely on a "silence" criteria. However, it did concentrate on the procurement of an aircraft which would be "quieter" than the currently operated aircraft and on the selection of the aircraft which would be most likely to be acceptable in terms of its environmental impact. A rank ordered marking scheme to assess the relative loudness/nuisance level of each aircraft for four separate parameters was designed. These parameters were:-

a. Noise levels of the aircraft.
b. Determining the SPL of the blade passing frequency.
c. The overall frequency content of the noise.
d. A subjective assessment of various "common" flight conditions (listed in Table 1).

The marks given to each parameter ranged from 1 to 6; where an award of 1 represented the quietest or least annoying aircraft and 6 represented the loudest/most annoying. Thus, the cumulative score indicated the nuisance level for each aircraft. It should be noted that this marking scheme was only a rank order for each assessment and did not represent the actual loudness/nuisance level.

4. MEASUREMENT OF AIRCRAFT NOISE

When conducting an assessment of the noise nuisance of an aircraft both the noise level and the frequency content are important and the parameters outlined above are used in the assessment process. Therefore, in order to record the noise levels of the various aircraft types accurately measurements must be recorded under controlled conditions using a central flight line, as shown in Figure 2, and the flight conditions listed at Table 1.

Table 1 - Flight Conditions

Condition No	Manoeuvre
1	Power Take-Off
2	120 Kts Altitude 250 feet
3	Max power Altitude 250 feet
4	120kts Altitude 500 feet
5	Max power Altitude 500 feet
6	Downwind power Altitude 800 feet
7	Max power Altitude 800 feet
8	100kts Altitude 4000 feet
9	Max power Altitude 4000 feet
10	Aerobatics - Altitude 4000 feet: Duration 3 minutes
11	Simulated Forced Landing

The flight conditions reflect the typical flying operations carried out by light aircraft. The most common conditions are general circuit work at 800 feet above ground level (AGL), aerobatics at approximately 4000 feet AGL and, to a lesser degree, low level flying at 250 feet AGL.

To ensure the validity of the measurements, two video tracking cameras are used to record the height of the aircraft and the lateral offset of the flight path. The recorded distances were used to correct the propagation distance between the aircraft and the measurement locations, where required. Additionally, details of the local meteorological conditions were recorded to ensure the noise measurements were not being adversely influenced by the effects of wind and temperature inversion.

5. ASSESSMENT OF NOISE NUISANCE

The LAmax, LAeq, LAe and associated $^1/_3$ octave band frequency spectra noise indices recorded during the trial were used to determine the annoyance and nuisance characteristics of each aircraft by evaluating and comparing the assessment parameters.

Aircraft Noise Levels. The noise indices recorded during the trial are used to compare the noise levels of the various aircraft types. Using Table 2 as an example of the recorded noise level data, the LAe levels for the individual manoeuvres were summed for each aircraft. The lowest and highest were given marks of 1 and 6 respectively and the other levels were apportioned linearly between them.

Table 2 - Noise Level Data

Manoeuvre	Aircraft A (LAe)	Aircraft B (LAe)	Aircraft C (LAe)	Aircraft D (LAe)	Aircraft E (LAe)	Aircraft F (LAe)
Take-Off at 200m	88.2	86.4	78.9	87.9	86.9	94.5
250ft, Max Power at 0m	89.2	90.3	88.1	83.8	88.8	95.6
800ft, Downwind Power	67.1	75.2	67.0	70.9	75.4	77.4
800ft, Max Power	81.1	83.3	79.6	77.5	80.0	87.5

Blade Passing Frequency. To evaluate the contribution to the overall noise nuisance of the blade passing frequency a combination of blade frequency and corresponding SPL was used for the various power settings. Table 3 gives the typical specification for each aircraft type. Samples of the frequency content of an aircraft whilst operating at 800 feet AGL for both power settings are shown in Figures 3 and 4. The LAmax spectra correspond to the frequency content of the noise at maximum noise level. The spectra were examined at the blade frequency and its corresponding SPL was compared for the different aircraft types. A judgement was made based upon the dominant tone; the lower dominant frequencies were penalised.

Table 3 - Specification for Each Aircraft Type

	Aircraft A	Aircraft B	Aircraft C	Aircraft D	Aircraft E	Aircraft F
Engine hp	196	260	160	180	180	260
No of Blades	2	3	2	2	3	4

Overall Frequency Content. The assessment for the spectral content was arrived at by comparing the overall linear SPL levels for a variety of flight conditions. As shown in Figures 3 and 4, the majority of the sound energy of each aircraft is centred between 80Hz to 4kHz. The blade passing frequency can be seen in all aircraft spectra. The maximum power setting produced greater noise levels at the higher frequencies, which resulted in a more noticeable and distinctive sound. The spectra were then examined and compared for their low, medium and high frequency content. Factors which would penalise the marking process were high tonal content, excessive low frequency content and high engine/transmission noise. From these factors a subjective judgment was made between the aircraft types in the rank ordering process.

Subjective Noise Assessment. A subjective comparison was carried out by a panel of assessors who listened to recordings, under laboratory conditions, of the various aircraft types performing three different flight conditions; a power take-off measured at 200 metres from the flight line, level flight at 250 feet, maximum power, measured directly below the aircraft and general circuit work. The aircraft were rank ordered based on the subjective assessment of their intrusiveness, loudness and general annoyance character.

The individual assessments for each parameter were tabulated (Table 4) and the rank ordering was summed. The cumulative score indicated the nuisance level for each aircraft. Again, it must be emphasised that the scores are not an indication of the actual loudness/nuisance level.

Table 4 - Individual and Overall Assessments for each Aircraft Type

Parameter	Aircraft A	Aircraft B	Aircraft C	Aircraft D	Aircraft E	Aircraft F
Noise Level	4	5	1	3	2	6
Blade Passing Frequency	3	6	2	4	1	5
Overall Frequency Content	2	5	3	4	1	6
Subjective Assessment	1	6	1	1	1	5
Cumulative Total	10	22	7	12	5	22
Overall Assessment	3	5	2	4	1	5

Note: 1 = quietest/least annoying, 6 = loudest/most annoying

6. REDUCTION OF AIRCRAFT NOISE

Attenuation of noise levels at source will result in a reduction in the noise nuisance. However, attenuation can be achieved by the correct choice of aircraft, careful management of operations and by design modification of existing aircraft. The latter could include increasing the attenuation of the exhaust and increasing the number of propeller blades. As the majority of the radiated sound energy is centered around the blade passing frequency (1/60th of the engine rpm multiplied by the number of propeller blades) and its harmonics, by increasing the number of blades the SPL of the blade passing frequency will be reduced. Thus, the introduction of aircraft with 3 or 4 blades can lead to a reduction in noise complaints.

Blade Passing Frequency. The blade passing frequency is the key frequency component in the noise signature of any propeller aircraft. The tonal value is typically greater than 5dB(A) above all other frequencies. Therefore, it is the frequency that is the most obvious, and usually the most annoying, element of the aircraft noise. The SPL of the blade passing frequency is reduced by increasing the number of blades, resulting in an increased torque output, which in turn results in a smaller propeller diameter. The SPL and the fundamental blade passing frequency of the propeller can give an indication of the noise signature of the aircraft. For constant speed propellers, the blade passing frequency remains constant, regardless of engine speed, whereas fixed-pitch blades will change the blade frequency.

Subjective Noise Assessment. As with any subjective comparison of different noises, the results are dependent on the individual assessor's personal feelings about the noise, ie whether they felt "comfortable" or whether they were distracted by key elements, eg exhaust noise, or the tonal elements of the noise and, typically, buzzing type noises.

Non-acoustic Factors. A variety of non-acoustic factors can contribute to the annoyance of light aircraft. The effects of operational patterns, hours of operation, weekend flying during the summer months, irregular flight patterns, a larger number of circuit paths, slow flying speeds and generally lower background noise levels all contribute to the nuisance values of light aircraft. However, with correct management of these non-acoustic factors the nuisance element of the aircraft can be reduced.

7. CONCLUSION

The method described has been shown to be a good way of grading aircraft types but it is essential that the same operating and measurement methodology is used with each aircraft type being considered. Similar methods were used successfully in a recent selection process for a replacement military helicopter. The validity of the decision reached was confirmed by a subsequent environmental noise survey. As a result, manufacturers may be encouraged to concentrate on the noise aspects of aircraft design. However, better aircraft design does not absolve the aircraft operator from managing his fleet in a manner which results in the least environmental impact.

REFERENCES

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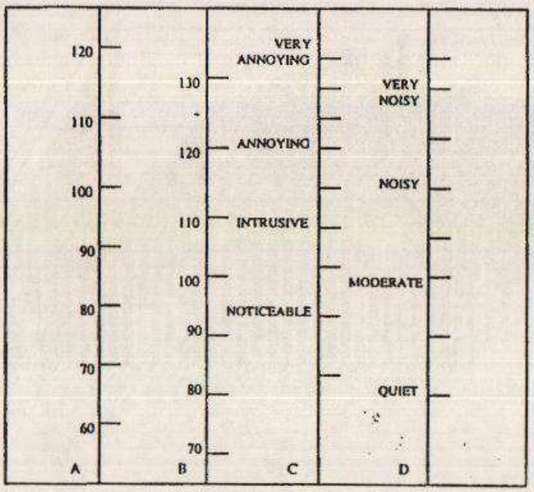
3. Kerry G, Wheeler P D and James D J. The Management of Light Aircraft and Microlight Noise at Military Airfields. Proc Internoise 97 pp 1223-1227.
4. Smeatham D, Kerry G and Wheeler P D. The Management of Light Aircraft and Microlight Noise at Military Airfields. University of Salford (unpublished SALF/MOD report).
5. Nelson P M. Transportation Noise Reference Book. Butterworths, London 1987.

Figure 1 - Relationship Between the Objective Scales of the Sound Level (dB(A)) and the Perceived Noise Level (PNdB) and the Category Scales of Subjective Intrusiveness and Noisyness



Note: Line A = Sound Level (dB(A)), Line B = Perceived Noise (PNdB), Line C = Subjective Intrusiveness and Line D = Subjective Noisyness

Figure 2 - Plan of the Airfield Showing Measurement Line

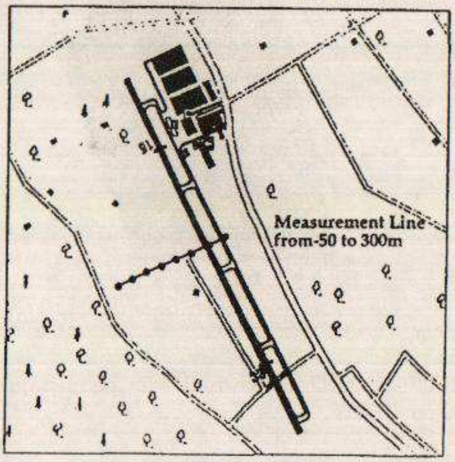


Figure 3 - LAmax Plot of Light Aircraft at 800ft AGL and Max Power

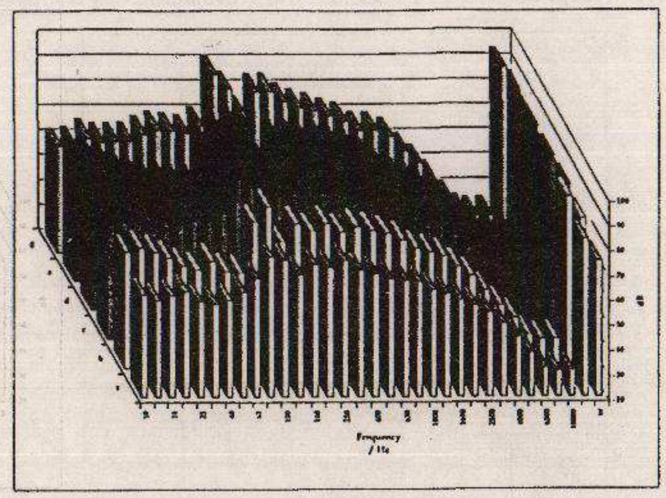


Figure 4 - Waterfall Plot of 250ft Maximum Power