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NUMERICAL EVALUATION AND EXPERIMENTAL COMPARISON OF AIRFRAME NOISE FOR THE OPTIMIZATION OF NEXT GENERATION AIRCRAFT DESIGN

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Abstract

In this paper the airframe noise of civil transport aircraft is numerically evaluated and compared with measurements taken in some european airports with the target of separating the airframe contribution from other noise contributions effective on a typical aircraft. The attention has been focused on airframe noise since it sets a lower limit below whichever reduction of noise generated by engine have no significant effect on the overall noise level perceived by an observer and due to the aircraft flyover. The intensity of airframe noise depends on the aircraft configuration: during the cruise the aircraft exhibit an aerodynamically 'clean' configuration that produces less noise than the configuration assumed by the aircraft during landing and take-off, that usually is referred as 'dirty' one. The configuration with slats extended, flaps down and undercarriage lowered is more noisy than the clean configuration. In this paper the results of numerical simulations performed on common operating aircraft are presented: these simulations allow the contribution breakdown and, therefore, the classification of the most noisy airframe components for the different approach and take-off configurations.

INTRODUCTION

This work has been performed inside a UE funded Project, SEFA (Sound Engineering For Aircraft) finalized at the development of technique, numerical and experimental, for the noise reduction in airport contexts. The main goal is in fact the development of virtual tools, aircraft and resident, capable, on one hand, to reproduce effective aircraft noise, due to the different noise sources acting on a typical civil aircraft, on other hand, to reproduce the human noise perception of such kind of sound. In this Project the authors contribute to separate the airframe noise, one of the possible noise sources, from the others in order to evaluate the weight of this contribution in quantitative terms and to identify the different airframe components contribution to the overall airframe noise: in this way it is possible to establish which of them is the most noisy component and which are its noise characteristics in terms of emitted spectrum and directivity. The importance of such an investigation is to quantify, for the airplanes subject of investigation, the lower limit of noise emitted below any reduction in noise of other sources, like the engine, makes not sense. On other hand, the airframe noise evaluation allows also the identification of the acoustical sources on which the attention should be focused for noise emission reduction by improvement of operating conditions, manoeuvres, take-off and landing paths and so on.

AIRFRAME NOISE

Airframe noise [1] is caused by airflow over airplane surfaces and is dependent upon the airplane configuration: using typically aeronautic terms, an aerodynamically ‘clean’ airplane is less noisy than a ‘dirty’ one, with slats extended, flaps down and undercarriage lowered.

An illustration of the magnitude of this difference in noise level for a typical airplane is shown in figure 1 where the solid curve represents the predicted noise spectrum for the airplane overhead, in the landing configuration, and the dashed curve is for the airplane in the clean configuration at the same location and flying at the same airspeed.

For airframe noise simulation in the far-field a computerised method provided by ESDU™ has been adopted. This prediction method, which is a semi-empirical one, has been developed from that proposed by Fink with changes to directivity and spectral functions based on available experimental data. This method requires in input the airplane geometry, related to the airframe components, and operating conditions. The program permits the estimation of the OASPL and of one-third octave band sound pressure levels within a frequency range and over polar and azimuthal angular ranges set by the user respect to an assigned position of receiver. The output values are for free-field and still, lossless atmospheric conditions. The values so obtained have been then corrected for taking in account atmospheric attenuation and ground reflection. The computerised method adopted can be used to predict airframe noise for discrete airframe elements and by summation for any selected combination of the following airplane components: wing (conventional or delta), slats, horizontal tail, vertical tail, flaps (single-, double- or triple-slotted), main landing gear, nose landing gear.

Although the fuselage does produce some lift, most of the fluctuating lift and drag forces which generate the noise are associated with the components listed above and for this reason the contribution of noise from the fuselage may be considered negligible at a reception point in the far-field. In addition to the prediction of airframe noise from turbo-fan and turbo-jet powered aircraft, the method may be used for aerodynamically clean airplanes like sailplanes.

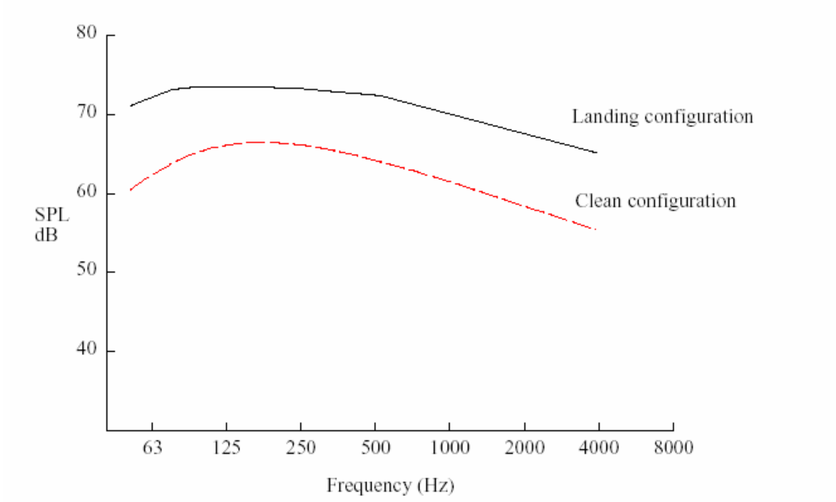

Figure 1: noise spectrum for a typical airplane in 'dirty' and 'clean' configuration (ref. [1])

THE PROCEDURE ADOPTED

For three typical airplanes operating in civil airports worldwide, the geometry required by ESDU™ has been defined. A Matlab™ tool has been implemented to generate the SPL third octave spectra at a receiver location fixed referring to the measurements taken at the Munich airport [2] during fly-over of the airplanes subject of investigation. In figure 2 the map of the Munich airport and the location of the measurement positions is reported. The attention has been focused on the take-off and landing phases: the flight path has been derived respect to the measurement position and has been used in input to the developed code for the definition of the receiver location respect to the airplane. The spectra so obtained have been then corrected for taking in account the atmospheric absorption and the ground reflection [3, 4].

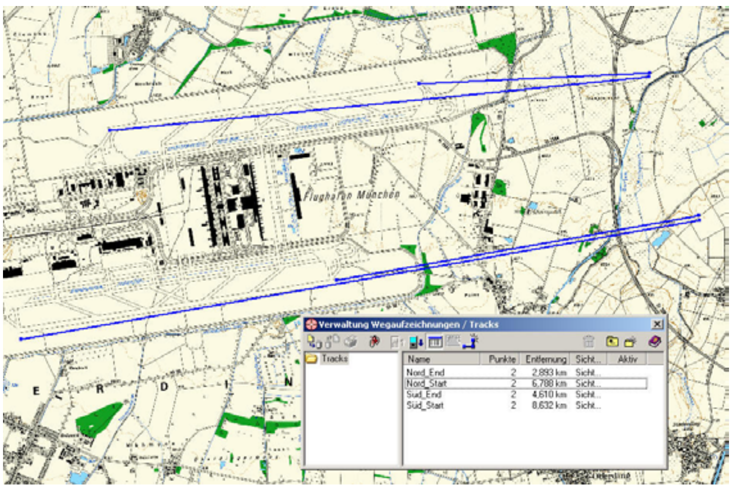

Figure 2: position of microphones at Munich airport

BACKGROUND TO METHOD, EQUATIONS, ACCURACY

In this chapter a brief overview of the background of method is presented. It works by modelling each individual airframe component as elementary source or source distribution: the components taken in account are wing, flaps, slats, tail and landing gear; it is not possible to take in account any interaction between them and their spectral and directivity characteristics are analytically or empirically derived. The spectral contribution of each single component is obtained and then a summation of the selected combination is performed at the receiver location. The method of calculating the broad-band noise contribution from each of the various airframe components is based on the references 5 and 6. The same basic sequence of steps is followed for each component but with appropriately different values of constants and functions. The sound pressure level at the reception point, adjusted for the difference in ambient pressures at airplane and reception point locations is given by the equation:

$$SPL = 10\log p^2 + 10\log\frac{\rho^2 c^4}{p_{ref}^2} - 20\log\frac{p_l}{p_0} \tag{1}$$

where p^2 is the mean-square acoustic pressure non-dimensionalised by ρ^2c^4. In this form, it is given by the following equation:

$$p^2 = \frac{Pb_w^2 D(\phi_f, \vartheta) F(Sr)}{4\pi r^2 (1 - M\cos\vartheta)^4} \tag{2}$$

The term Pb^2_w in Equation 2 is a function of Mach number, and has the form:

$$Pb_w^2 = k_1 M^{k_2} k_3 \tag{3}$$

where k_1, k_2 are constants and k_3 is a geometry function depending on the airframe component under consideration. The Strouhal number has the form:

$$Sr = \frac{fl}{Mc}(1 - M\cos\vartheta) \tag{4}$$

where l is a length scale characteristic of the airframe component. Each airframe component also has its own directivity function, $D(\phi_f, \vartheta)$, and spectrum function, $F(Sr)$. Motion of the source is accounted for by the Doppler frequency factor $(1 - M\cos\vartheta)$, and a source amplification factor $(1 - M\cos\vartheta)^4$. The airframe noise prediction procedure adopted is not suitable for use on propeller-driven airplanes. The principal reason for this unsuitability is that installation effects associated with propellers are likely to be very different from those associated with the turbofan airplanes used to develop the prediction method. The prediction method is not designed to account for either tonal components or to consider interaction between different airframe elements; furthermore, does not address airbrake or winglet noise, or the effect of podded undercarriages. Wing incidence effects is neglected. Although there are no explicit limits on take-off weights or airspeed, this prediction method has been validated for multi-engined turbofan airplanes with maximum take-off weights ranging from 42000 kg to 390000 kg and flying at airspeeds ranging from 70 m/s to 145 m/s. Wherever possible, data for runs in which engines had been set to flight idle were used for the validation process. The airframe noise component is at its maximum fraction of the total airplane noise during the final approach, because all the high lift devices are usually deployed, the undercarriage is lowered, and the engines are set at the minimum thrust setting required for maintaining the desired glide slope. Comparison with experimental data showed that the error depends on the frequency and on the receiver position: for azimuthal positions of the airplane respect to the receiver the error does not exceed 2 dB.

RESULTS

In the following figures the results are reported for one of the three civil airplanes subject of investigation. At first the landing phase has been simulated: the landing path derived by the measurement campaign has been given in input to the developed Matlab™ tool able to perform the different numerical simulations at each instant of time at every position of the airplane respect to the receiver. In figure 3 the altitude of the airplane (experimentally obtained by the taken measurements) respect to the receiver, that is located on the zero of the x-axis, is reported. In figure 4 it is evident that OASPL reaches the maximum value before the azimuthal position on receiver. Furthermore during the landing phase the most important contribution to overall noise level is given by the high lift devices: flaps and slats.

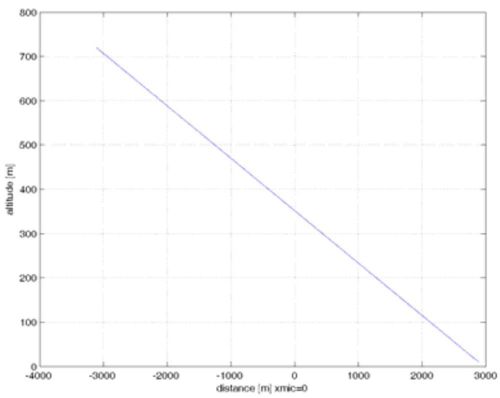

Figure 3: landing path of airplane 1

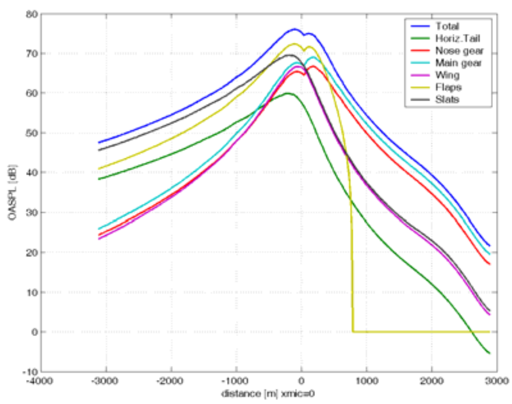

Figure 4: OASPL at receiver location and its breakdown into components

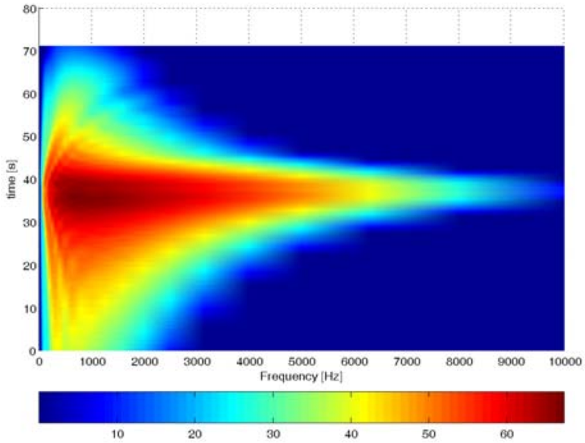

Figure 5: spectrogram of the landing airframe noise of airplane 1

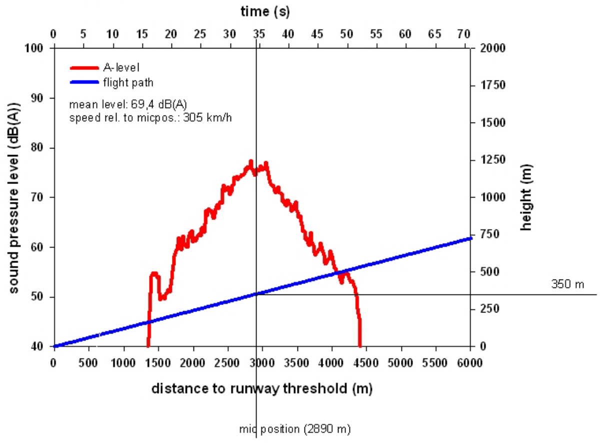

Figure 6: dBA SPL acquired during landing of airplane 1

The results show the strong directivity of the flaps that is the dominant acoustic source until the airplane reaches the azimuth on receiver, afterwards the main acoustic contribution is given by the landing gear.

From figure 5 it is evident that the frequency content of the airframe noise is characterized by low frequencies components: this is also due to the atmospheric absorption effect besides the spectral characteristics of each acoustic component contributing to the airframe noise. The figure 4 should be compared to the taken measurements reported in figure 6: the airframe noise maximum level predicted is about 76 dBA while the global (airframe, engine and all other sources) noise level measured is about 77 dBA: this is in part expected because during the landing phase the engines are set at the minimum thrust and the airframe noise is the main acoustic source. Further investigations are needed to improve this numerical-experimental correlation. In the following figures the results of airframe noise simulation during take-off are reported.

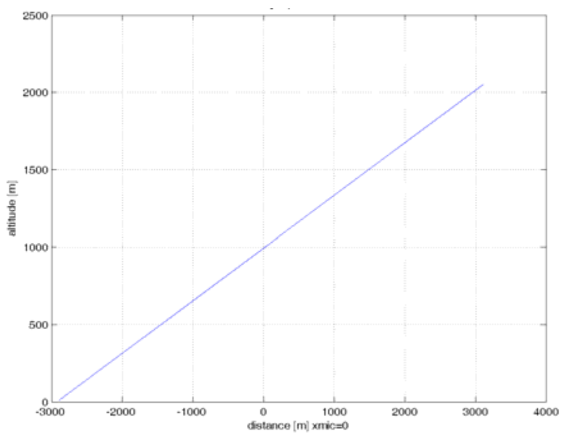

Figure 7: take-off path of airplane 1

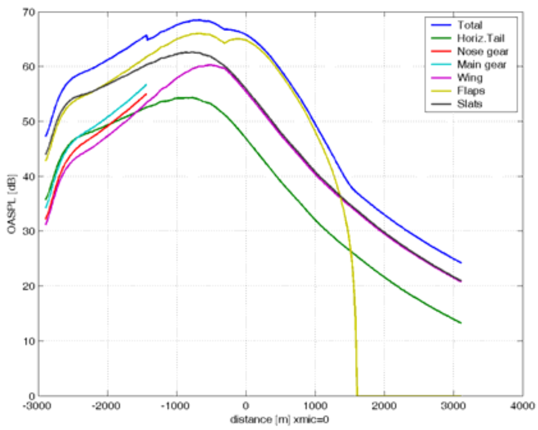

Figure 8: OASPL at receiver location and its breakdown into components

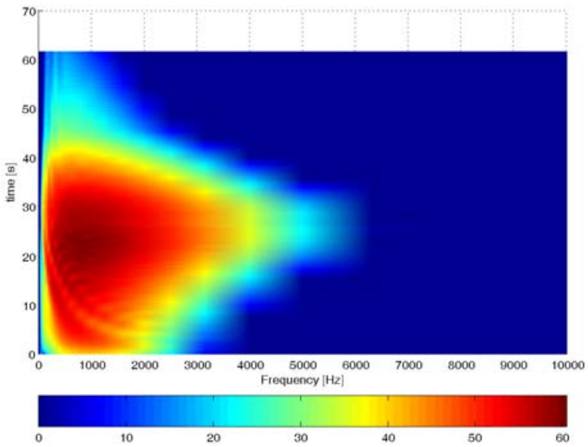

Figure 9: spectrogram of the take-off airframe noise of airplane 1

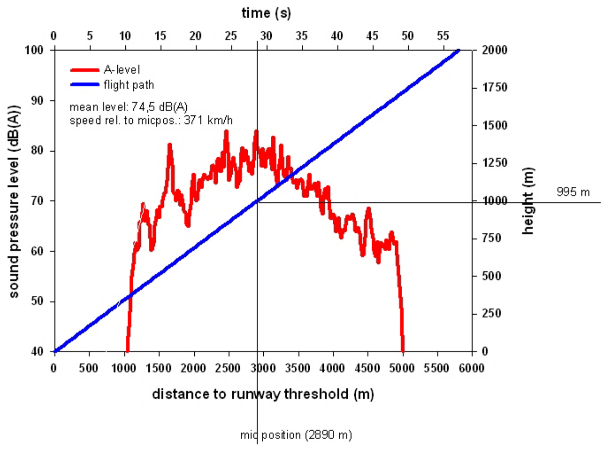

Figure 10: dBA SPL acquired during landing of airplane 1

From figure 8 it is evident that the landing gear contribute to the overall noise during the first part of take-off until it is completely retracted: such circumstance has been modeled numerically as an instant event and leads to a discontinuity of the total noise curve corresponding to the time instant in which the landing gear is retracted.

Furthermore after the fly-over on receiver the most important contribution is given at first by the flaps and then by wing and slats, also if their contribution become dominant when the total overall noise is lower than 40 dBA.

The numerical-experimental correlation should be performed comparing the predictions of the figure 8 with the measurements reported in figure 10: it is evident that the airframe noise maximum level predicted is about 69 dBA while the measured SPL show a fluctuation around a reasonable value of 80 dBA. This difference is expected since during the take-off the engines are the main acoustic source and their contribution seems to be dominant on the airframe.

From figure 9 the same considerations of the corresponding landing spectrogram come out with the only difference that, during take-off, the altitude of the airplane on the receiver is higher than during the landing and this leads to a further decrease of high-frequencies contribution.

CONCLUSION

Airframe noise evaluation is essential to evaluate the lower limit below reductions in engine noise emission have no significant effect. A numerical procedure based on ESDU™ has been implemented for evaluating airframe noise due to take-off and landing of 3 civil aviation aircrafts operating in worldwide civil airports. Future steps in this activity can be a more detailed numerical-experimental correlation on the available data and investigation on the possible improvements of the airframe noise by innovative architectural concepts (main gear, nose gear, high-lift device)

ACKNOWLEDGEMENTS

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