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Uncertainties of Measured and Calculated Aircraft Noise and Consequences in Relation to Noise Limits

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The uncertainties of measured and calculated aircraft noise have been analyzed in a thesis at ETH Zurich. The thesis provides information and methods for estimating uncertainties, it shows possibilities for handling these uncertainties and it provides guidance to courts and administrative bodies on how to deal with such uncertainties in applying the legal noise limits. To estimate the uncertainties of calculation and measurement the Swiss aircraft noise calculation program FLULA2 and a lot of measured data has been analyzed. Using radar data it is possible to reach a standard uncertainty of the calculated Leq between 0.5 dB for day-time and 1.0 dB for night-time. The analyses also show that the uncertainty of measurements at automated stations is in the same order of magnitude like the calculations. Therefore the yearly calculated and measured aircraft noise shows no significant deviations. Furthermore with FLULA2 it is possible to stick an uncertainty on a confidence level of 90%. It is now up to administrative and legal bodies to set up rules on how to account for uncertainties of calculations in evaluating noise situations close to legal noise limits.

1 Introduction

Nowadays, aircraft noise is usually calculated over entire areas by means of computer programs. However, information concerning the uncertainty of such calculations is rarely available. In addition, instruction is lacking in regard to how the legal and enforcement aspects should be handled. In a dissertation at the ETH Zürich [1] solutions have been suggested in order to cover this problem.

2 Goals

The work cited above has the following goals:

- Identifying the most important influences in the calculation of aircraft noise and quantifying the uncertainty of the calculated aircraft noise exposure;
- Representing the determined calculation uncertainties in the form of maps;
- Identifying the significant factors and systematic effects in the measurement of aircraft noise and the quantifying of the uncertainties in the measured aircraft noise exposure;
- Validating the calculations and identifying the systematic effects in the calculation by means of comparison of the measured and calculated sound levels in consideration of the calculation and measurement uncertainties;
- Presentation of proposals with regard to the uncertainties in the evaluation of aircraft noise exposure.

3 Basic concept and methodical approach

Measurements as well as calculations are only estimates of the true, although unknown sound levels. When measurements and calculations are compared, for example in order to determine systematic deviations, the uncertainties of both the calculations and measurements must be known. Within the framework of the dissertation and in agreement with GUM [2], the uncertainty is to be described by means of a parameter, which characterises the statistical spread of the measurement value. This parameter can be the standard deviation or a multiplicity of standard deviations.

The main attention in the dissertation is focussed on the uncertainty of the calculated and measured equivalent sound pressure levels. The equivalent sound pressure level stems from a multitude of individual events. Thus, the uncertainty of the equivalent level is a function of the uncertainty of the event level and it is therefore the event level which has to be considered in evaluating the uncertainty. To a good approximation the event level can be determined through the maximum level [3]. Thus, it will be assumed that the uncertainty of the equivalent level may be estimated though the uncertainty of the maximum level.

The various uncertainty components which lead to the uncertainty of an individually measured or calculated maximum level, resp. event level are empirically estimated in the dissertation by means of simulations or specific measurements or are estimated analytically through sensitivity analyses. Then, the uncertainty of the equivalent level is obtained using the procedure suggested by Probst & Donner [4] with regard to the error propagation of sound levels.

4 Uncertainty of a calculated individual flight

To determine the calculation uncertainty over an entire area, the aircraft noise model, FLULA2, developed by Empa was analysed.[5] The following components of the model were identified as yielding the main contributions to the calculation uncertainty: the modelling of the aircraft as a sound source and the modelling of the sound propagation process. The standard uncertainty of the aircraft varies from aircraft to aircraft due to differences in the quality of the data base. It ranges from 0.5 to 5 dB and averages 1.4 dB. The standard uncertainty of the modelling of the sound propagation process likewise depends on the type. At flight levels below 300 meters the uncertainty stems from the uncertainty in determining the exact position of the aircraft. Here, this amounts to more than 3 dB. When the distance between the source and receiver exceeds one kilometre, meteorological effects dominate the uncertainty. The standard uncertainty ranges from 1.5 to 2.4 dB depending on the aircraft type and operation (takeoff or landing). It increases by 0.2 dB to 0.8 dB per kilometre.

5 Uncertainty of the calculated equivalent level

A multitude of individual flights contributes to the yearly noise exposure. Each of these flights is characterised by a different uncertainty depending on the aircraft type and the distance between the source and receiver. Based upon these individual uncertainties the standard uncertainty of the yearly noise exposure for the entire area was calculated (see Fig. 1), employing simulation and the principle of error propagation. For this purpose, FLULA2 was appropriately extended and applied to the actual exposure conditions in Geneva and Zurich. This yielded standard uncertainties for the equivalent level of 0.5 dB for the daytime and 1.0 dB for the night time. However for forecasts the uncertainties increase to 0.9, resp. 1.2 dB as a result of the uncertain assumptions regarding the aircraft operations.

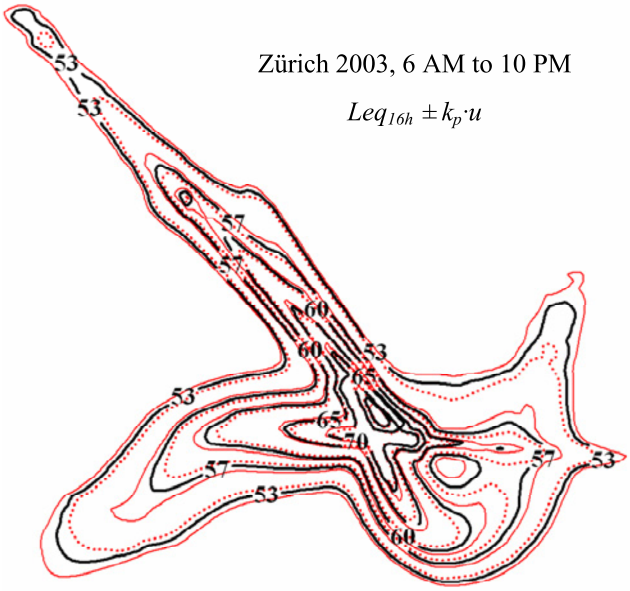

Fig. 1 Zurich airport, daytime noise exposure as a 16 hour equivalent level (black lines) with extended uncertainty region (k_p=2; p=95%) as red lines.

6 Comparison with measurements

In order to ascertain whether the FLULA2 calculations vary significantly from the measurements, the calculated yearly noise exposures were compared with measurements (see Fig. 2). The significance test was carried out in consideration of the calculation and measurement uncertainties. It was found that although the measurement uncertainty is dependent upon the measurement station, the values were generally similar to the calculation uncertainties. Depending on the station, the standard uncertainty of the yearly noise exposures ranged from 0.5 to 0.9 dB.

For the automatic measurement installations systematic errors resulted from the threshold criteria and background noise. These had to be corrected. Taking into account the calculated and measurement uncertainties, the comparison of the values calculated by FLULA2 and the measured values showed for the most part no significant deviations. Nevertheless differences of 1 to 2 dB remained for some locations.

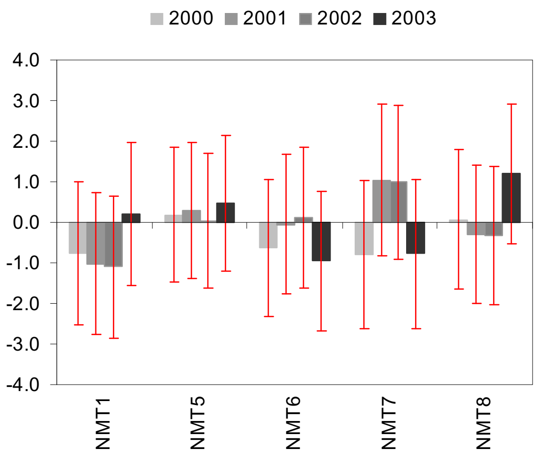

Fig. 2 Comparison of calculations and corrected measurements at selected monitoring stations in Zurich. The columns show the differences (calculation minus measurement) for the daytime equivalent levels (6 AM to 10 PM), the error beams show the combined standard uncertainties of the respective level differences, extended by a factor of 2.

7 Handling the uncertainties

If aside from FLULA2 other calculation procedures are employed, the calculation uncertainties should, in the opinion of the author, absolutely be added to the calculated values as a tolerance before a noise evaluation is considered from the legal standpoint. In addition only calculation procedures should be used which have been validated and shown to yield no systematic deviations to measurements. In addition, the procedure should not yield calculation uncertainties greater than a specified confidence level. The tolerance values should be designated as limit uncertainties. These amount to 1.5 dB for the daytime and 2.5 dB for the nighttime and apply to the noise limits for aircraft noise according to the Swiss Environmental Protection Law.

8 Conclusions and outlook

It can be shown that with FLULA2 it is technically possible under given premises to adhere to specified limit uncertainties with a confidence level of 90%. It is in the hands of the legal and regulatory authorities to define how calculation uncertainties are to be considered with regard to the legal noise exposures. Here, the concept of calculation uncertainty as a tolerance, the concept of noise limit uncertainty and the allowable error probabilities need to be discussed and established. Thereafter the land use planning and economic consequences may be estimated.

References

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