Euronoise 2015 Maastricht

Estimating variation in community noise due to variation in aircraft operations

Athanasios Synodinos, Rod Self, Ian Flindell, Antonio Torija
University of Southampton, ISVR, SO17 1BJ Southampton, UK

Summary

Notwithstanding considerable effort by many researchers world-wide, the estimation of community noise due to changes in aircraft fleets and operations remains subject to considerable uncertainty. This paper describes a new taxonomical architecture for aircraft noise prediction models that can be adapted to differing levels of input data and required outputs. Sound levels on the ground are estimated at base level using a custom noise prediction tool. The aim then is to determine variations on this base level depending upon differences in known input data whilst by-passing the full complexity of engineering models for which the necessary inputs can often only be assumed or are not even available for particular cases. The architecture is well-adapted for estimating incremental change associated with single input variables, such as approach glide slope angle, or flight track concentration associated with performance based radio navigation. The research is being carried out as part of a wider effort to better understand environmental and economic interdependencies, for which taxonomical models can be highly beneficial.

PACS no. 43.50.+y, 43.28.+h

1. Introduction

The predicted increase in air traffic growth underlines the need for additional aircraft noise mitigation measures, in terms of both aircraft technology and flight operations. The accurate assessment of potential abatement measures is therefore a matter of some significance.

Historically, the prediction of individual aircraft noise levels (and reduction due to decreased source levels) has been motivated by the need of manufacturers to meet increasingly stringent certification levels, as measured in EPNLdB. Consequently, a number of detailed 'engineering' noise prediction tools have been developed to help meet this need. Typically these tools consider the individual sources on the aircraft together with installation effects (such as wing reflection and liner attenuation) as the basis for predictions. In turn, this may require knowledge that is commercially confidential if accurate predictions are to be made. Conversely, community noise levels arising from mixed fleet operations are normally assessed using average metrics, for example L_{eq} and L_{den}, which can be predicted with tools, which we refer to as 'airport models'. Unlike the engineering tools, these treat the aircraft as a lumped acoustic source and use Noise-Power-Distance (NPD) curves fixed using empirically measured data points available in the public domain.

It is apparent that these differing philosophies towards prediction mean that a direct assessment in terms of community noise levels arising from variations of source levels (either directly or indirectly as a result of operational variation) is a far from simple task. Not least because the custodians of one type of toolset tend not to be expert in the use of the other and vice-versa.

The purpose of the research reported in this paper, which is part of a wider effort to better understand environmental and economic interdependencies, is to develop a simple method of estimating community noise variations due to changes in aircraft source levels and operational variation that bypasses difficulties associated with having two differing prediction methods and the need for detailed knowledge of source models. It will form the acoustical basis of a tool based on a new taxonomical architecture, which only uses changes as inputs and gives as output the variation to the base community noise levels as predicted using existing tools.

For the purposes of illustrating the method, discussion will be centred on finding the variation in noise due to a change of approach angle when an aircraft is landing. Whilst the base noise level could be calculated using INM, a simplified tool (which we refer to as the Custom Noise Tool) will be used. This has the advantage of allowing the exact error in the new method to be displayed.

2. Description of noise prediction tools

In this section we first review briefly the underlying methodologies of airport and engineering models, followed by a description of the Custom Noise Tool.

2.1. Airport models

Airport models, such as INM [1] or ANCON [2], rely on Noise-Power-Distance (NPD) databases derived from measurements together with semi-empirical modules. More specifically, noise levels at a given observer point due to a given aircraft thrust setting, are obtained by interpolation across NPD curves. Airport models are useful at legislation and commercial level, as they aim at improving the effectiveness of environmental rules and the competence of airports and airlines, in terms of existing technology and configuration. Since the calculations rely on actual measurements rather than on complex mathematical models, airport models can sensibly predict average values of aircraft noise exposure, in reasonable time. However, they are also subject to uncertainties, mainly because it is practically impossible to produce experimental datasets for all aircraft-engine pairs and configurations; which poses limitations on their simulation potential regarding contemporary procedures and configurations, revised suppression technologies and advanced designs. Additionally, flyover measurements can be unreliable due to unpredicted parameters, such as wind and slight trajectory or weight alterations, implying that multiple measurements are needed for the sake of statistical reliability. Another limitation is that since airport models treat the aircraft as a lumped acoustic source, they do not predict noise contribution from individual components and thus critical noise sources remain unidentified.

2.2. Engineering models

Engineering models, such as ANOPP [3] or SOPRANO [4], are physics-based and typically attempt to simulate the extremely complex aircraft noise generation and propagation mechanisms. Therefore they are associated with computationally intense and complicated calculations. These tools consider the individual sources on the aircraft together with installation effects (such as wing reflection and liner attenuation) to make predictions. Engineering models are normally employed at research level, as they can evaluate noise from new aircraft and unconventional configurations. In terms of modelling individual sources of the aircraft (fan, jet, combustor, etc.), engineering models often give the user the freedom to choose the precise model employed, which may be a private model, or

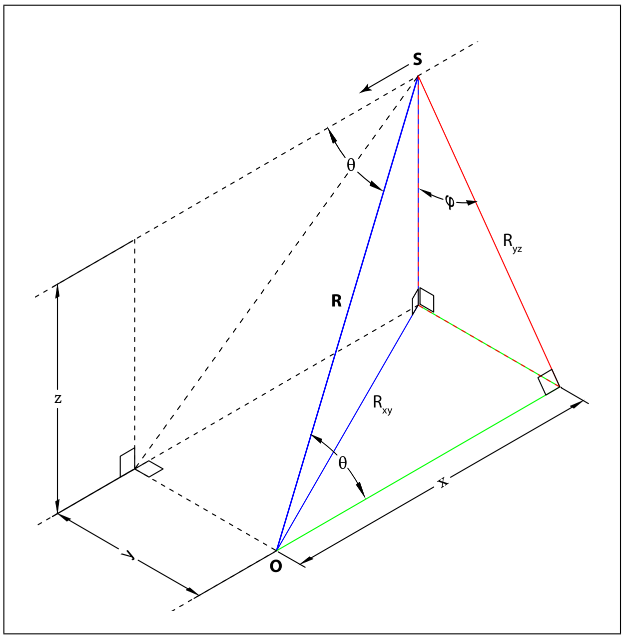

Figure 1. Representation of the coordinate system and notation used.

a publicly available method, such as the methods of Stone [6] for jet noise and Heidmann [7] for fan noise. Needless to say, private commercial models are often more accurate than their publicly available counterparts.

2.3. Custom Noise Tool

The Custom Noise Tool is in reality a simplified engineering model. It uses the geometric layout and notation of Figure 1. Points S and O represent the aircraft centre of gravity and observer respectively, with the distance between them denoted by R. The tool uses an aircraft model consisting of 4 airframe and 8 engine noise sources, as listed in Table I. Each noise source contribution to the overall emitted noise varies depending on flight operation; for instance, dominant components in the landing configuration are the landing gears, high-lift devices, fan and combustor. Sound noise power values for each source of a typical aircraft being in landing configuration are taken from [5]. Directivity of aircraft noise sources, which plays an important role in the way sound propagates towards an observer, is expressed in terms of the polar and azimuthal directivity angles with appropriate functions $D(\theta, \phi)$ respectively. Regarding engine noise sources, the Custom Noise Tool uses directivity indices in dB taken by ANOPP theoretical manual [3], with interpolation where required followed by a suitable normalisation. Airframe noise sources (landing gears and high-lift device) are considered as omnidirectional sources. The SPL at an observer located at distance R and direction (θ, ϕ) from an aircraft con-

Table I. Aircraft noise sources considered by the Custom Noise Tool.

Airframe	Engine
Nose Landing Gears	Fan Inlet Broadband
Main Landing Gears	Fan Discharge Broadband
Leading Edge Slats	Turbine Broadband
Flaps	Jet Broadband
	Combustor Broadband
	Fan Inlet Discrete Tone
	Fan Inlet Combination Tone
	Turbine Tone

sisting of m noise sources with power W_i and directivity $D_i(\theta, \phi)$ is obtained by:

$$\mathrm{SPL}(\theta,\phi,R) = 10\log\left[\sum_{i=1}^{m}\frac{W_i D_i(\theta,\phi)}{R^2}\right] + C\,. \quad (1)$$

In the equation above, C is a constant related to the ambient conditions.

The main simplifications made are that (1) no Doppler shifting or retarded time effects are considered, (2) atmospheric attenuation is ignored and (3) no accommodation of the varying spectral content of the different sources is made.

Additionally, although no explicit mention of installation effects is made, it will be argued later that this is not a serious concern. Likewise, we will later discuss the other simplifications.

From Equation 1 the value of the community noise metric for a single aircraft operation can be obtained. As the aircraft moves along its flying path, coordinates (θ, ϕ, R) vary, meaning that the SPL at the observer position is an implicit function of time. Thus, a time average can be made:

$$\mathrm{L}_{eq} = 10\log\left[\frac{1}{T}\int_0^T 10^{SPL/10}\,\mathrm{d}t\right]\,. \quad (2)$$

In Equation 2, T is the duration of the aircraft noise event.

3. Noise Variation Estimation

The purpose of this section is to develop simplified ways of estimating the variations expected to SPL and L_{eq} arising from variation in source level and operational variation and to estimate the expected error in doing so.

For any relative position of aircraft and observer, the SPL at a receiver R meters away will be given by equation 1 above. If the power of source j changes to $W_j + \Delta W_j$, then SPL at the receiver becomes:

$$\begin{aligned}\mathrm{SPL}' &= \mathrm{SPL} + 10\log\left(1 + \frac{\Delta W_j D_j}{\sum_{i=1}^{m} W_i D_i}\right)\\ &= \mathrm{SPL} + \Delta dB\,, \end{aligned} \quad (3)$$

where an estimation of the ΔdB can be made using an asymptotic expansion of the log function as:

$$\Delta dB_{Est} \approx \frac{10}{\ln(10)}\frac{\Delta W_j D_j}{\sum_{i=1}^{m} W_i D_i}\,. \quad (4)$$

Equation 4 significantly reduces complexity since the estimated SPL change at the receiver point, under the new conditions, is only dependant on the power change of noise source j. Furthermore, we can recast this equation in terms of the base level SPL as

$$\Delta dB_{Est} \approx \frac{10^{(1-SPL/10)}}{\ln(10)}\frac{\Delta W_j D_j}{R^2}\,. \quad (5)$$

By integrating over time we also obtain an expression for the estimated change in L_{eq}:

$$\Delta L_{eq_{Est}} \approx \frac{10}{\ln(10)T}\int_0^T \frac{10^{(-\mathrm{SPL}/10)}\Delta W_j D_j}{R^2}\,\mathrm{d}t\,. \quad (6)$$

3.1. Approximation Error

In the following section, the validity of Equation 4 is investigated. Using the notation of Equations 3 and 4, the error e in dB arising from the above approximation is:

$$e = |\Delta dB - \Delta dB_{Est}|\,. \quad (7)$$

Figure 2 illustrates the approximation error when applied to acoustic power variations of individual noise sources. The aircraft is assumed to be in the landing configuration, with the fan inlet broadband noise dominating, followed by the landing gears and flaps noise. Clearly, due to the logarithmic nature of the decibel scale, there is much more space for increasing the noise level of non-dominant sources, such as the jet and the turbine, without producing significant error. For example, as seen in Figure 2, estimating the SPL change at the receiver due to a 1 dB increase of fan discharge noise produces almost no error. In contrast a 1 dB increase of the fan inlet noise, which is the dominant source, generates an approximation error of around 0.6 dB.

Figure 3 illustrates the difference between calculated and estimated SPL change at the receiver, in dB, due to a percentage change (increase) of the dominant source noise power. As already mentioned, in the landing configuration considered, the dominant noise

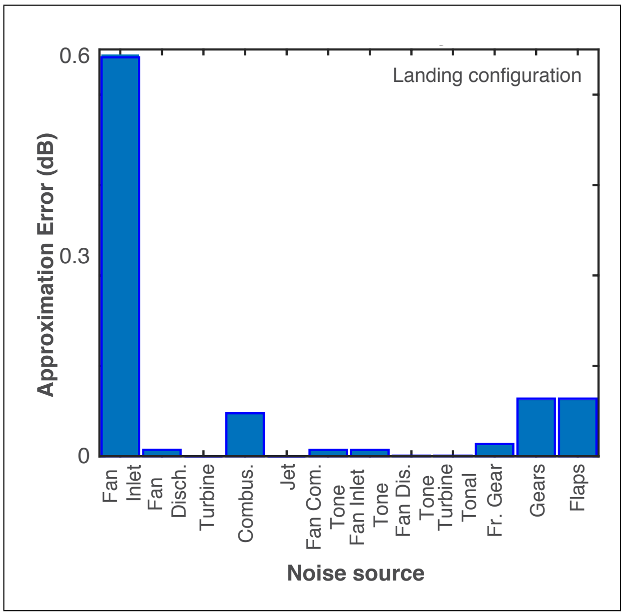

Figure 2. Error when estimating the SPL change at the receiver due to a 1 dB increase of the level of individual aircraft noise sources.

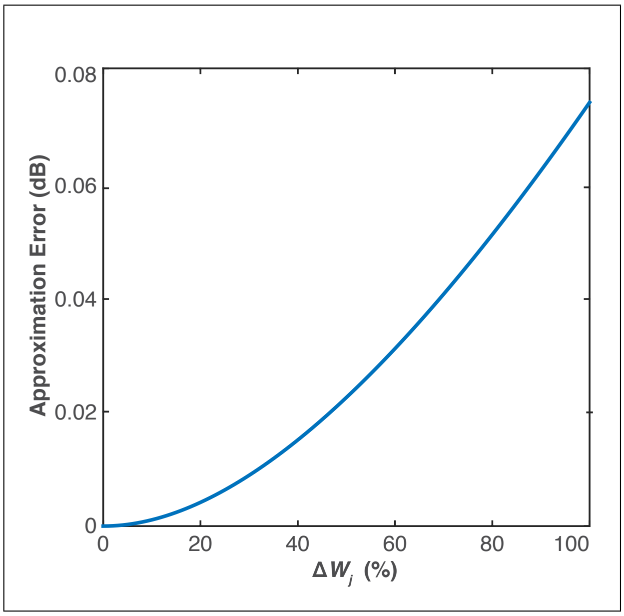

Figure 3. Error when applying a percentage change (increase) to the dominant source noise power.

source of the aircraft is the broadband component of the fan inlet. It is observed that we get a small error, even for significant percentage changes of the dominant source sound power. For example, if the dominant source sound power is increased by 80%, the estimated SPL error will lie well below 0.1 dB. This also implies that non-exact ΔW_j values arising from approximation models, such as the methods of Stone [6] and Heidmann [7] would have a negligible overall effect.

Table II. Calculated and estimated noise metrics for normal and steep approach.

	Normal Calc.	Steep Calc.	Steep Estim.	Difference Calc. - Est.
L_{eq} (dB)	78.76	73.04	73.20	0.16
SEL (dB)	87.68	85.03	84.93	-0.09
L_{max} (dB)	82.44	76.77	77.05	0.28
SPL, Land. Cert. (dB)	82.37	76.74	76.87	0.13

4. Example Application: Steep Descent

As an example, the method is used to estimate the noise variation due a change of final approach angle from the traditionally used 3° to 6°. Figure 4 gives a schematic representation for both approaches. In both cases, the aircraft follows a Continuous Descent Approach (CDA), decelerating at a constant rate from an airspeed $u_0 = 250$ knots to a touchdown airspeed $u = 134$ knots. In the normal approach case, the aircraft descends from 6,000 ft to sea level, covering a distance d. For comparison to be objective, the two approaches are time-synchronised, so the same trajectory length d is used for the steep approach case. Consequently, as illustrated in Figure 4, the aircraft is supposed to start its steep descend from a higher altitude. Furthermore, it is assumed that steep approach is accompanied by a 10% increase of noise power W at source; this is not only due to the increased drag involved in a steeper approach that is compensated with increased thrust and thus increased noise, but also because flaps may need to be further extended than normal and thus become noisier. The observer position is at the landing certification point, which is 2 km away from the airport, on the runway axis.

Table II lists the calculated and estimated noise for these scenarios under the most commonly employed aircraft noise metrics; these are the equivalent sound level L_{eq}, the Sound Exposure Level (SEL), the Maximum sound level (L_{max}) and the instantaneous sound level when the aircraft flies over the certification point. Figure 5 compares the calculated, using the Custom Noise Tool, SPL time history at the observer point for both approaches. The time is considered zero when the aircraft flies directly over the observer. Figure 6 illustrates the calculated and estimated, using the proposed method, SPL time history for the steep approach.

Figure 6 suggests that the variation was estimated rather accurately using the proposed taxonomical architecture. The calculated and estimated SPL curves almost match. With reference to the same Figure, the noticeable (but very small in absolute value) discrepancy observed in the short period from around -2 seconds to around 7 seconds, is found to be caused by the assumption that directivity factor remains the same.

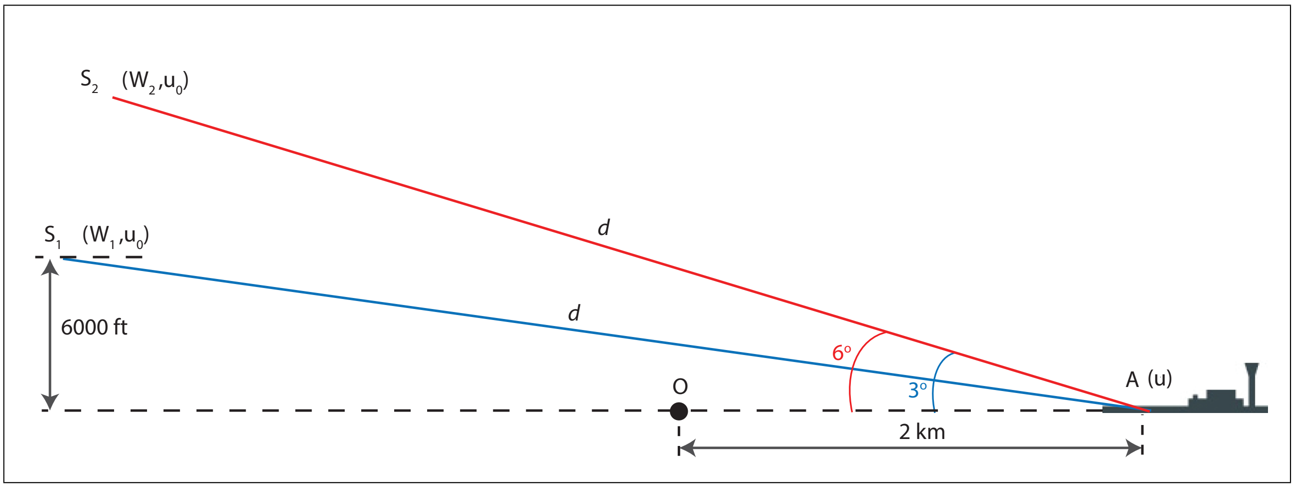

Figure 4. Schematic representation of normal and steep approach.

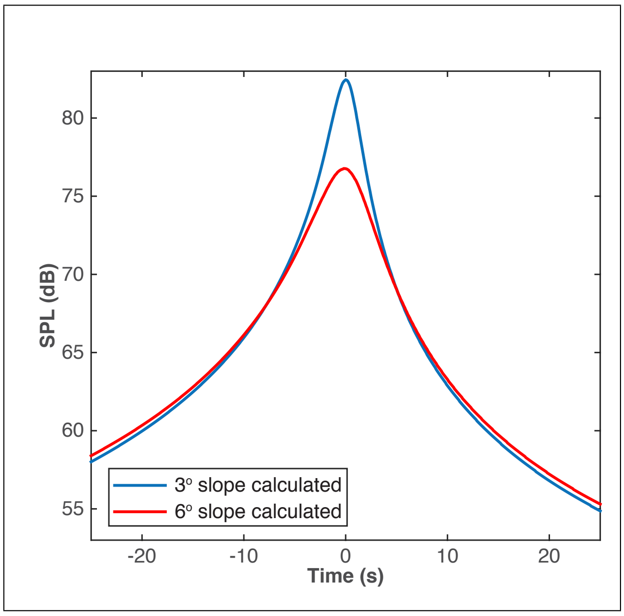

Figure 5. Calculated SPL time history at the observer point for normal and steep approach. The time is considered zero when the aircraft flies directly over the observer.

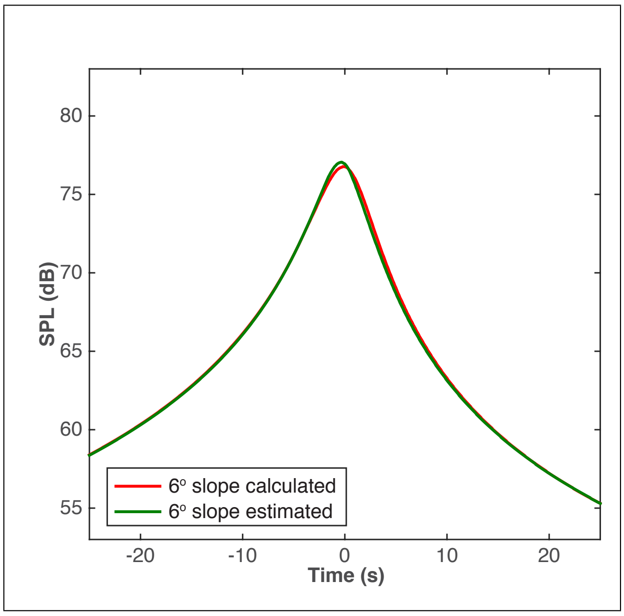

Figure 6. Calculated and estimated SPL time history at observer point for the steep approach. The time is considered zero when the aircraft flies directly over the observer.

In fact, this assumption is purely true only when the aircraft is directly above the observer. In any other point there is a slight alteration of the polar angle (azimuthal angle is zero in both cases) generating this difference between computed (which accounts for this directivity difference) and estimated SPL.

Table II shows the accuracy of the method in terms of noise exposure metrics. The difference between calculated and estimated L_{eq} is only 0.16 whereas calculated and estimated SEL values almost match.

5. Discussion

The analysis has demonstrated an accurate estimation procedure for determining changes in aircraft SPL levels (and hence community noise levels L_{eq}) due to a change of individual noise sources. However, the analysis was made ignoring several factors that are known to apply in real cases, such as Doppler effects, installation effects and atmospheric absorption. It is important to judge the robustness of the method if such effects had in fact been included and justify the statement above that it is.

To take installation effects as an example. In engineering models of aircraft noise, installation effects are normally included as a ΔdB on the corresponding source term:

$$W_j + \Delta W_{j,install}\,; \tag{8}$$

and we can assume that $\Delta W_{j,install} \ll W_j$ i.e. the installation effects are first order correction. Rather clearly, if the uninstalled source strength changes then there will also be a change in the installation delta $\Delta W_{j,install}$, which is a second order correction – hence ΔW_j is in fact a reasonable estimate of the change in installed source levels. Note that it is not necessary in this case to know the value of the installation effect as the method uses the aircraft SPL levels in the calculation and these implicitly include installation effects. Similar arguments can be made for Doppler shifting, retarded time effects and atmospheric attenuation.

Furthermore, Equations 3 to 6 involve the source directivities D_j and these must be estimated using a source model of some kind.

As we have already noted, engineering models that rely on publicly available source modules (e.g. Stone [6] and Heidmann [7] tend to be less accurate at predicting absolute levels than those utilising commercially sensitive data. However, as a general rule, they perform reasonably well at predicting changes in source noise levels.

This paper has shown that if a change of individual noise source is known then an extremely accurate estimate of overall aircraft noise can be made, using only the initial aircraft noise (base SPL), which is available in the public domain. Thus, it opens the possibility of an extremely useful hybrid methodology that estimates very accurately the change ΔdB of community noise due to a source noise power change ΔW_j, by combining this change, which is publicly available from engineering models, with a base SPL, which is also publicly obtainable through tools like INM [1].

6. Conclusions

This paper illustrates the basis for a new hybrid method of estimating changes in community noise due to changes in aircraft noise sources and operations that does not rely on commercially restricted data. As it does not require detailed calculation of Doppler effects, installation effects and atmospheric absorption it will be considerably simpler and quicker than exact calculations.

Further work involves the incorporation of the effects of frequency and testing against real aircraft data.

Acknowledgement

The main author (AS) wishes to acknowledge financial support from Anderson Acoustics consultancy.

References

[1] E. R. Boeker, E. Dinges, B. He, G. Fleming, C. J. Roof, P.J. Gerbi, A.S. Rapoza, J. Hemann: Integrated noise model (INM) Version 7.0. Technical report FAA-AEE-08-01, Federal Aviation Administration, January 2008, Washington, D.C., USA.

[2] Ollerhead J B, The CAA Aircraft Noise Contour Model: ANCON Version 1, Civil Aviation Authority, DORA Report 9120, November 1992.

[3] W. E. Zorumski: Aircraft noise prediction program : theoretical manual. NASA, Scientific and Technical Information Branch, Washington, D.C., 1982.

[4] N.Van Oosten: Users manual of Soprano aircraft noise prediction code, Volume I, Silence(r) Consortium, 2001

[5] A. Filippone: Advanced Aircraft Flight Performance. Cambridge University Press, 2012.

[6] J.R.Stone, D.E.Groesbeck, C.L.Zola: Conventional profile coaxial jet noise prediction, AIAA Journal, 21(1) (1983), pp. 336-342

[7] M.F.Heidmann: Interim prediction method for fan and compressor source noise, NASA Technical Report TM-X- 71763, 1979