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PSYCHOMETRIC ANALYSIS OF STATIONARY AIRCRAFT SOUNDS

Rudolf Bisping*[1], Crispin Dickson[2] and Shafiq Khan[2]

[1]SASS acoustic research & design GmbH, Hagelkreuz 46, D-45134 Essen, Germany
[2] Kungliga Tekniska Högskolan (KTH), Teknikringen 8, 10044 Stockholm, Sweden
sass.consult@t-online.de

Abstract

The acoustical properties of aircraft sounds dynamically change during the time-history of the fly-over. It is therefore difficult to determine the relationship between the human perception of aircraft sounds and these acoustical changes. One option could be to use time continuous judgment to find relationships between acoustical and perceptual data, e.g. by applying cross-correlation methods. Since aircraft sounds comprise many acoustical features which might change simultaneously this method has a limited range of validity. To overcome such problem in the present study synthesized stationary aircraft sounds were used instead of the natural aircraft sounds. This allows the experimental variation of just one feature of interest at a given time. The sounds were generated to represent three different angles of the aircrafts flyover position relative to the observer at 78,7°, 90° and 101,3°. These three positions were found to cover a significant part of the acoustical phenomena which may occur during fly-over, e.g. tonal components, fan noise, low- versus high frequency broadband effects, etc. Synthesis was performed based on the measurements of six different aircrafts and two flight conditions (take-off & arrival). All the sounds were equalized to have the same EPNL-level. The sounds were judged by 25 subjects using a multidimensional scale having five different attributes: loudness, annoyance, hardness, power and pitch. The statistical analysis of the data showed highly significant differences between the acoustical phenomena and all chosen perceptual attributes. The paper will present the applied methods and the results.

INTRODUCTION

When analyzing the perception of aircraft fly-over sounds the experimenter meets the problem of allocating properly the subjects response to the time varying acoustical features of the sound. As many acoustical components, e.g. fan noise, turbine sound, airframe noise, etc., may vary simultaneously it is not easy if not impossible to establish a causal link to the subjects response. This is true even when using time continuous judgment and applying cross-correlation between the time history of selected acoustical properties, e.g. level, and the subjects response in order to identify possible event based relationships. To overcome this problem in the present study synthesized stationary aircraft sounds were used instead of the natural aircraft sounds. This allows the experimental variation of just one feature of interest at a given time. The sounds were generated to represent three different angles of the aircrafts flyover position relative to the observer at 78,7°, 90° and 101,3°. These three positions were found to cover a significant part of the acoustical phenomena which may occur during fly-over, particularly tonal components and broadband effects. To analyze these phenomena an experiment was set up to answer the following questions:

- What is the perceptual effect of different angles relative to the observer?
- What is the perceptual effect of tonal versus broadband sounds?

METHOD

Sound Material

The sound material is based on acoustic measurements of fly-over events which were performed within the framework of the European SEFA-project (Sound Engineering for Aircraft). For 6 airplanes and two flight conditions (arrival, take-off) sound samples of 2 sec. were chosen at three different angles (78,7°, 90°, 101,3°) within a range of +/- 1,3°. Figure 1 shows the time history of the A-level of one of the aircrafts take-off (airplane 11) relative to flight path parameters.

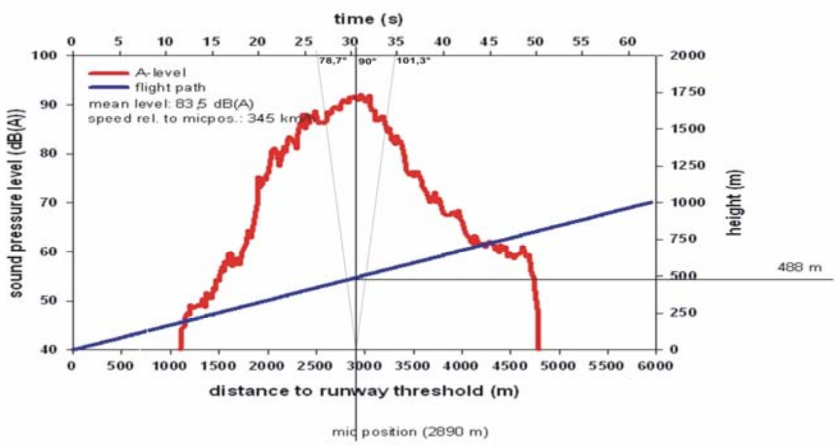

Figure 1 – A-level time history of a take-off (airplane 11) relative to flight path parameters

For each sample the mean amplitude spectrum was calculated with SASSWin V.1.98 and a synthesis filter was designed representing the individual spectrum. For each synthesis filter a synthesis control filter was designed having the same gross spectral shape as the original spectrum but no tonal components.

Applying the various filter to 10 sec of white noise 72 different stationary sounds were generated (6 airplanes x 3 angles x 2 flight conditions x 2 filter conditions = 72 sounds). All sounds were adjusted to have the same EPNL. Figure 2 shows an original signal and control spectrum of airplane 11 at 78,7° and 101,3°.

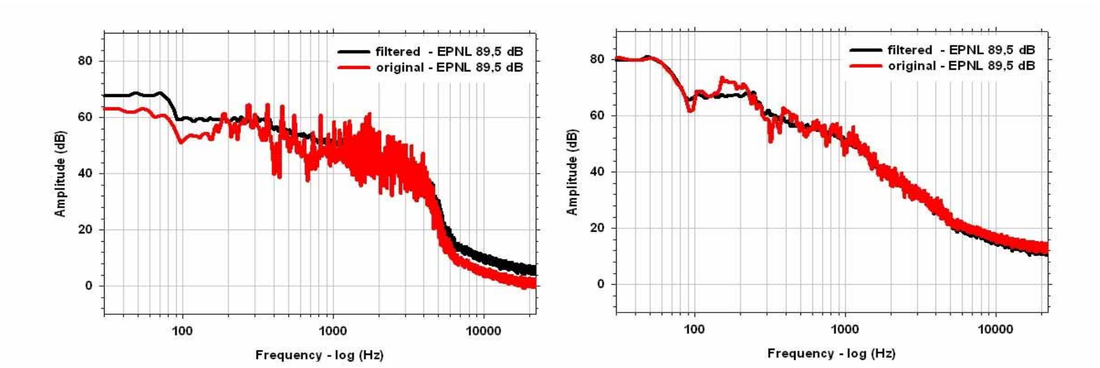

Figure 2- EPNL-equalized signal and broadband spectra of airplane 11during take-off at an angle of 78,7° and 101,3°

Note that with an original signal having dominant tonal fan-noise components (left spectrum) the spectral level of the control signal is elevated. This is due to the effect of the EPNL which is quite sensitive to tonal components and, thus, significantly reduces the level of tonal signals in case of equalizing to its broadband control. This effect does not occur if the original does not have prominent tones (right spectrum).

Scaling

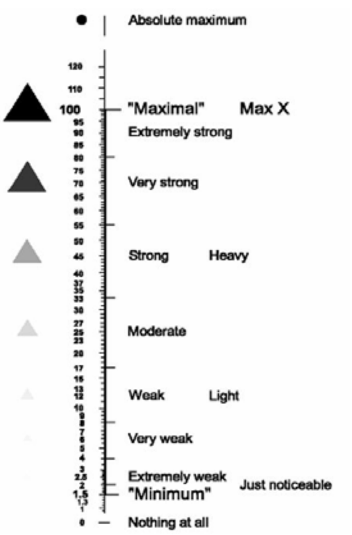

Figure 3- Boris scale

Figure 3 shows the Boris scale used for the assessment of judgments. The following psychometric attributes were scaled by the subjects:

- Loudness
- Annoyance
- Hardness
- Power
- Pitch

The subjects were asked to scale the intensity of a given sound in respect to the five attributes. One hundred meant “maximal” intensity. In case of a stronger feeling than “100” the subject was allowed to use a higher number. If the subject was sure not to feel anything a number of “0” was appropriate. Each attribute was scaled separately, i.e. the subjects were allowed to concentrate on one attribute and could replay the sound as many times as needed to achieve at a reliable judgment before proceeding to the next attribute.

Procedure

- A panel of 25 subjects (14 male, 11 female, age range: 20 – 30 years) took place in the experiment.
- Prior to experimental testing each subject had to pass an audiometric test.
- Sounds were presented by stereo loudspeakers. The mean level was adjusted to 74 dB(A).
- Order of presentation was randomized.
- Prior to the actual listening tests, two sounds were played back to the subjects in order to familiarize with the listening procedure.
- The experiment was run on two separate days (thirty minutes duration per day).

Statistical Analysis

Separately for both flight conditions each of the five psychometric attributes were submitted to ANOVA (SPSS V.13) with repeated measurement on the aircraft-, angle- and filtering factor.

RESULTS

Table 1 summarizes of the ANOVA main effects.

Table 1

variable	exp. conditions	take-off		arrival	
		F	p	F	p
loudness	ac	8,3	< 0.001	9,07	< 0.001
	angle	0,2	n.s	0,55	n.s
	filtering	37,6	< 0.001	10,42	= 0.003
annoyance	ac	5,97	< 0.001	28,7	< 0.001
	angle	8,97	< 0.001	5,02	= 0.01
	filtering	0.01	n.s	1,90	n.s
hardness	ac	6,29	<0.001	12,86	<0.001
	angle	11,05	< 0.001	5,71	= 0.005
	filtering	3,67	n.s.	0,36	n.s.
power	ac	5,84	<0.001	1,01	n.s.
	angle	1,73	n.s.	0,19	n.s.
	filtering	47,83	<0.001	9,28	=0.005
pitch	ac	7,35	<0.001	18,04	<0.001
	angle	25,82	<0.001	9,80	<0.001
	filtering	34,96	<0.001	9,88	=0.004

For loudness, power and pitch the ANOVA results in highly significant effects in respect to the aircraft and the filtering factor for both take-off and arrival with just one exception (the power effect at the aircraft / arrival condition is n.s.). Figure 4 und 5 depict the data for both flight conditions. Note that loudness and power show a close correspondence in their pattern of effects. Broadband filtering in most cases is felt as louder, more powerful and lower pitched as the tonal signals. With all three variables remarkable differences can be observed between the six aircrafts.

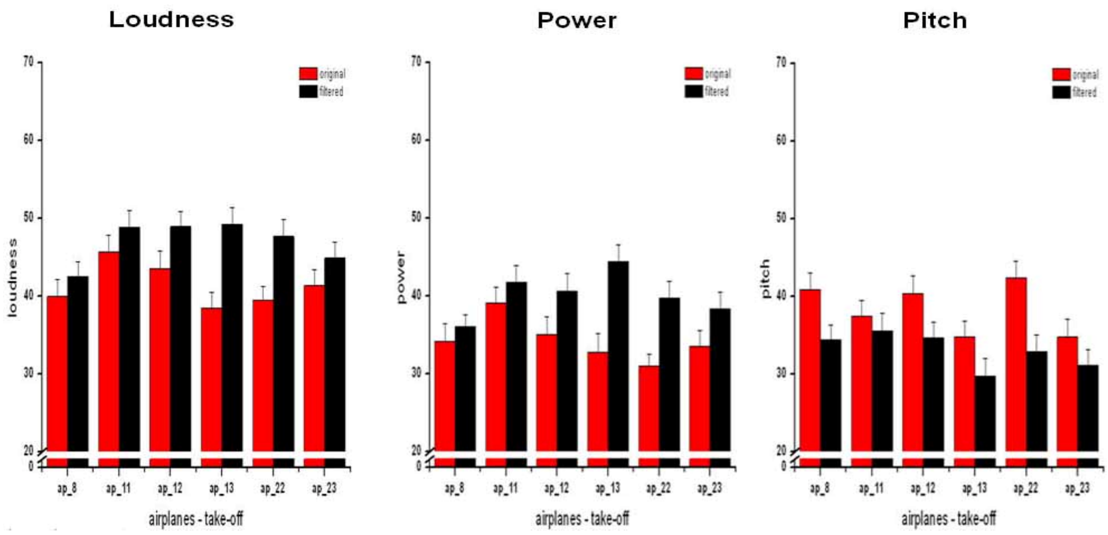

Figure 4- Take-off aircraft and filtering effects for loudness, power and pitch

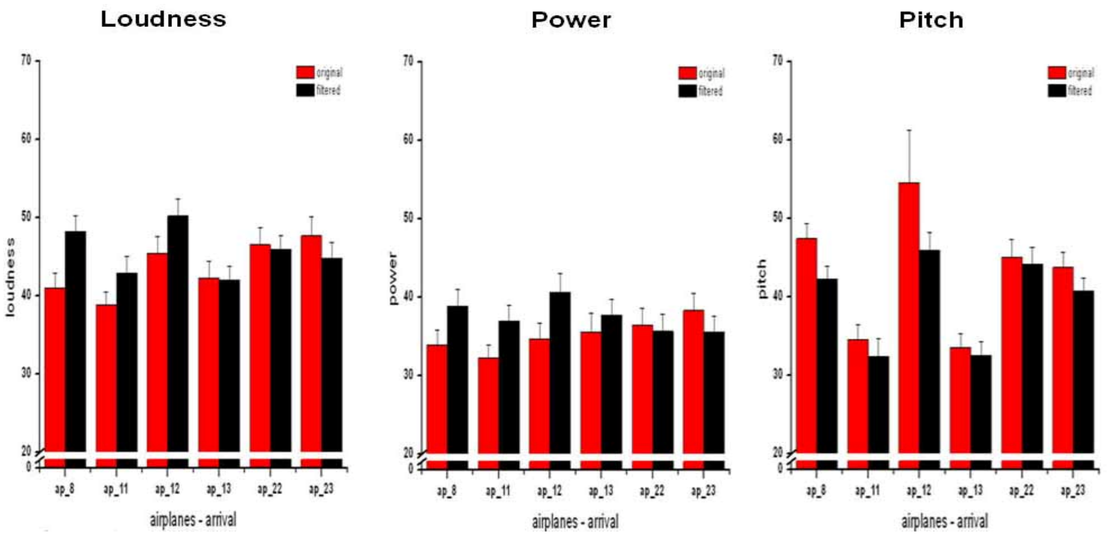

Figure 5 - Arrival aircraft and filtering effects for loudness, power and pitch

For annoyance, hardness and pitch (figure 6 and 7) with no exception the ANOVA reveals highly strong statistical effects in respect to the aircraft and the angle factor for both flight conditions. Note that annoyance and hardness resemble each other in their data pattern. In most cases the 101,3° angle condition is felt as less annoying, less hard and lower pitched than the two other conditions. The maximal annoyance effects can be observed at an angle of 78,7° (figure 6: airplane 11 and 12; figure 7: airplane 12). All aircrafts again differ from each other with all three scales.

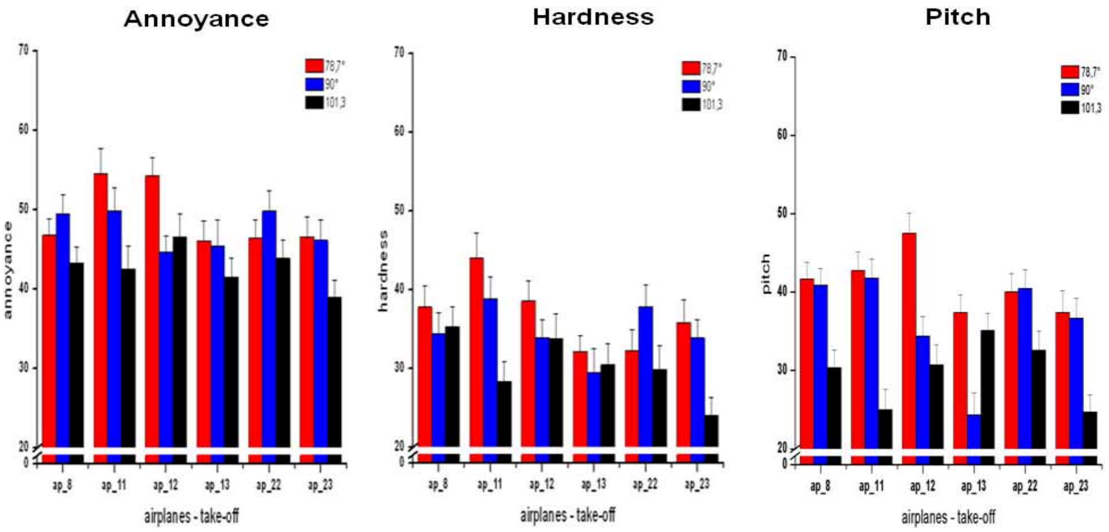

Figure 6 –Take-off - aircraft and angle effects for annoyance, hardness and pitch

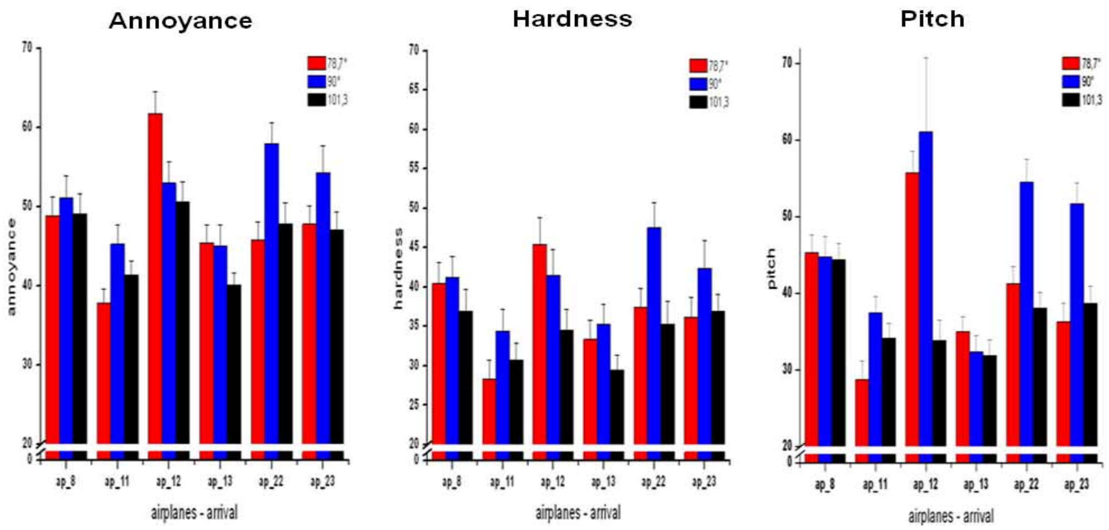

Figure 7 –Arrival - aircraft and angle effects for annoyance, hardness and pitch

CONCLUSION

The experiment reveals clear statistical effects in respect to the five sound quality attributes.

The angle condition shows significant differences in respect to annoyance, hardness and pitch. Strong annoyance effects were found with an angle of 78,7° (aircraft 11 and 12). At this angle position - particularly during take-off - the engine sound prevails (see figure 2). In most cases the 101,3° angle shows less effects than the two others. At this angle the aircraft has already passed the observers position and other sources, e.g. low frequency jet noise, become dominant.

Filtering proves to have a strong impact on loudness, power and pitch. The difference in pitch between the filtered sounds and the originals reflects the fact that filtering erased all tonal components in the spectrum. The difference in loudness and power between original and filtered versions is due to an artificial level reduction of tonal sounds by the EPNL-equalization.

The results will be used in further research as a guideline for selecting specific conditions for aircraft target sound design [1]. As the study indicates that tonal engine effects may be of particular importance further research will concentrate on this topic.

REFERENCES

[1| Bisping, R., “Aircraft Target Sound Design”, Proceedings of the ICSV12, Lisbon, Portugal (2005).

ACKNOWLEDGEMENT

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