inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 6.2

ASSESSING THE AURAL RESPONSE TO LOW ALTITUDE MILITARY JET AIRCRAFT NOISE - A ROLE FOR ULTRA SHORT LAEQ?

C. Lomax*, G. Kerry*, P.D. Wheeler*, D.J. James**

* University of Salford, The Crescent, M5 4WT, Salford, United Kingdom

** Royal Air Force, HQPTC, RAF Innsworth, GL3 1EZ, Gloucester, United Kingdom

Tel.: +44 161 295 3030 / Fax: +44 161 295 5427 / Email: c.lomax1@salford.ac.uk

Keywords:
AIRCRAFT, ASSESSMENT, EAR, REFLEX

ABSTRACT
Overflight noise from military aircraft is often characterised as loud and sudden. It is a transient, broadband noise, of duration typically around 1-3 seconds, with a rise time of around 0.5 seconds, depending upon the method of calculation. The rate of onset is governed primarily by the height and speed of the aircraft. It has been suggested that the rise time of noise from such events might be faster than the response time of the auditory reflex, reducing the protection provided by the reflex to the inner ear. Our analysis of the response of the reflex to transients of this nature suggests that a significant degree of protection may be achieved. However a simple means of quantifying relatively fast onset-rates in practice is still required. This paper investigates the use of "ultra short" L_{Aeq} measurements for this purpose.

1 - INTRODUCTION
Previous studies [1] have highlighted that when assessing community response to low altitude flight noise, the noise level of the overflight alone is unlikely to be an adequate descriptor. A draft ANSI standard [2] has suggested that when judging annoyance, a correction or penalty based upon the rate of rise of the noise at the start of the event should be added. Studies in the UK [3] have found that methods of quantifying the onset rate tend to measure the gradient of a portion of the waveform which has a specific pressure level increase (eg. the gradient over the steepest 10 dBA), and by definition can yield very different values for the same event. The resulting onset rates are often not representative of a complex waveform such as the noise from low-flying military jets, whose gradient tends to vary over the duration of the rise of the event. They are also unlikely to account for the way the human ear will respond to the noise. However, a simple standardised measure of onset rate is required, that is able to quantify the speed of rise of a waveform and take into account the response of the human ear. This paper examines why onset rate is so important in assessing the human response to complex transients like the noise from low-flying military jet aircraft, and defines a possible measure for onset rate, using ultra short L_{Aeq}.

2 - THE IMPORTANCE OF ONSET RATE
To assess the importance of stimulus onset rate, work has been carried out to assess the response of the human ear, and in particular, the acoustic reflex. Typical values for the main reflex parameters were derived from the literature, to create a simple model [4] which represents the performance of the average acoustic reflex. The parameters given below were selected to take account of the characteristics of the noise from low-flying military jet aircraft, in particular its broadband nature and gradual rise characteristics.

Acoustic Reflex Threshold (ART): 75 dBA (or 85 dBA for people over 50) [5].

Reflex Latency: for stimuli whose level increases gradually over time, latency varies with stimulus onset rate. Latency (ms) can be estimated using the relationship (0.3dt + 96.4), where dt is the time taken (ms) for a change in stimulus level from ART to ART+10 dBA [6].

<u>Reflex Rise Time</u>: The response time of the reflex for a stimulus increasing from ART to (ART+10 dBA) is not dependant on the rise time of the stimulus and is reported as 530 ms [6]. As the signal increases beyond ART+10 dBA, the reflex begins to respond more quickly.
<u>Attenuation</u>: For broadband noise, the acoustic reflex will continue to respond to a stimulus until the stimulus level reaches ART+50 dBA [7]. The attenuation will increase linearly over this 50 dBA range, and will saturate at 20 dBA [8,9] when the signal level reaches ART+50 dBA.
The above values were used to estimate the impedance change at the middle ear over time (tympanogram) for stimuli of constant onset rate. Figure 1 shows the procedure for a signal increasing at 60 dBA/s. A tympanogram evaluated for a signal rising to ART+50 dBA can be applied to any signal which increases at the same rate to levels greater than ART+50 dBA (since the reflex saturates at ART+50 dBA). For signals not reaching ART+50 dBA, the appropriate point should be selected (b,d,f or h for signals increasing to 10, 20, 30 or 40 dBA re ART respectively) to stop the rise of the tympanogram and predict the correct attenuation.

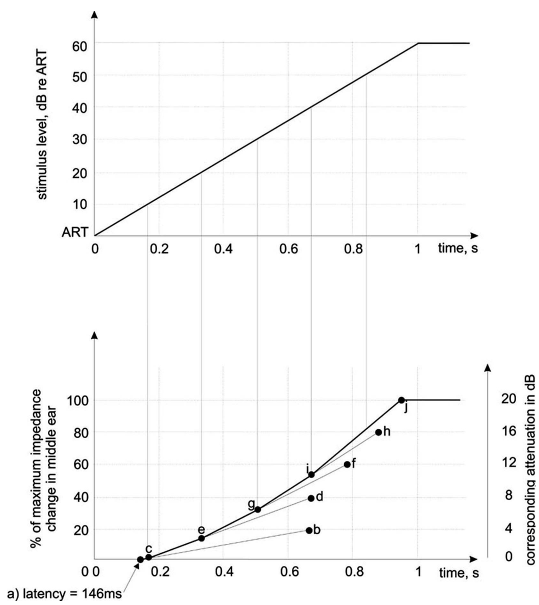

Figure 1: Calculating a tympanogram for a stimulus with constant onset rate; top - stimulus with constant slope rising at 60 dBA/s to an L_{Amax} of 135 dBA; bottom – estimated tympanogram.

Tympanograms were created in this way for signals with constant onset rates between 20 dBA/s and 450 dBA/s, and maximum levels of 85, 95, 115, 125, 135 and 145 dBA, assuming ART is 75 dBA. Figure 2 shows the signal incident on the middle ear and the corresponding signal transmitted to the inner ear after attenuation by the acoustic reflex, for signals with maximum level of 125 dBA and onset rates of 30, 120 and 450 dBA/s. At 30 dBA/s, the reflex is able to keep up with the signal, providing the full attenuation of 20 dBA by the time the signal reaches its maximum level. When the onset rate is increased, the reflex begins to struggle to keep up with the signal, as shown at an onset rate of 120 dBA/s when the reflex is providing some attenuation, but not the maximum. When the onset rate reaches 450 dBA/s, the reflex can no longer respond quickly enough to attenuate the maximum level reaching the inner ear.
In figure 3, the predicted attenuation provided by the acoustic reflex is plotted as a function of stimulus L_{Amax} and onset rate. Workers agree that reflex attenuation is dependent on level. This work shows that it is also dependent on onset rate.
Figure 4 demonstrates this pictorially. If a stimulus falls into area A, the reflex can 'keep-up' with the increase in level, and will provide maximum attenuation before the stimulus reaches its maximum level. If a stimulus falls into area B, the reflex will provide some attenuation before the stimulus reaches its maximum level. If a stimulus falls into the area C, the reflex will provide no attenuation to the maximum level reaching the inner ear. The dotted line represents the point at which the level reaching the inner ear is 125 dBA (if ART=75 dBA).

3 - APPLYING THE MODEL TO REAL LOW FLYING AIRCRAFT SIGNALS

The work described above was carried out using straight forward signals with constant onset rate. The

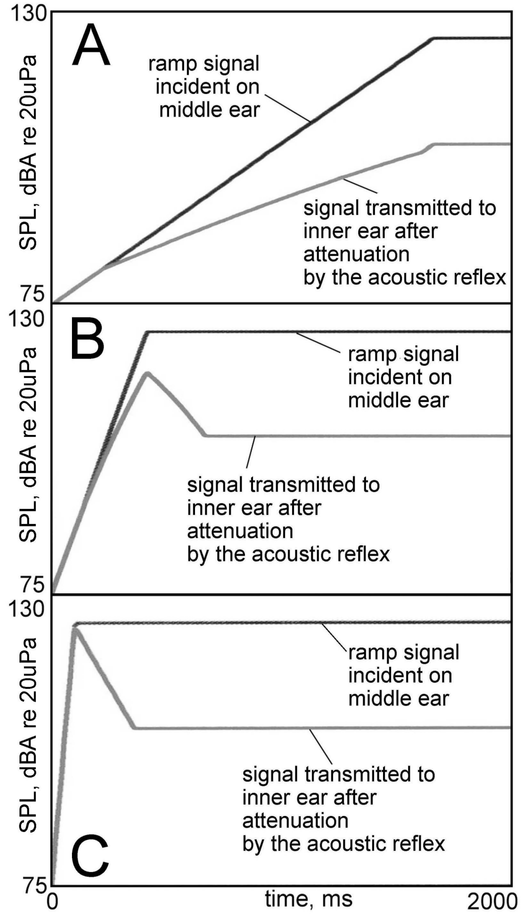

Figure 2: Attenuation of signals with constant onset by the acoustic reflex; A − onset 30 dBA/s; B − onset 120 dBA/s; C − onset 450 dBA/s.

same model was also applied to the complex noise waveforms recorded from low flying military jets during field trials held at a military airfield in the UK [10]. Examples were selected to provide a representative sample of flyovers flying at heights and speeds around the UK low-flying limits. To estimate the attenuation effect of the reflex, the ultra short L_{Aeq} time histories (duration = 8 ms) were smoothed using a running average of 96 ms. The point at which the level exceeded ART was determined, (in this case ART was taken as 80 dBA, since the waveforms fluctuate somewhat around the 75 dBA mark. In practice this will have little effect on the result, tending to underestimate the typical effect of the reflex). A tympanogram was produced for each event, and the attenuation calculated assuming a maximum attenuation corresponding to the maximum level of the waveform. This was then applied to the original waveform to estimate the attenuation effect of the reflex. An example of the results can be seen in figure 5. Table 1 shows the actual height and speed, L_{Amax}, the maximum attenuation for each flyover and the predicted attenuation calculated from the model. The results show that for real low-flying military jet aircraft signals, the acoustic reflex can provide some degree of attenuation to the level reaching the inner ear. This is not always the maximum possible reflex attenuation, and the noise from low-flying aircraft will typically fall into area B in figure 4.

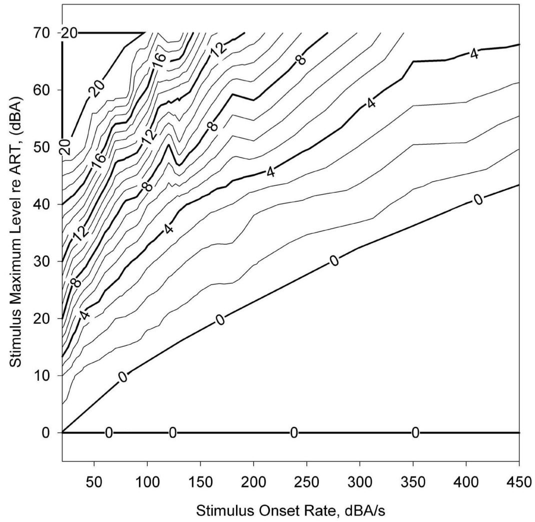

Figure 3: Variation of attenuation with onset rate and maximum level, predicted by model.

Flight	Height, ft	Speed, kts	L_{Amax} (fast) dBA	Maximum reduction in L_{Amax}, dBA*	Predicted reduction in L_{Amax}, dBA
1	227	427	108.7	12.1	9.4
2	113	462	119.5	16.5	10.2
3	141	552**	124.6	17.8	14.3
4	167	559**	125.5	18.2	11.0

Table 1: Attenuation by acoustic reflex predicted by simple model using a sample of Tornado overflights from specially arranged trials where aircraft were asked to fly close to current UK limits (*since the reduction is only 20 dBA if L_{Amax} reaches or exceeds ART+50 dBA (in this case, 130 dBA); **outside current UK low flying limits).

4 - USING ULTRA SHORT L_{AEQ} TO DEFINE ONSET RATE

The importance of onset rate in assessing the effects of noise on the human ear has been demonstrated above. Due to the limitations of existing methods to represent the onset rate of low-flying military jets, this study has considered how onset rate could be measured to reflect the way that the acoustic reflex responds to such sources. For signals with *constant slope*, L_{Amax} and rise time give a good indication of the effect of the signal. However, the noise from low flying military jet aircraft does not have a constant slope. To take account of the more complex slope characteristics (important when assessing the response of the ear) a parameter is required which will vary with slope characteristics, such as the envelope beneath the curve. We have already deduced that the reflex begins to respond when the signal level exceeds ART, and that the reflex takes an amount of time to respond to a signal which has exceeded ART. Therefore it will keep up with a slower increase in level, whereas a fast increase may 'beat the reflex'. Considering figure 6, the reflex will keep up with (a) better than it will keep up with (b). In turn, it will keep up with (b) better than it will keep up with (c), so a concave slope should elicit more protection from the reflex than a convex slope. This property could be accounted for in a measure of onset rate which used the area above the curve (area X in figure 6) in the calculation. To calculate X, the rise portion of the signal would require sampling, using short L_{Aeq}. An effective rise time, t_{eff}, can then be evaluated:
Effective rise time, $t_{eff} = 2X/(L_{Amax} - ART)$
The effective rise time will be greater than the actual rise time for a concave signal, and smaller than the actual rise time for a convex signal. This procedure suggests that a signal with a gradient that varies over the rise portion of the waveform, is equivalent to a signal of the same level, with a constant slope of rise time t_{eff}. The effective onset rate of the signal can then be calculated:
Effective onset rate (dBA/s) = $(L_{Amax}\text{-}ART)/t_{eff}$
Only the portion of the signal which exceeds ART is taken into account, reflecting the way the ear

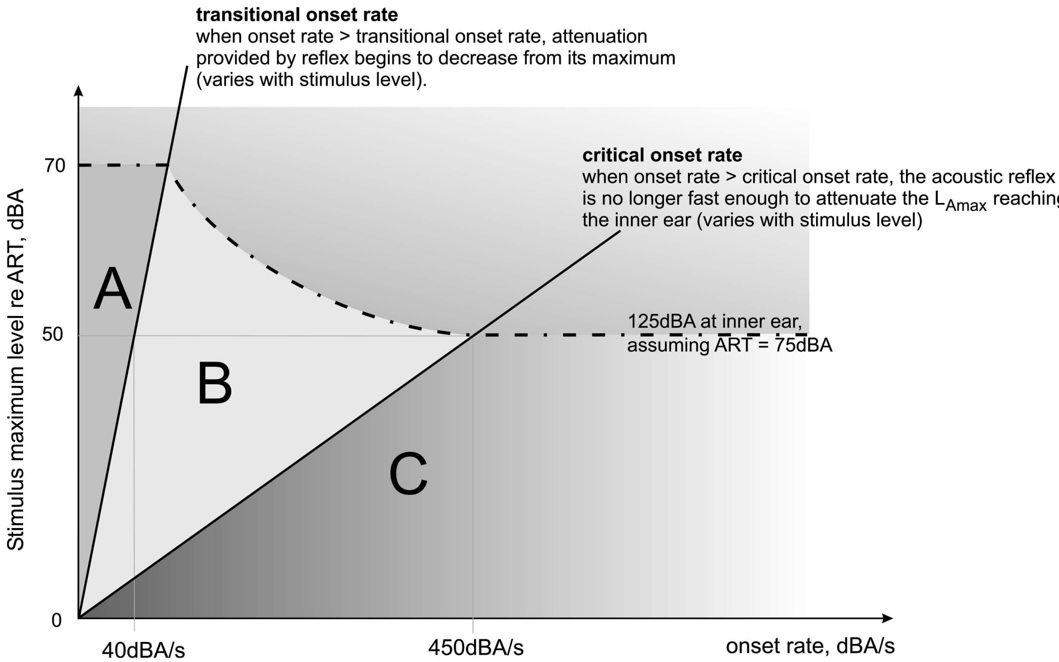

Figure 4: Pictorial representation of fig. 3, showing how onset rate is crucial in the assessment of the effect of the acoustic reflex; area A: reflex 'keeps up' with increase in signal and gives the maximum attenuation; area B: reflex provides some attenuation of L_{Amax}, but is not quick enough to provide maximum attenuation; attenuation decreases as onset rate increases, from maximum attenuation at the transitional onset to 0dBA at critical onset rate; area C: reflex not fast enough to attenuate L_{Amax} reaching inner ear.

responds. This is the most critical portion of the waveform, and the characteristics of this portion alone will determine whether the reflex will offer protection to exposure from a loud transient noise.

5 - APPLYING THE SHORT L_{AEQ} METHOD FOR ONSET RATE

The Onset Rate, calculated using the Ultra Short L_{Aeq} method described above, was calculated for each of the events used as examples in section 3, and each event was plotted on the contours shown in figure 3. Values were also plotted using the NPL method [3] of measuring onset rate. A predicted value of attenuation, derived from the work carried out in section 4 was then taken from the plot for both the Ultra Short L_{Aeq} and NPL methods. This value was compared to the attenuation calculated using the literature based model on real aircraft events in section 4. Table 2 shows that the attenuation can be predicted reasonably well using figure 3 for both methods of onset rate. However, for the louder, faster events the predictions using the Ultra Short L_{Aeq} method results are more accurate, with the NPL method tending to underestimate the attenuation and the Ultra Short L_{Aeq} method slightly overestimating the attenuation.

6 - CONCLUSIONS

This work has shown that Ultra Short L_{Aeq} can be used to calculate a value for onset rate that takes into account the way the acoustic reflex responds to a transient noise signal, and in particular the noise from low-flying military aircraft. It has also shown that it is possible to predict a value for the attenuation provided by the acoustic reflex, with a suitable onset rate measure and a diagram similar to that presented in figures 3 and 4. With further work, it could be possible to adapt this work into a criteria which will relate to both annoyance (as in the ANSI Standard [2]) and health effects. The model used in this study is a simple one, based on values taken from the literature. To investigate further the results presented here and fully validate this technique it will be necessary to use a proven middle ear model that incorporates true acoustic reflex characteristics. In addition, work is continuing to refine the Ultra Short L_{Aeq} methodology. It is felt that this approach towards identifying a method of assessing the noise from low flying military jet aircraft, or other complex transient noise sources (for example the noise from high speed trains), shows considerable promise.

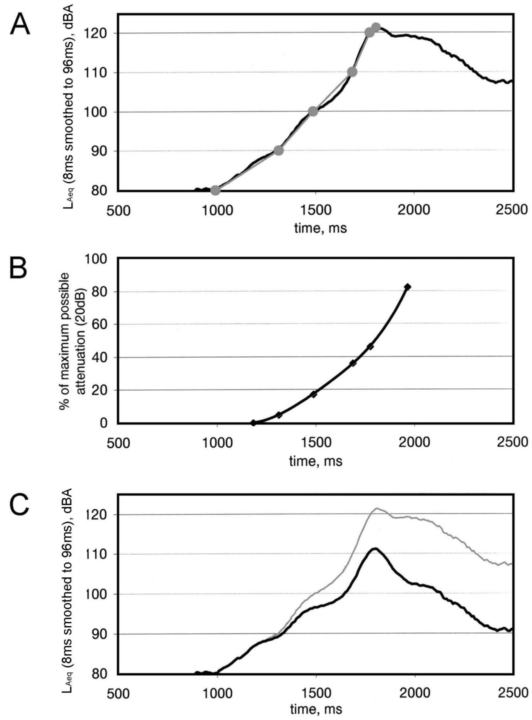

Figure 5: A − signal incident on middle ear split into 10 dBA sections; B − tympanogram produced by analysis of each 10 dBA section; C − signal incident on the middle ear compared to signal after attenuation by the acoustic reflex.

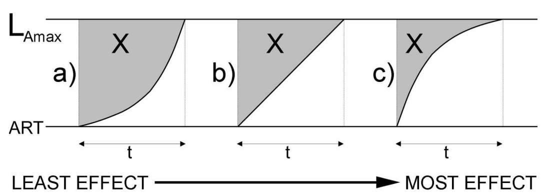

Figure 6: Slope characteristics.

ACKNOWLEDGEMENTS
This work was supported by the Ministry of Defence (MOD), however the views expressed in this paper are based on the professional experience of the authors and may neither reflect the MOD's view nor be binding on the Ministry. British Crown Copyright 2000/MOD. Published with the permission of Her Britannic Majesty's Stationary Office.

Event	Height (feet)	Speed (knots)	L_{Amax} (fast) dBA	Reflex Attenuation predicted by model, dBA	Short L_{eq} Method		NPL Method	
					Onset Rate, dBA/s	Predicted attenuation from fig. 3	Onset Rate, dBA/s	Predicted attenuation from fig. 3
1	227	427	108.7	9.4	20.9	11.2 (+1.8)	22.3	11.0 (+1.6)
2	113	462	119.5	10.2	42.1	13.2 (+3.1)	54.3	11.2 (+1.0)
3	141	552	124.6	14.3	15.0	17.5 (+3.2)	87.3	9.9 (-4.4)
4	167	559	125.5	11.0	62.0	13.0 (+2.0)	107.5	7.8 (-3.2)

Table 2: Prediction of attenuation by the acoustic reflex, using literature based model on real overflights, and predicted from figure 3 using the ultra short L_{Aeq} and the NPL methods of measuring onset rate.

REFERENCES

1. **K. J. Plotkin et al**, *Environmental noise assessment for military aircraft training routes Volume 1: Recommended noise metric*, Wyle Research Report WR 86-21

2. **ANSI S12.p-199x**, Quantities and procedures for description and measurement of environmental sound, Vol. Draft 6, 1996

3. **G. Kerry, C. Lomax, D. J. James**, Assessment and relevance of methods for calculating onset of low altitude flight noise, In *Internoise, Hungary*, pp. 1227, 1997

4. **G. Kerry, C. Lomax, P. D. Wheeler, D. J. James** , The response of the acoustic reflex to noise from low flying military jet aircraft, *Acustica (ASA/EAA Berlin)*, Vol. 85 (S1), 1999

5. **S. A. Gelfand**, The contralateral acoustic-reflex threshold, *The Acoustic Reflex, Shlomo Silman, Academic Press*, 1984

6. **Mcpherson and Thompson**, Quantification of the threshold latency parameters of the acoustic reflex in humans, *Acta Oto-Laryngologica*, Vol. S353, 1977

7. **S. Silman**, Magnitude and growth of the acoustic reflex, *The Acoustic Reflex, Shlomo Silman, Academic Press* , 1984

8. **E. Borg**, A Quantitative study of the effect of the acoustic stapedius reflex on sound transmission through the middle ear of man, *Acta Oto-Laryngologica*, Vol. 74, pp. 163-171, 1972

9. **Zakrisson**, The effect of the stapedius reflex on attenuation and poststimulatory auditory fatigue at different frequencies, *Acta Oto-Laryngologica*, Vol. S360, pp. 118-121, 1979

10. **C. Lomax, G. Kerry, D. J. James**, Wideband noise signatures from low-altitude military jet overflights, In *ICA/ASA Seattle*, 1998