NOISE MONITORING AND EXTRACTION OF NEW INFORMATION FROM OLDER INSTRUMENTS AND ARCHIVES

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Abstract

Several thousand permanent monitoring terminals have been deployed around the world for monitoring aircraft noise. A large proportion of these were designed more than twenty years ago, primarily to record A-weighted levels, but later enhanced to include levels pertaining to C- and Z-weighting, third octaves, effective perceived noise, stationary loudness, and more recently, non-stationary or dynamic loudness. In addition, acoustic recording of events with levels above a prescribed threshold and neural network classification were added. Noise events are frequently caused by more than one type of sound source, so that it becomes important to quantify the aircraft contribution to the noise impact. In addition to the enhanced facilities of noise monitoring terminals, the sonograms of the acoustically recorded noise events prove to be especially useful. In many cases a quick glance at the sonogram will reveal the presence of several other noise sources, such as barking dogs, loud birds, trains and other ground-based sources. Moreover, the sonogram permits the speed of trains and aircraft, with surprisingly good agreement with aircraft speed data obtained from radar, to be estimated. Distinctions between different types of jet, turbo-prop and helicopter aircraft show up readily on the sonograms. In this paper, examples of sonogram evaluations will be presented, including cases where non-aircraft noise events have been wrongly ascribed to certain aircraft movements, or the wrong type of aircraft has been ascribed to the noise event. The methodology can similarly be applied to other situations of environmental noise to reveal more details of the noisescape.

1. Introduction

Monitoring and quantifying the effects of aircraft noise has been a subject of much discussion from the moment that aircraft noise became a matter of social and political urgency. The first question was what should be measured. For example, should it be a simple physical measure related to energy, or something related to physiological damage or perception of 'loudness' or annoyance? Fletcher and Munson were conscious of this issue in 1921 as quoted in their classic paper of 1933 [1]:

> "In a paper during 1921 one of us suggested using the number of decibels above threshold as a measure of loudness and some experimental data were presented on this basis. As more data were accumulated it was evident that such a basis for defining loudness must be abandoned."

In the case of aircraft noise, the reason for monitoring the noise is because people complain about it, in terms such as "too loud" or "very annoying", which would suggest that one should endeavour to measure some appropriate approximation to these perception attributes. Yet in spite of Fletcher and Munson's insight of 94 years ago as well as all the extensive and meticulous work performed by several other investigators [2]-[6], when it came to choosing an IEC standard for measuring environmental and especially aircraft noise in the nineteen-fifties, of all the possibilities then available: A-,B-,C-,D-weighting, Zwicker loudness [5], noisiness and perceived noise [6], the worst possible choice – A-weighting – was made. Although it is understandable that implementation at that time could be problematic for some of these metrics, at least the simpler B-weighting would have been an easy and better approximation for measuring aircraft noise [3], [4]. In any case, the standard was seen by most of the knowledgeable people as a temporary measure until newer technology became more readily available. Today, with so much powerful technology readily available, there is no excuse for maintaining a standard that results in measuring the wrong quantity in the same standard wrong way.

1.1 Adaptations of current instrumentation

The outdoor noise-monitoring equipment produced by Lochard Ltd has been equipped since 1994 [7] with A-,C-, and Z-weighted metrics, as well as effective perceived noise and stationary Zwicker loudness metrics. A-weighting has been used exclusively for regulation-required noise monitoring; the other metrics have been employed mainly for research purposes. Neural network analysis of event discrimination [8] was added in 1995. Incorporation of all audio-to-digital signal conversion inside the microphone, as close as possible to the pre-amplifier, was pattern approved [9] in 2000. Audio recording of noise events was incorporated in 2001, which enables the realization of the diagnostic tool that provides the material for the main part of this paper, viz. the sonogram. Other aspects of time-frequency analysis have been studied and applied in various forms to resolving mixed sources of noise, e.g. [14], [15]. Dynamic loudness [10] was incorporated into permanent noise monitoring terminals in 2010, and offers some interesting new aspects, apart from its superiority to A-weighted levels. Certain intermediate parts of the algorithm are calculated at 0.5 ms intervals to produce a parameter LN5,0.5s, the loudness level exceeded for 5 percent of the time in each 0.5 s interval, i.e. by 50 0.5-ms-samples. The 5th percentile of dynamic loudness is a significant measure of loudness perception [16]. A second parameter, called LN_unfilt,0.5s_max is the maximum "unfiltered" loudness level in each 0.5 s interval. It is obtained from a signal that is tapped off from the algorithm before the final stage of time–integration (Fig.1). The difference between these two parameters turns out to be a very useful aid in characterising certain types of noise events [11] - [13].

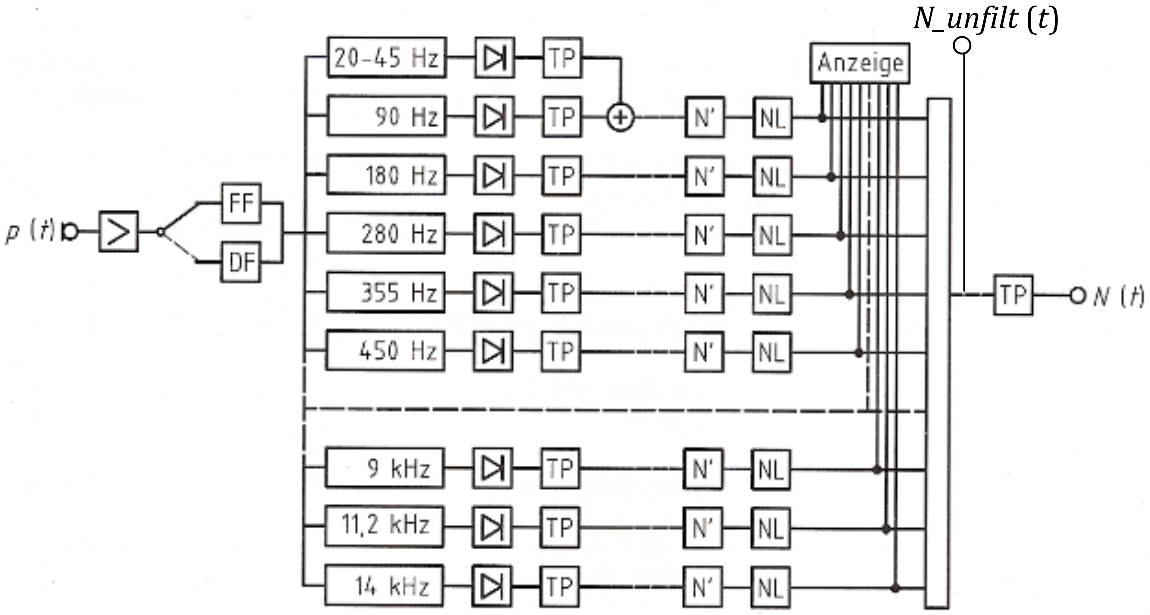


Fig.1 Schematic of the dynamic loudness algorithm (DIN 45631/A1)

The difference parameter (LN_unfilt,0.5s_max- LN5,0.5s)_event_max is called LN_dif and is frequently used in the following discussion.

2. Examples of time-frequency analysis of noise events by means of the sonogram.

We first consider examples of sonograms where the noise events are straightforward aircraft noise events, which have been correlated to specific aircraft via radar tracks data. These sonograms clearly show dominant tones from which the Doppler shift can be readily calculated. They also show clear patterns of tones, some of which are harmonically related, which are characteristic of the type of aircraft under its specific operational condition. The radar tracks data and the Doppler shift enable us to assess some degree of the uncertainty in the difference between the two methods of determining aircraft speed. Once this is established, we can then examine examples of other moving objects that were incorrectly correlated with aircraft, and stationary or slowly moving noise sources that corrupt records of aircraft noise events.

2.1 Straightforward aircraft noise events.

In the following sonogram tables, we use the following abbreviations:

min. dist., i.e. the apparent minimum distance between the aircraft and microphone as determined by radar tracks data;
rad. speed, i.e. the speed derived from radar tracks;
dopp. speed, i.e. the apparent speed as determined from Doppler shift;
geom. corr. i.e. an approximate geometric correction, applied to the simple Doppler shift, based on the apparent minimum distance, the times of the event-start and event-end, and the speed derived from radar tracks data, which is assumed constant;
LAeq_mx, i.e. LAeq,1s_max; LN5_mx, i.e. LN5,0.5s_max.

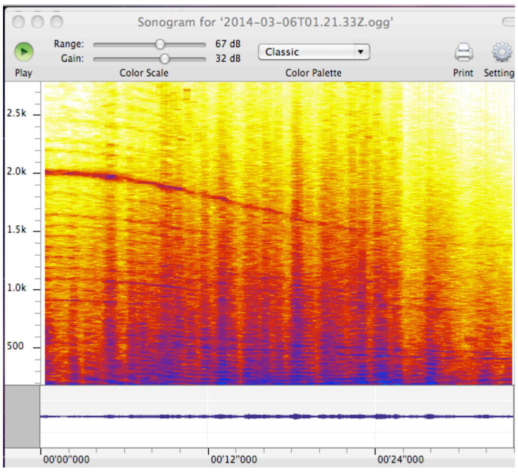


Fig.2 A320 departure noise event sonogram

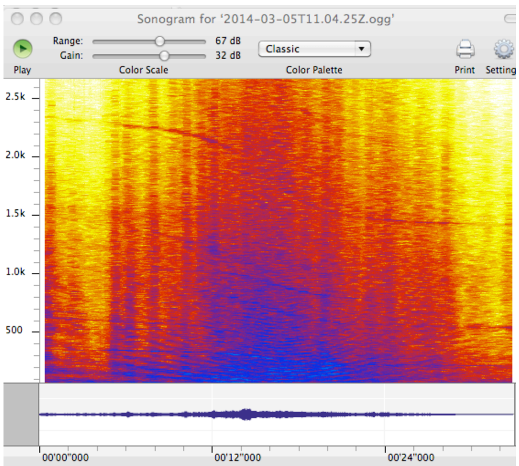


Fig.3 A320 arrival noise event sonogram

Some of the important parameters derived from these noise events and subsequent noise events are listed in the following tables.

Table 1

	min. dist km	rad. speed m/s	dopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.2	1.25	88	61	85	6.2	67.8	82.7
Fig.3	0.469	79	78	85	6.0	73.9	87.3

Table 2

	min. dist km	rad. speed m/s	lopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.4	0.902	112	89	115	6.3	75.1	89.3
Fig.5	0.480	90	81	87	6.2	77.2	90.4

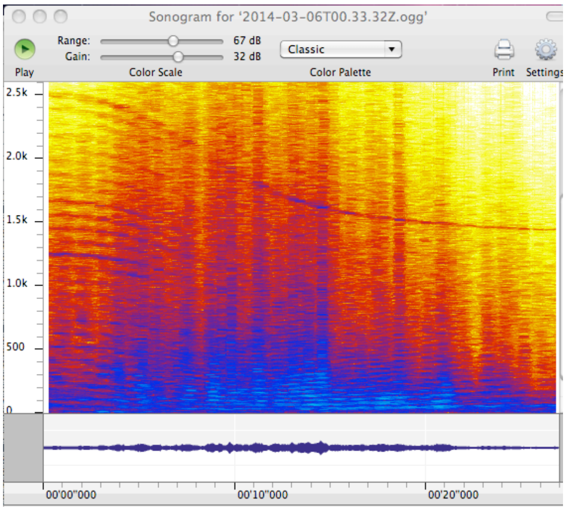


Fig.4 B738 departure noise event sonogram

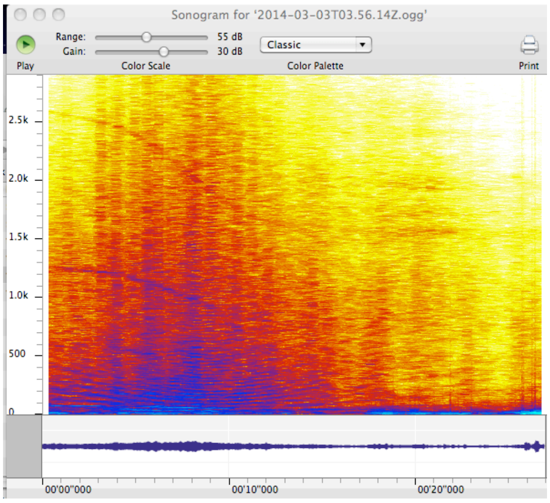


Fig.5 B738 arrival noise event sonogram

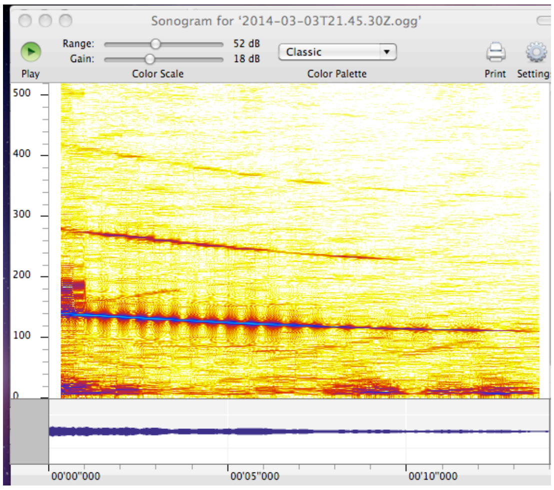


Fig.6 BE20 departure noise event sonogram

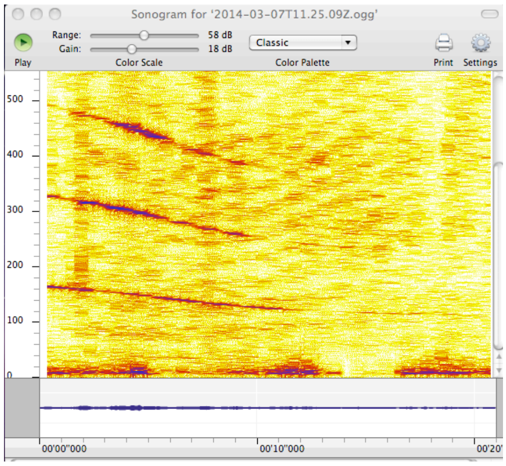


Fig.7 BE20 arrival noise event sonogram

Table 3

	min. dist km	rad. speed m/s	dopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.6	0.835	81	36	94	6.2	69.1	83.7
Fig.7	0.480	81	62	83	6.5	70.1	82.8

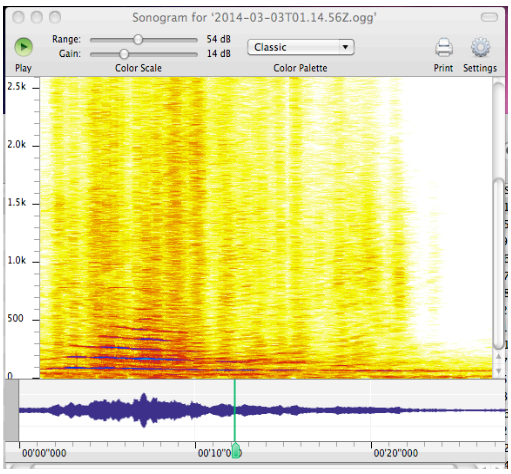


Fig.8 DCH8 arrival noise event sonogram

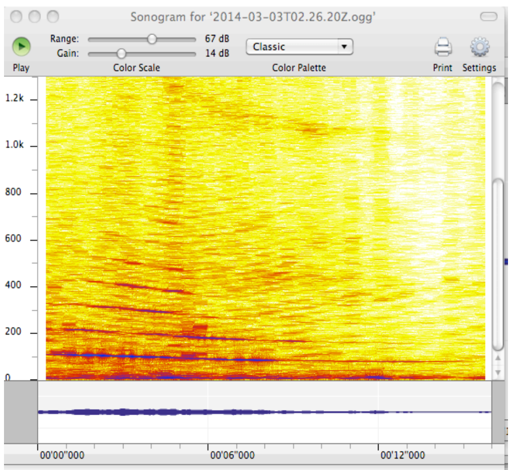


Fig.9 SF34 arrival noise event sonogram

Table 4

	min. dist km	rad. speed m/s	dopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.8	0.539	60	51	70	7.9	73.9	89.6
6.0 < LN_dif < 7.0 for 12 half secs; LN_dif > 7.0 for 3 half_secs							
Fig.9	0.491	72	54	86	8.4	71.4	86.0
6.0 < LN_dif < 7.0 for 8 half secs; LN_dif > 7.0 for 1 half_sec							

Some points to note from these examples:

1. They all show clear tones from which the Doppler shift can be readily estimated.
2. The geometric correction, error prone as it is, does give a better agreement with the radar information than the simple Doppler shift.
3. The value of LN_dif for the pure jet aircraft ranges from 6.0 to 6.3, which is typical for such aircraft noise events that have not been contaminated by other sources.
4. The difference between LAeq,1s_max and LN5,0.5s_max ranges from 13.2 to 14.9 dB (phon), which is a relatively small range consistent with the range of values of the apparent minimum distances from the microphone (0.5 to 1.2 km).
5. The DH8 and SF34 aircraft have significantly higher values of LN_dif than the pure jets or the BE20 aircraft.

2.2. Noise events that were not correlated to fixed wing aircraft

We next consider some cases of helicopter noise events that were not correlated to any aircraft type. Since helicopters frequently do not use a transponder, correlation with an aircraft type is not possible. The identification as a helicopter must come from other means; the acoustic signal, which contains a lot of information, then becomes especially important. Apart from listening to the recorded sound, one indication that the events may be caused by helicopters is if LN_dif > 8.0 phon. However, a reasonably accurate estimate of the speed of the sound source is also very important. There are numerous other types of sound sources, including stationary sources, which generate values of LN_dif exceeding 8.0 phon.

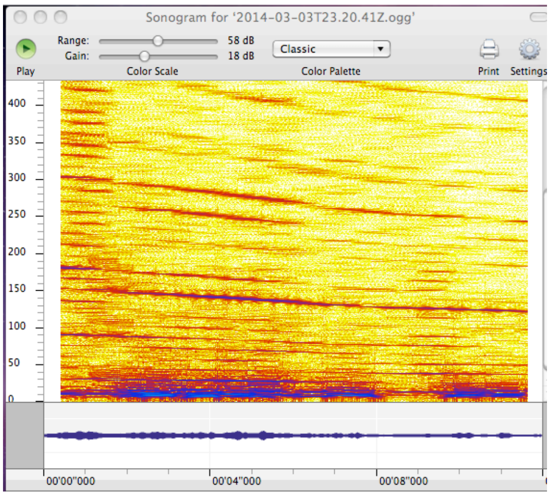


Fig.10 Uncorrelated noise event sonogram

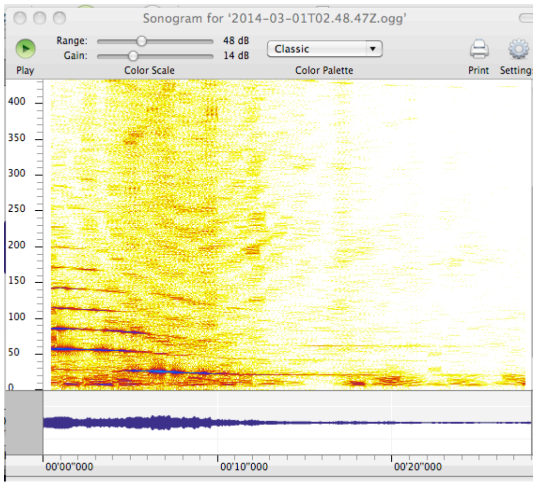


Fig.11 Uncorrelated noise event sonogram

Table 5

	min. dist km	rad. speed m/s	dopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.10	0.495	55	35	70	7.2	69.4	82.8
6.0 < LN_dif > 7.0 for 4 half_secs; LN_dif > 7.0 for 1 half_sec							
Fig.11	0.368	62	55	63	8.4	76.8	86.0
6.0 < LN_dif > 7.0 for 12 half_secs; LN_dif > 7.0 for 3 half secs							

In spite of no aircraft correlation in Fig.10, a helicopter presence is doubtful: LN_dif > 7.0 for only one half-sec interval and the sonogram shows similarities to Figs 6 and 7. However, listening to the audio recording confirms a helicopter presence. In contrast, in the case of Fig.11, the values of LN_dif do indicate a possible helicopter event, which is supported by the presence of harmonics of approx. 9 Hz separation and confirmed by listening to the audio recording.

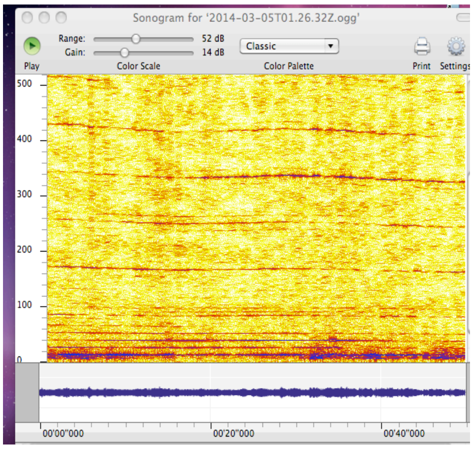


Fig.12 **Uncorrelated noise event sonogram**

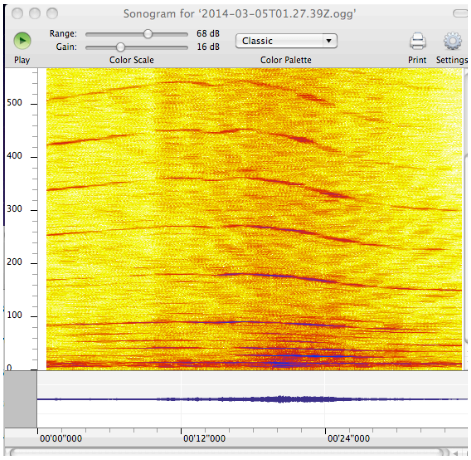


Fig.13 **Uncorrelated noise event sonogram**

Table 6

	min. dist km	rad. speed m/s	dopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.12	0.492	42	9	21	7.2	66.6	81.6

6.0 < LN_dif < 7.0 for 18 half-secs; LN_dif > 7.0 for 6 half_secs.

Fig.13	0.404	59	30	-	8.7	66.6	84.7

6.0 < LN_dif < 7.0 for 19 half-secs; LN_dif > 7.0 for 12 half_secs; LN_dif > 8.0 for 4 half_secs.

In the case of the events of Figs.12 & 13, the listening test and the presence of tones spaced at 9 and 15 Hz intervals confirm a helicopter. The higher tones indicate variations in direction or possibly in speed. Because of likely flight direction variations, the geometrical correction is unreliable.

2.3. Contaminated aircraft noise events

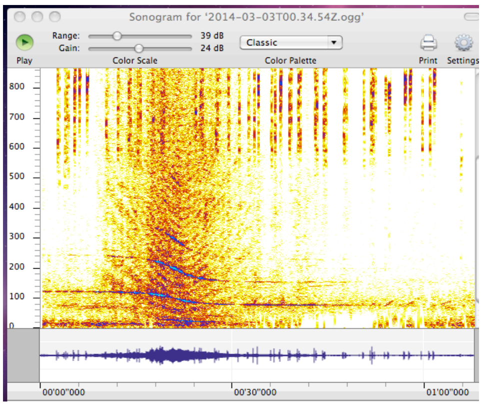


Fig.14 SF34 arrival noise event sonogram

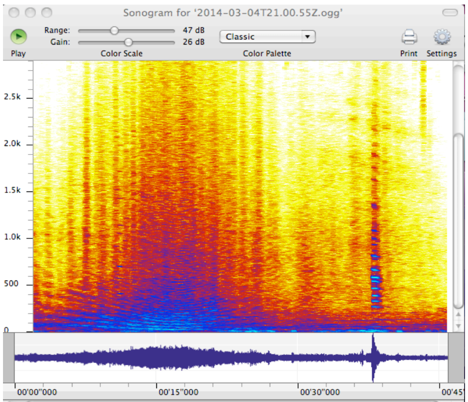


Fig.15 B738 arrival noise event sonogram

Table 7

	min. dist km	rad. speed m/s	dopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.14	0.532	80	75	78	12.0	70.8	86.3

6.0 < LN_dif < 7.0 for 24 half_secs; LN_dif > 7.0 for 22 half_secs; LN_dif > 8.0 for 13 half_secs.

Fig.15	0.414	73	71	75	7.3	79.3	91.4

6.0 < LN_dif < 7.0 for 3 half_secs; LN_dif > 7.0 for 1 half_sec;

In the case of the event of Fig.14, the above data and the appearance of the sonogram indicate some strongly disturbing impulsive sound superimposed on the aircraft sound. Listening to the recorded sound identifies a strongly barking dog, which is louder than the aircraft at its closest approach.

In the case of the event of Fig15, at about the 38 sec mark, the warning signal of a train is present with a duration of about 1 sec, which is responsible for the values of LN5_mx and LAeq_mx. If this part of the signal is removed, the maximum values drop to LN5_mx = 89.4 phon, i.e. 2.0 phon lower, and LAeq_mx = 72.6 dB, i.e. 7.3 dB lower. The sonogram shows a further non-aircraft feature: a bird at around the 46 sec. mark, with tones extending from 2 to 3 kHz. However, in this instance the bird, although audible, does not contribute to the maximum values. Another feature of this event is that the train is not audible (at least to this listener) except for its warning signal. But for a major part of the duration of this event, the dominant third-octave frequency is between 100 and 25 Hz (Fig. 16), indicating the presence of the train, whose perceived loudness is nevertheless swamped by that of the aircraft.

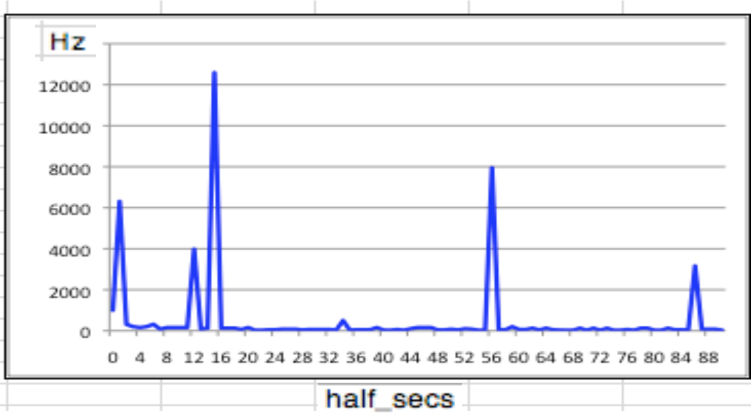


Fig. 16 Shows the dominant third-octave frequency as a function of time

'Dominant' is meant in the sense of the level at the centre frequency of the filter that exhibits the maximum protrusions above the levels of its immediate neighbours ("pitch" discrimination).

2.4. Noise events apparently wrongly correlated with aircraft

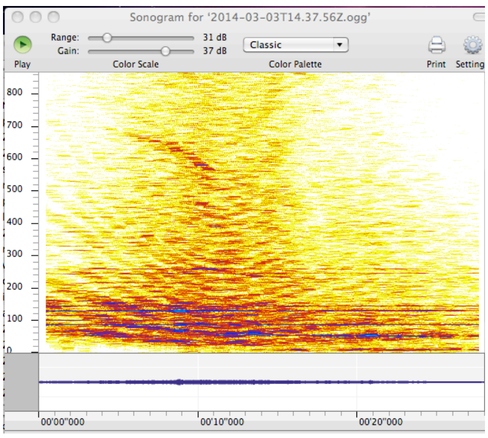
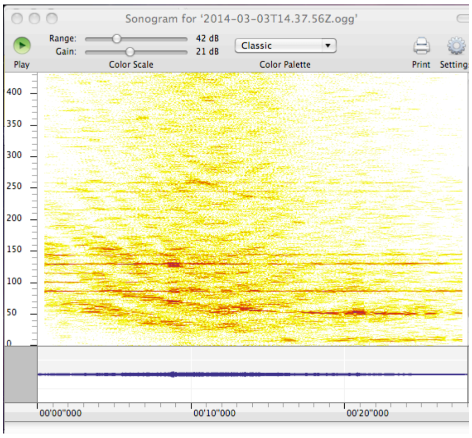


Fig.17 B463 arrival noise event sonogram



Figs.18 B463 arrival noise event sonogram

Table 8

	min. dist km	rad. speed m/s	dopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.17	0.477	75	72 (700Hz)	77	5.7	71.0	85.3

Figs. 17 & 18 portray the same event but with different frequency scales. Fig. 18 emphasises the frequencies below 200 Hz. The Doppler shift of tones below 100 Hz appears to be negative.

This raises the question of what is really going on with this event. LN_dif seems to be too low for an event caused by a 4-engine jet aircraft, and the clear apparent harmonic tones based on 15 Hz are out of character for such a jet aircraft. Listening to the recorded sound indicates a heavy diesel engine, consistent with goods trains on the railway, which is known to be at a min. dist. of 0.181 km. Further evidence is provided from an (uncorrelated) noise event immediately preceding this event (Fig.19). The listening test very clearly indicates a diesel train. There are no aircraft tones present, but the harmonics based on 15 Hz are very clear. Furthermore, the levels are similar to those of the following event. Since this event immediately precedes the event of Figs 17 & 18, we would expect the train to still be present in the later event. The small negative value for the Doppler shift indicates that the train is beginning to slow down as it approaches a nearby station. Once the speed becomes variable, the estimate of train speed is then much more uncertain. The conclusion is that the event of Figs 17 & 18 is caused by a mixture of train and aircraft contributions and is about 2 phon louder than the pure train event. Even so, the aircraft can hardly be heard in combination with the train. The train dominates so that the event should not be ascribed to the aircraft.

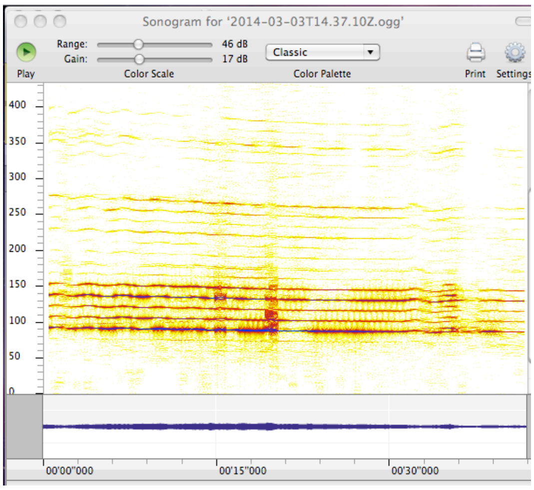


Fig.19 Diesel train noise event, uncorrelated

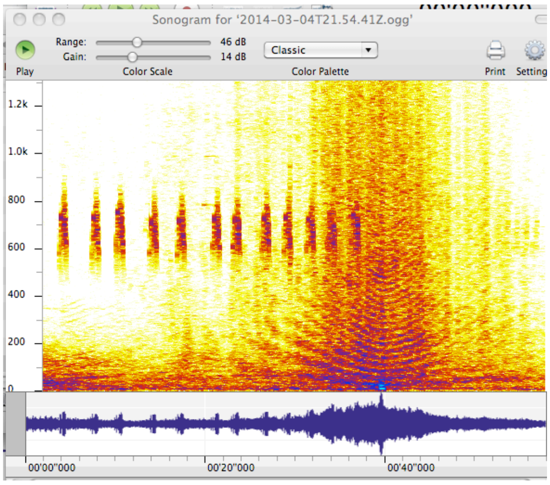


Fig.20 Contaminated B738 arrival noise event

Table 9

	min. dist km	rad. speed m/s	dopp. speed m/s	geom. corr. m/s	LN_dif phon	LAeq_mx dB	LN5_mx phon
Fig.19	0.181	-	13	16	5.7	67.3	83.7
Fig.20	0.415	75	77	79	6.8	75.3	89.3

The event of Fig.20 is interesting because there is an aircraft responsible for about 16 sec of the event, simultaneously with a relatively small contribution by a bird and a dog. But for 32 sec of the event the bird is totally responsible. As a result the exposure levels would be incorrect if ascribed to the aircraft:

Total event levels: LAE = 85.3 dB, LN5E = 98.7 dB, LAeq_total = 67.7 dB.
Contaminated Aircraft levels: LAE= 83.5 dB, LN5E = 97.5 dB, LAeq_contaminated = 71.1 dB.
Bird only levels: LAE = 80.1 dB, LN5E = 91.3 dB, LAeq_bird = 65.3 dB.
Event-tail-end: LAE=70.8 dB, LN5E= 86.3 dB, LAeq_tail = 60.8 dB.

The issue is further brought into focus in Fig.21, which shows how the LN5 plot gives a better discrimination between the bird and aircraft parts of the event than does the LAeq plot. A listening test confirms this verdict. The sonogram also clearly shows the dominant bird portion and the section of aircraft sound penetrated by the bird calls. This is a case where the relatively long period of a non-aircraft source results in a significant error in the exposure level due to aircraft as obtained by the standard process. At it happens, this particular site is often subject to prolonged periods of dog and bird interjections. The conclusion is that because of the long period of contamination of the event compared with the short period of unquestionable aircraft noise, the A-weighted exposure level of the total event is not a good approximation to the A-weighted exposure level of the aircraft. In contrast to the event of Figs 17 & 18, the aircraft sound is not fully masked by the bird sound.

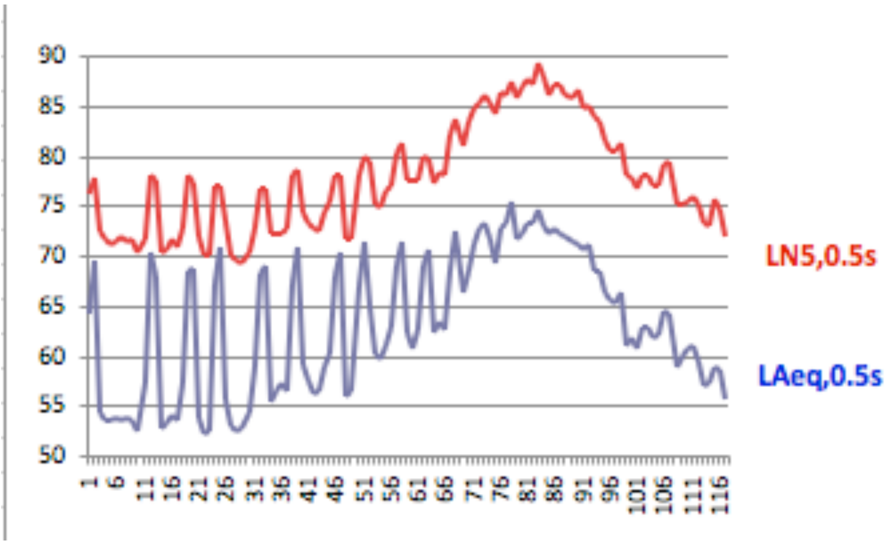


Fig.21 Time dependencies of LAeq,0.5s and LN5,0.5s during the event of Fig.20.

3. Discussion

Noise monitoring inherently involves many forms of uncertainty. The first concern is the instrumentation. Permanent outdoor instrumentation is vulnerable to the weather, lightning, birds, insects, vandals etc. It is therefore vital that continuous monitoring of as many as possible of the most important factors that can impugn correct measurement are recorded and transmitted reliably and regularly to the base offices [17]. Placing all the analogue-to-digital conversion circuitry as close as possible to the acoustic transducer, i.e. inside the microphone [9], is a standard electronic engineering practice that immeasurably facilitates the functional monitoring of the measuring process. The simple and sometimes crude calibration checks that are permitted by the ISO and ARP standards are barely adequate for their purpose without frequent and costly visits to the monitoring sites. Irrespective of the instrumentation, all aspects of noise monitoring and interpretation are fundamentally accompanied by uncertainties [18], which can be quite large and are often difficult to quantify. Radar, acoustic data, atmospheric conditions, actual aircraft movements, modelling and human perception all have their individual uncertainties. It is for this reason that as many separate independent methods as possible are made available, and are brought to bear on the problems of characterising the “noisescape”. The use of sonograms, together with the LN5 parameters leads to more detailed information about each noise event. With practice, the process of evaluation becomes considerably faster than having to listen assiduously to recordings, possibly with several repetitions. Ideally, one would like to automate the whole evaluation process, using either signal processing of the raw data or making use of the visual recognition processes that are evident on viewing the sonogram, with all its adjustment possibilities for colour, intensity and contrast. This could be an interesting challenge for a younger generation of researchers. Above all, the primary purpose of monitoring must never be forgotten. What people hear is the key issue, not what signals can be detected, but which may be masked in the hearing process.

Within the scope of this paper, it has not been possible to explore the advantages of scrapping A-weighting entirely and basing the whole structure of noise events, thresholds, exposure levels and their interpretation on a loudness level parameter such as LN5,0.5s. Amongst other factors, a critical aspect is how to choose the noise-event threshold. This topic has been partially explored in [11] – [13] but needs to be taken further. Ultimately, one would like to discard the whole concept of noise-event and simply characterise each half-second of received sound perceptually as either aircraft, non-aircraft, or uncertain sound and use that data set from which to calculate both aircraft, non-aircraft and uncertain noise-loads.

4. Conclusion

In this paper we have endeavoured to show some of the possibilities of what can be achieved by enhancing the capabilities of instruments that have long been in operation in the field with additional programming. The sonogram, in conjunction with other existing features of the monitoring system, can be an especially useful tool in post-processing of primary measurement data to provide more detailed knowledge of the noisescape in the neighbourhood of airports.

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