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LIGHT AIRCRAFT NOISE - A SIMPLIFIED METHOD FOR PREDICTION OF LEQ CONTOURS *

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1. INTRODUCTION

An extensive collection of light aircraft external noise measurement data, over a range of typical flight conditions, has formed the basis for a simplified method of defining the envelope shape and size of noise exposure contours. No specialised knowledge of the actual reference noise levels and aerodrome performance of individual light aircraft types is required as input. The method is extended to include microlight aircraft generally. It allows aerodrome owners or operators and local authorities to gauge the broad area of land within which community noise problems might present a problem when planning applications for aerodrome development are being considered, although it cannot be considered to provide a formal set of Leq contours and should not be used where general aviation takes place as only a part of the total operations at larger aerodromes.

2. AIRCRAFT TYPES

The aircraft which have been included in this study comprise single piston engine powered propeller driven types having a fixed pitch propeller (FP) and a fixed undercarriage; single piston engine variable pitch (or constant speed) propeller driven types (VP) normally having a retractable undercarriage; and single two-stroke piston engine driven adjustable fixed pitch flexible wing microlight aircraft (ML) having a fixed undercarriage. Engine power, which primarily determines the noise emission levels, can conveniently be grouped as follows: High kW, usually including the VP propeller types with engine power above 175 kW; Medium kW, normally FP propeller types, with engine power in the range 125 to 175 kW; Low kW, with FP propellers and ending power from 75 to 125 kW and Ultra-low kW for the ML types having engine power less than 75 kW (they are typically almost half this limit). Typical aircraft used for ab initio pilot training, such as the Cessna C152 or the Piper PA38-112 Tomahawk fall within the Low kW FP group, whereas the more advanced training or private transport aircraft, such as the Piper PA28-161 Warrior Archer or the Cessna 172 fall into the Medium kW FP group. Typical of aircraft falling into the High kW VP Group are the more "sporty" CF172J Reims Rocket plus the Pitts Special S-1/S-2 and Steen Skybolt biplanes. Many of these high performance types have aerobatic capability, but we are solely concerned with normal flight conditions in the present study.

Formal definition of a light aircraft is not straightforward. Bearing in mind that the Air Transport (AT) sector of aviation is that concerned with the carriage of fare paying passengers, General Aviation (GA) encompasses all other forms of civil aviation. This in turn includes Business Aviation (BA). Hence GA is a grouping which employs aircraft with a wide range of gross weights, number of engines (piston as well as turbine and jet propulsion as well as propeller driven), and includes helicopters. For the purpose of this

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paper, single propeller driven aeroplanes designed to carry no more than 4 persons (including the pilot) of less than 1,200 kg MTOM (maximum take-off mass) were studied. Light twin propeller driven aeroplanes up to about 2,250 kg MTOM are also considered although no data for these were analysed.

Microlight aircraft <u>are</u> formally defined by S106 of the Air Navigation Order 1989 as "... *an aeroplane having a maximum total weight authorised not exceeding 390 kg., a wing loading at the maximum total weight authorised not exceeding 25 kg. per square metre, a maximum fuel capacity not exceeding 50 litres and which has been designed to carry not more than 2 persons..*"

3. NOISE MEASUREMENT DATA

3.1 Operations Considered

For the present purposes the operational phases considered are the take-off runway roll and lift-off at maximum rated engine power; initial climb to circuit height at maximum continuous power; level flight within the circuit pattern; approach from circuit height at normal glide-slope to cross the runway threshold at a height of 15 m and touchdown thereafter. These phases are illustrated in Figure 1 which also includes the relevant distance and angular parameters which will be used.

3.2 Noise Characteristics, Metrics and Exposure Index

Light aircraft noise in the vicinity of the aerodrome from which they operate can conveniently be characterised in terms of three noise metrics for each operational phase, namely the maximum A weighted sound level symbolised LA_{Max}; the sound exposure level L_{AE} (alias, L_{SE}, SEL or, when integrate between limits within 10 dBA of LA_{Max}, the LAX - all being time integrated sound energy levels referred to a notional 1 second duration); and the duration of the event τ seconds (or τ_{-10} for the 10 dBA below maximum version) which can also conveniently be studied in terms of the difference L_{AE} minus L_{AMax}. It is generally assumed that τ is proportional to s/V where s is the shortest distance from observation point to the flight path segment of interest and V the aircraft ground speed. In turn, to a reasonable accuracy, the difference L_{AE} minus $LA_{Max} = 10.\log_{10}(\tau_{-10}/2)$, ie proportional to $\log_{10}(½s/V)$.

The L_{AE} is, of course, the primary ingredient of the computation of the new UK aircraft noise index Leq [1] which, for daytime, is evaluated for the average number of aircraft movements taking place or forecast for the three monthly summer period 16 June to 15 September inclusive and over the hours 0700 to 2300 local time (in contrast to 0700 to 1900 used by the NNI, an index which has long been recognised as unsuitable for light aircraft noise evaluation) [2]. $L_{Aeq,16\,hour} = L_{AE,Avg} + 10.\log_{10}(N) - 47.6$ in units of dBA where N is the number of movements significantly contributing to the noise exposure and Avg denotes the average value over all such movements by all aircraft types using all relevant flight paths.

Contours of the $L_{Aeq,16\,hour}$ index can be calculated by computerised noise models such as the CAA's ANCON [2] or the Integrated Noise Model (INM) developed in the USA [3].

3.3 Planning Guideline Requirements for Aerodrome Operators and Local Planning Authorities

Broadly the new Planning Policy Guideline "Planning and Noise" [4] which replaces the former NNI based Circular 10/73 suggests that, normally, noise need not be taken into consideration if the Leq is no more than 57 dBA. However, when the operations include circuit training so that aircraft repeatedly overfly dwellings, research [5] suggests that criterion level some 5 to 6 dBA lower might be more appropriate. Where movements are irregular and average less than about 30 per day it is recommended that other factors should be taken into account. Such factors might include examination of the contours of LA_{Max} as an example. Some local authorities have developed planning guidelines with even lower noise limits, which attempt to take account of such factors as low rural area background noise and a predominance of flying activity at weekends or on public holidays [6].

Many decisions regarding new or intensified operations by light aircraft (including repetitive circuit training activities) seem to be taken without the production of formal noise exposure contours. This is possibly due to economic concerns but more probably because there are rarely comprehensive input data for the necessary calculations and because there is a very large range of potential light aircraft types which could use the aerodrome. For strategic planning or for actual consideration of planning applications where there is no other suitable information, a method which gives a good indication of the land area covered by the noise criterion values of noise exposure mentioned would be very useful. Such a method might simply define the critical noise impacted land by a rectangle envelope approximation to the real contour shape. A rectangle with the corners cut off or chamfered would be somewhat more realistic. We will now examine some actual measured data from light and microlight aircraft to see how this might be accomplished.

3.4 Data Correlation

The author has accumulated a large number of readings of the L_{AX} and L_{AMax} for a range of typical light aircraft. In each case the position of the aircraft at the time of passing closest to the measurement point was determined by a simple photographic method. In some cases, where the aircraft was known to be flying along a path close to passing overhead with wings substantially level the same photographs could be used to determine the observer to aircraft elevation angle β relative to the horizontal ground plane. Where the aircraft was passing by well to the side-line and the photograph showed both aircraft and the ground horizon the value of β could again be determined with sufficient accuracy. In other cases β was estimated by eye, again to reasonable accuracy for the present purpose. Whatever the β value, the primary parameter s could always be determined by photo-scaling the image wing span or fuselage length to the real dimension regardless of whether β was known accurately.

The scaling accuracy is improved by projecting the images onto a screen at a constant magnification. Typically the error in s was such that distance correction terms (for rates of attenuation close to that for inverse square law assumptions) could be determined within ± 0.5 dBA. β was only required to judge whether it would be necessary to apply a further correction for over-ground excess attenuation using the inverse of the method used in the new Leq contour calculation. This was rarely invoked for data obtained in the vicinity of the take-off or landing approach phases of operation, but for some instances data obtained from circuit activity at relatively great sideline distances and fairly low elevation angles were in need of such correction. Since the over-ground attenuation method tends towards a constant 10 dB under this condition, again the relatively simple method of aircraft location measurement was reasonably robust.

The results were assembled into a data base using a standard spreadsheet package to produce a graph plot and the least squares regression line of the noise exposure level L_{AX} data against the logarithmic slant range parameter $\log_{10}(s/152.4)$ with s in metres as shown in Figure 2. On such a plot, the ordinate level of the regression line at zero on the abscissa is the best estimate of the reference noise level (RNL) at 500 ft slant distance (152.4 metres). A similar trend was obtained when the L_{AMax} parameter was plotted thus. This led to a realisation that there was only a very small scatter of the data points between aircraft of type/engine power category Ultra-low, Low and Medium kW. However for the High kW or VP types the data trend was about 10 dBA higher, hence some form of further normalisation is required.

It is well known that propeller noise is a function of the relative tip speed and propeller disc mass flow which in turn relates to the aero-mechanical power required to drive the propeller. Constant speed and variable pitch propellers invariably involve higher engine power being absorbed than the lower capacity FP propellers fitted to ab initio training aircraft and microlights. The regulations for standard correction of UK noise certification data [7] for propeller driven types provide a useful insight to the rate of change of noise to be expected in terms of the helical tip Mach number M. For small propeller driven aeroplanes for which the application for a certificate was accepted on or after 1 January 1988, when there is no CAA approved manufacturer's data for the purpose, the correction for engine power should be $150.\log_{10}(M_R/M_T)$, where R denotes a reference value and T denotes the actual certification test value. For microlight aircraft the correction method, although expressed in terms of the altitude and air temperature, effectively amounts to the same rule with a multiplier of 170 instead of 150. The average value of 160 has therefore been adopted. At and below an M value of 0.7 the noise correction required is zero.

A similar noise certification data correction applies to small aircraft if the engine power differs between test and reference conditions, in this case with a multiplier 17. This is close to the value of 20 which would be deduced from simple propeller noise theory and which has been adopted here. The values of helical tip Mach Number were therefore computed and the noise levels corrected to a reference value of 0.7 (with no correction for cases below 0.7). Similarly the actual engine power was estimated from basic light aircraft performance data contained in aircraft recognition manuals and other publications and this was used to correct the noise results to 100 kW, ie the mid band engine power of for the Low kW group.

The resulting further normalised correlation plot is shown in Figure 3. Although still not perfect, there is no longer the exceptionally high trend for the High kW or VP types and the UL types now give values as high as any of the categories. Perhaps with more accurate information, or even more noise measurements pooled, the correlation would collapse even closer to the regression line shown in Figure 3. However, from the available data it can reasonably be deduced that, over a slant range from about 50 metres to 500 metres (164 to 1640 ft) under take-off climb conditions, the L_{AX} decreases at 6.3 dBA for each doubling of the slant range and that the normalised RNL is 73.0 dBA.

Applying such normalising techniques to the L_{Amax} data and the duration related Difference between L_{AX} and L_{Amax} provides correlation plots as shown in Figures 4 and 5. Note that the difference value regression line slope of +1.4 dBA/dd lies very close to the value of +6 dBA per decade (or +1.8 dBA/dd) which has been found to be appropriate for a wide range of aircraft types and is adopted in the INM [3]. The intercept value is +5.6 dBA normalised to 160 knots, so that the value at the reference distance for a typical light aircraft take-off climb speed of 60 to 80 knots lies in the range 8.6 to 9.8 dBA.

Similar analyses provide the regression data summarised in Table I as follows:

Table I	Take-off & Climb Phase		Landing Approach Phase		Level Flight or Circuit Phase	
	L_{AX}	L_{Amax}	L_{AX}	L_{Amax}	L_{AX}	L_{Amax}
Normalised RNL dBA	73.0	69.9	67.1	58.2	76.6	65.1
Slope Factor K	-20.8	-27.7	-11.1	-16.9	-21.3	-17.8
Slope dBA/dd	-6.3	-8.3	-3.4	-5.1	-6.4	-5.4
Standard Deviation dBA	2.0	2.5	3.6	4.5	2.0	3.1
R^2	0.56	0.45	0.23	0.30	0.78	0.52

For the landing approach case the corrections for engine power and propeller Mach number were omitted. The reference data can be adjusted to become relevant to any particular class of engine power and/or Mach number by reversal of the corrections described. Thus, for a typical ab initio training aircraft with about 110 kW engine power and propeller tip Mach number of about 0.8 at take-off and climb power, the actual RNL would be $73.0 + 160\log_{10}(0.8/0.7) + 20\log_{10}(110/100) = 83.1$ dB L_{AX}.

The evolution of a contour prediction scheme also requires height profile data. Figure 6 shows the assembled data plot for the take-off climb after correction to a 10 knot headwind, and Figure 7 is for the landing approach. It is typical of light aircraft operations that there is a wide variation in heights over the ground, due in part to the low ratio of airspeed to headwind speed. Nonetheless, for take-off, it is reasonable to draw the mean trend lines through the three categories as indicated in Figure 6. For the approach it is clear that light aircraft tend to adopt a glide-slope somewhat above the usual 3° for major airports and that microlights typically descent at about an angle of 6°. The Panshanger data includes some approaches using a runway where a steeper approach was routinely instructed for student pilots passing over housing. If those cases were omitted the remaining conventional aircraft would show a trend towards a 4° glide-slope.

4. CONTOURS

4.1 Calculation

The results from the above data correlations, adjusted for the appropriate actual values of the engine power and propeller Mach Number, were input to the INM model as user defined noise tables and profile data. The values were additionally adjusted to a duration reference appropriate for the 160 knot ground speed for the SEL data base implicit in the INM. The full noise versus power and distance tables were adapted from the existing versions for the GASEPF and GASEPV types in the model by level differences giving the best fit (at the RNL distance of 500 ft) to the values at the corresponding part of the INM SEL versus distance curve typified by Figure 8. The model assumed straight line take-off and landing approach tracks following the extended runway headings (taken as west-east for convenience) and an arbitrary total of 100 movements per day split equally as take-offs and landings.

Variables examined were the runway directional use mode (10%:90% through 90%:10%), ground track lateral dispersion (none, 3 track model, 5 track model) using typical dispersion statistics for general aviation aerodromes and the percentage of the total movements operated by the High kW or VP category.

Figure 9 shows an example set of contours for mode 70%:30%, 5 track dispersion and 0% High kW or VP. The contours are of the $L_{Aeq,16 hr}$ from 45 to 72 dB in steps of 3 dB.

4.2 Simple Envelopes

Figure 10 shows a simple rectangular envelope to the 51 dB contour from Figure 9 plus a slightly more elaborate envelope in which the corners are chamfered. For the moment considering the rectangular approximation only, we are interested in the length, width, aspect ratio (length/width), area enclosed and the offset from symmetry along the runway axis. Figure 11 shows how the area varies with the contour value. The regression line indicates that the enclosed area doubles for every 3.2 dBA reduction in the contour value. This is extremely close to the theoretical 3.0 dBA change for each halving of the total movements per day. Thus, to a good approximation the contour area can be linearly scaled in terms of its value per some reference number of movements. Figure 12 shows similarly the relationships between contour length, width and aspect ratio versus dBA value. To a close approximation the aspect ratio remains constant, only significantly diverging from about 7:1 above the 57 dBA point. This is useful since the length can simply be extended by doubling for each 5.6 dBA reduction in the contour value.

Next, the shift along the runway axis of the (almost constant width) envelope at a given contour value is investigated as a function of the runway mode split percentage value. Figure 13 shows that, from 10% to 70% of the take-off movements in a given runway direction, there is a straight line trend amounting to 0.1 km bias of the 57 dBA contour for each 10% change in the mode. It only reduces to about ⅓ this rate above 70% take-off dominated mode. Figure 13 also shows the 52 dBA contour relationship to be generally similar.

The effect of the % High kW or VP types in the movements mix is demonstrated in Figures 14 and 15. The aspect ratio again remains almost constant at 7:1. Hence the length and width of the enveloped changes in step at a rate averaging just over 15 dBA per 1% inclusion of these types in the mix. Here the variation has been expressed in terms of the equivalent change in the dBA value for the contour envelope calculated without any High kW VP types in the movements mix.

5. QUICK CONTOUR METHOD

Using the results and trends noted, it is now possible to develop the "Quick Contour" method as follows:

Basic Contour Sizes:

At 57 dB $L_{Aeq,16hr}$ with 100 Movements/day and with 100% Low kW FP aircraft type:
Draw rectangle centred on runway axis and mid-length 1.7 km long and 0.25 km wide (hence area = 0.425 sq km, aspect ratio = 6.8:1).

Or, at 52 dB $L_{Aeq,16hr}$ with 100 Movements/day and with 100% Low kW FP aircraft type:
Draw rectangle centred on runway axis and mid-length 3.0 km long and 0.45 km wide (hence area = 1.35 sq km, aspect ratio = 6.67:1).

Adjustments:

For runway mode split:

Set contour envelope symmetrically between the two opposite direction runway thresholds for 50%:50%. For each 10% increase in mode split, move the contour envelope 0.1 km in the direction of the higher % of take-offs (and vice versa). However, when increasing the mode split beyond 70% in the direction of the higher % of take-offs, decrease the shift rate to 0.033 km per 10% beyond a 70% mode value.

Add 3 dB to Contour Value for each doubling of Movements per day [+10 * $\log_{10}(N/100)$] before:

Double the length for each 5.6 dB reduction in L_{Aeq} and double the width for each 7.3 dB reduction in L_{Aeq} to regain the desired contour value (eg to get back to the 57 dB contour)

Adjust for the % High kW or VP within the daily movements mix by:

Doubling the length for each 16.7% increase and doubling the width for each 13.4% increase.

Refinements:

Figure 10 indicates the general principles for refinement of the contour envelope by chamfering each corner of the basic rectangle. Each edge of the rectangular envelope for each of its sub-zones (demarcated by the tangent point line and the track line) should be cropped according to the rules set out in the following Table II:

Table II	Tangent Points Line	Crop Corners by:	Exceptions to General Corner Cropping Rule	
Mode Split (higher) %			Above 51 dBA	Below 51 dBA
50	Mid Length	Two thirds of edge		
70	One third length from High% end	Two thirds of edge	at High% end, half of edge	
90	One third length from High% end	Half of each edge		at High % end, two thirds of edge and at Low % end, the whole edge

For a Movements Mix having other Categories of Engine Power:

The method can be extended to cater for a movements mix with other aircraft type categories (eg Medium kW and/or ML) by using the engine power and propeller Mach number normalisation factors in reverse and then determining an equivalent number of movements for all Low kW movements.

For Light Twin Propeller Driven Types:

Although not evaluated through measurements in the present study, both the INM data base and general experience shows that light twin propeller aircraft exhibit a value for the L_{AE} RNL approximately 6 dBA higher than the Low kW single FP propeller types. Hence, provisionally, this can be used for quick contours if each twin aircraft movement is reckoned as 4 movements by a Low kW FP type.

For Aerodromes with Multiple Airstrips:

These can be treated approximately by estimating the envelopes for each airstrip separately employing the appropriate parameters for each. Then the envelopes should be overlaid on the map base and the junctions faired using triangular fillets equivalent to a 3 dB interval of L_{Aeq}.

For the Modally Averaged Contours of L_{Amax}:

Proceed as for the L_{Aeq} contours but adjust the contour sizes as if the daily movements were 11,600 times the actual movements or 116 times the reference 100 movements per day for the basic contour envelope. The multiplier is determined by adding back the exact values of the constant term in the formula for $L_{Aeq,16\,hr}$ less the regression constant for the averaged difference between the L_{AE} and the L_{Amax} (ie equivalent to + 47.6 - 7.0 = 40.6 dBA increase in the contour value). Naturally the L_{Amax} value for a specific runway mode or for a specific aircraft type in the movements mix can be somewhat higher than this modally averaged result.

For noise under the circuit path:

At 100 circuits per day, all by the Low kW FP category flying level in the circuit at 1000 ft above aerodrome level, with allowance for track dispersion, the $L_{Aeq,16\,hr}$ contour value directly under the nominal circuit path is 40 dBA. Adjust this value for difference numbers of circuits by + 3 dBA for each doubling and for circuit height by - 6.4 dBA for each doubling. Use the lateral offset distances in Table III in order to calculate the circuit contour swathe semi-width for other contour values:

Contour Value relative to Value directly under Nominal Circuit Path - dBA	0	-1	-4	-7	-10	-13
Swathe Semi-width Offset - metres	0	115	445	705	1030	1385

For the modally and dispersion averaged L_{AMax} values add 16 dBA to each contour value, ie the central value becomes 56 dB L_{AMax}. Actual L_{AMax} values for an aircraft circuiting directly overhead will be about 8 dBA higher than the averaged value.

6. CONCLUSION

A quick method of estimating the broad area of noise impact for light piston engine propeller driven aircraft operations in the vicinity of general aviation aerodromes has been devised. The method requires only basic and readily obtainable information about the performance groupings of the types of aircraft concerned plus a knowledge of the overall number of movements taking place within the new UK Aircraft Noise Index Leq summer season and daytime hours split into the percentages operating in each runway direction.

The method can be used to provide an initial indication of the land impacted by light aircraft noise with reference to planning guideline noise exposure levels in terms of the new UK Aircraft Noise Index, but for more formal, and perhaps critical, situations a full assessment from contours generated by the usual computer model should always be performed.

7. REFERENCES

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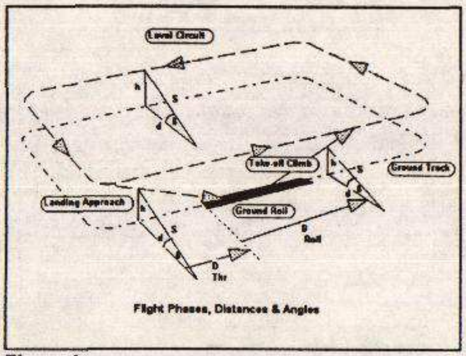

Figure 1

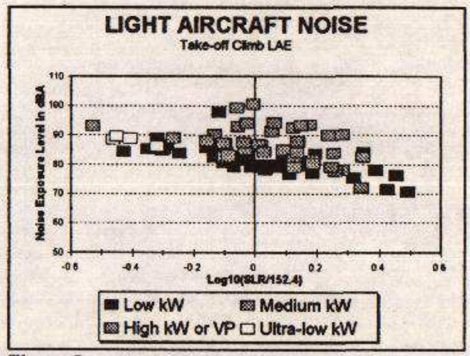

Figure 2

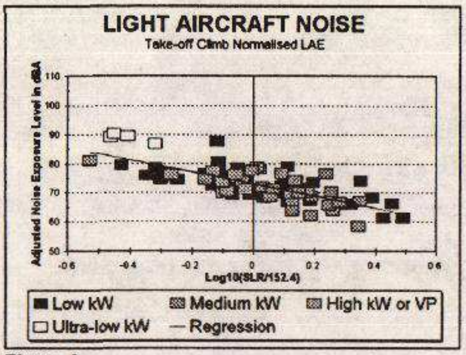

Figure 3

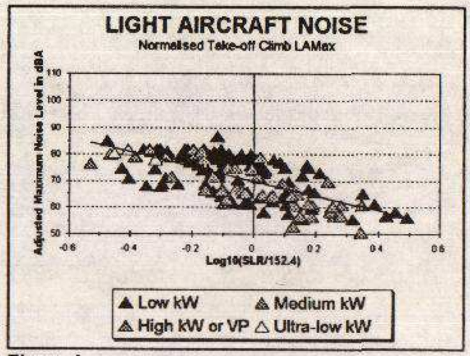

Figure 4

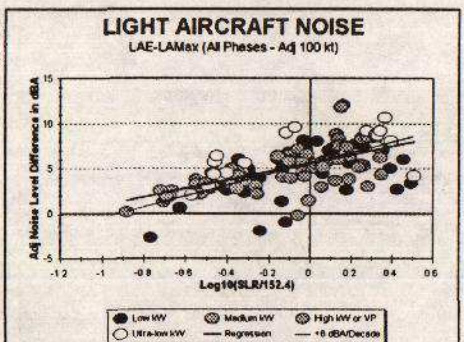

Figure 5

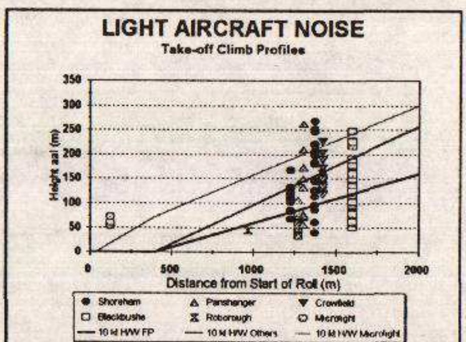

Figure 6

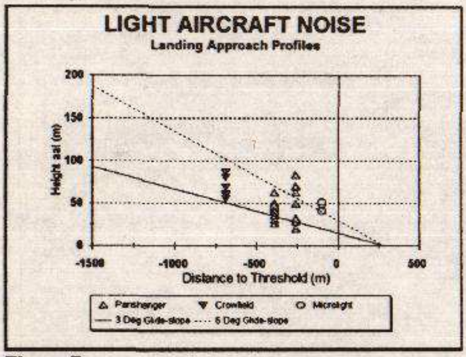

Figure 7

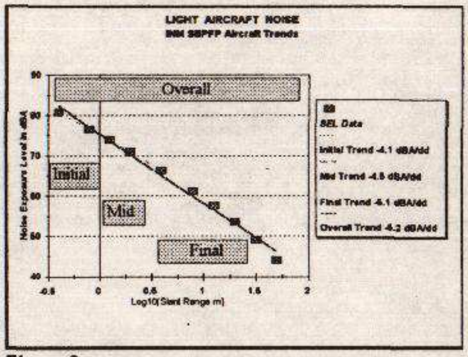

Figure 8

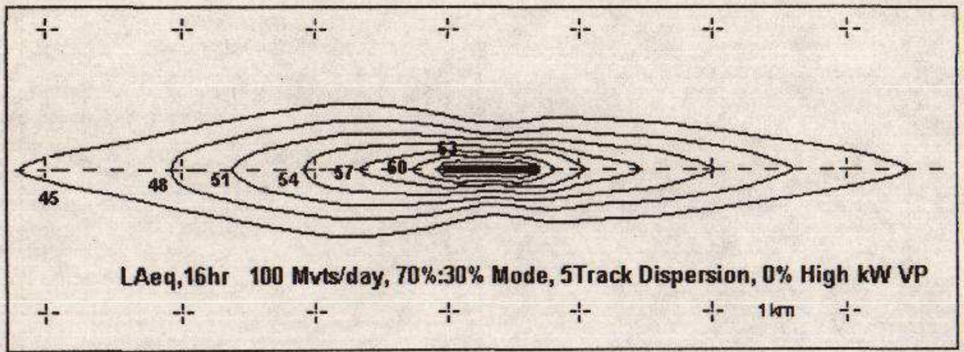

Figure 9

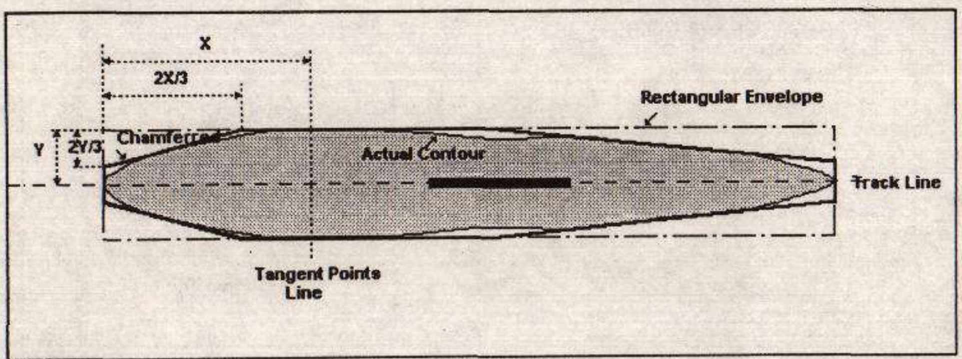

Figure 10

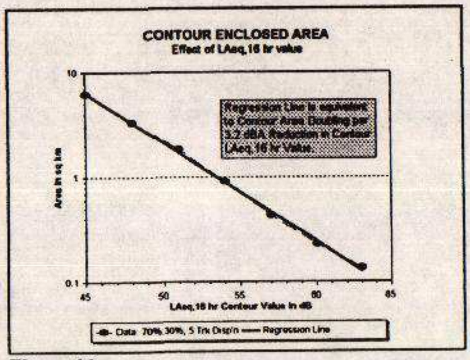

Figure 11

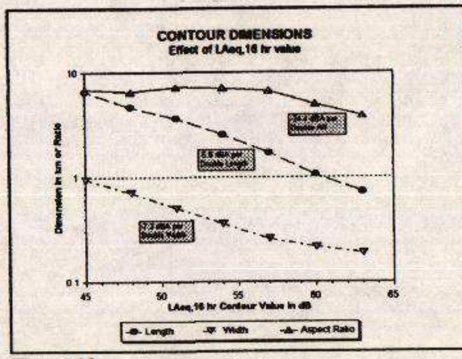

Figure 12

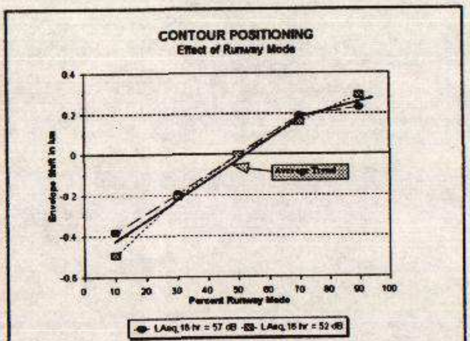

Figure 13

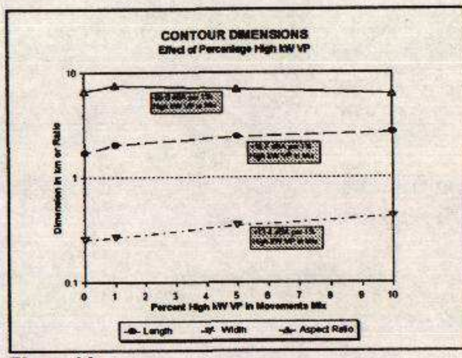

Figure 14

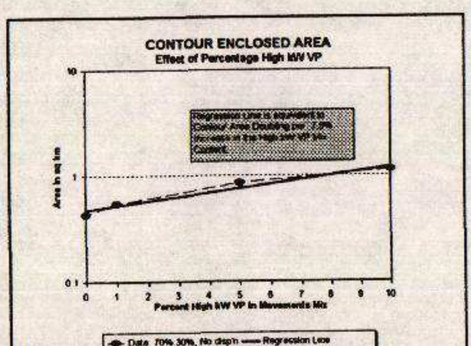

Figure 15