Validation of Aircraft Noise Models with Fly-over Data

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Review

Comparison of Aircraft Noise Models with Fly-over Data

Antonio Filippone*
University of Manchester, United Kingdom

Lothar Bertsch†
DLR Göttingen, Germany

This note deals with validation and verification issues in aircraft noise prediction. We use two different comprehensive simulation software: FLIGHT and PANAM. The comparison is done on the basis of extensive flight data taken on an Airbus A319-100 operated by Lufthansa. This paper aims to contribute to the establishment of rational validation standards, as well as realistic accuracy margins on integral noise metrics. The computer codes are briefly described. Results are shown for a variety of microphone positions, located sideways and directly along selected departure and approach flight ground tracks.

Although noise levels have been driven down by a combination of technological advances and international regulations, they remain unacceptably high. Thus, the problem has expanded to include land planning, flight scheduling and noise zoning. Simulation is inevitable in order to assist decision making for land-use planning, design of operational procedures, and the assessment of low-noise technology and vehicle concepts. Fast but accurate simulation methods are required. A number of such simulation methods for overall aircraft noise prediction have been developed over the years. The scope of this contribution is to identify and establish a first set of recommendations for a comparison and validation of overall aircraft noise prediction codes. Based on available data from a dedicated flight campaign (Airbus A319-100), two selected tools are compared and validated. The established rules and the proposed proceeding is demonstrated.

Fast Aircraft Noise Prediction Models

In order to fight aircraft noise pollution, fast simulation methods are required. An increasing demand for these tools can be identified¹. In general, these noise prediction tools can be assigned to two

*Senior Lecturer; Senior AIAA Member. School of Mechanical, Aerospace, Civil Engineering, Manchester M13 9PL. E-mail: a.filippone@manchester.ac.uk.

†Research Engineer, DLR, Helicopter Department, AIAA Member; lothar.bertsch@dlr.de.

major categories, i.e. best practice and scientific prediction methodologies².

Best practice tools are usually based on fully empirical models derived from ground noise measurements, thus offer no physical insight into the nature of aircraft noise. The noise source modeling is inherently reduced to one overall noise source for the entire aircraft. As a consequence, individual noise sources that can dominate along realistic (approach) flight procedures are not accounted for². For example, dominating contribution of various airframe noise sources is experienced along typical approach procedures according to the complex schedule of configuration changes. Yet, best practice tools are characterized by a high prediction accuracy for longterm scenarios. These tools are qualified for application in air-traffic management and legislation processes with the focus on noise protection zones, land-use planning, and consulting. The most prominent example is the Integrated Noise Model (INM) developed by the US Federal Aviation Administration³.

Scientific tools on the other hand are based on semi-empirical but physics-based approximations². Noise generation and propagation are separately modeled according to basic physical effects. Parametric and component models are applied in order to separately simulate each relevant noise source on-board of the aircraft. As a consequence, the noise prediction methodology can account for the specific operational conditions along a simulated flight and the component's geometry. In contrast to the best practice tools, scientific tools enable a feasible evaluation of single approach flight events with varying configurations settings. The dominance of individual noise sources during realistic flight operation can be simulated and monitored. Ultimately, scientific or comprehensive noise prediction tools are required in order to pursue ICAO's balanced approach². The most prominent existing scientific tool is NASA's ANOPP^{4;5} and its successor ANOPP2⁶. The main focus of the presented research lie on low-noise flight procedures^{7;8} and low-noise aircraft design⁹, respectively. Consequently, application of scientific or comprehensive noise prediction tools becomes inevitable.

PANAM. The *Parametric Aircraft Noise Analysis Module* (PANAM) serves as an integration framework to exploit and incorporate existing and future DLR capabilities in airframe and engine noise modeling, vehicle design, flight procedures, air traffic management, and evaluation of noise effects. Specialists from individual disciplines can use PANAM in order to evaluate their individual technologies on a system level, thus assess the overall impact on vehicle performance and the environment. The individual airframe noise components (i.e. lifting and control surfaces, leading and trailing edge devices, spoilers, and landing gear) are modeled with DLR in-house approaches^{10;11}, . Engine noise models are based on available and published solutions^{12;13} but have been modified and adapted¹⁴. Furthermore, a DLR-in-house model to account for the noise absorption due to acoustic

liners has been implemented¹⁵.

Required airframe geometry parameters, e.g. high lift system layout, come from available manufacturer's data sheets and DLR in-house data bases. The remaining vehicle design parameters come from the aircraft design synthesis code PrADO¹⁶. PrADO's weight estimations for the selected vehicle are in the order of $\pm 2\%$ with respect to the original aircraft².

Larger deviations can be experienced for the engine cycle modelling. High fidelity simulation is applied to the selected reference engine and resulting parameters are provided as input for the noise prediction with PANAM. Very limited validation data are available from the engine manufacturers; uncertainty can increase if engine performance is simulated for off-design operating conditions. Thus, the overall deviation of specific engine performance parameters is difficult to assess.

Additional result uncertainties are imposed by the noise source models. Whereas prediction accuracy of implemented airframe noise source models is in the order of ± 1 dB(A), engine noise source models can show larger deviations, up to ± 4 dB(A). Overall, inherent uncertainties on the order of several dB(A) are experienced within the noise prediction process. Consequently, a comparison of predictions and flyover noise measurements can only indicate the feasibility of the simulated results.

FLIGHT. The program FLIGHT was developed with the aim of creating a reliable software framework for the current generation of commercial aircraft powered by gas turbine engines. Both turbofan and turboprop aircraft can be modeled^{7;17;18;8}. The simulated aircraft include transport and cargo airplanes, as well as business jets. At the analysis level, the code includes modules for geometry, aerodynamics, propulsion, airframe-engine integration, flight mechanics, trajectory optimization, thermo-structural performance, static stability, parametric analysis and aircraft noise. The aircraft noise is modeled on the basis of the method of components, with some consideration for interference factors. The noise module consists of routines at three levels: 1.) noise sources, split into airframe (non propulsive) and propulsion; 2.) noise interference; 3.) noise propagation. The signal analysis consists in first assembling all the noise contributions at in the full spectrum. Then several steps are taken to derive various levels of noise metrics: a.) instantaneous noise metrics as a function of time and frequency; b.) instantaneous noise metrics as a function of time (SPL, PNL, PNLT, loudness and other quantities) c.) event based metrics (EPNL, EPNL, SEL, LAeqT, maximum PNL). Several sub-models are necessary in order to be able to simulate the noise of a complex event such an aircraft fly-over. A full discussion of the theory is given in Ref.⁸.

Comparison Strategy

For the anticipated applications, FLIGHT and PANAM promise huge advantages over the best practice methods. Yet, it is quite challenging to make an assessment regarding accuracy and consistency of the underlying complex and physics-based simulations. The proposed validation strategy is twofold, i.e. direct comparison of simulation results ("numerics") and recomputing of available experimental data ("experiment").

Simulation of predefined operating conditions of flight segments allows to directly compare the predictions of both tools. This can be understood as a feasibility check prior to the validation with experimental data. Such a check should include (1) noise emission directivities, (2) noise source ranking, and (3) general noise related effects, e.g. impact of flight speed on noise emission. An initial comparison of these topics indicates that both prediction tools generate reasonable effects. Some deviations, e.g. noise emission directivity of specific components, could be identified and are selected for further detail investigations which were not in the scope of the presented activities. A dedicated comparison with experimental data is preferable. One of the key shortcomings of such a validation and verification is the lack of reliable data and standards.

Fly-over Noise Data

Flyover noise measurements were conducted in the year 2006 at the Baltic-Airport in Parchim, Germany. The measurements were part of the German national funded research project *Lärmarme An- und Abflugverfahren* and the flights were performed by Lufthansa Airlines^{19;10}. For the comparison, representative observer locations have been preselected, see Figure 1. The meteorological conditions during the flight tests were close to those defined for aircraft noise certification.

Figure 1: Selected observer locations for code comparison.

Results and Discussion

In order to confirm the feasibility of any simulation, a direct comparison with experimental data is inevitable. In the case of aircraft noise prediction, available noise recordings at selected observer locations should be selected for this comparison. The recorded SPL time-histories can then directly be compared to simulated results. A good agreement of time-histories and emitted noise energy can only be achieved, if certain effects and interdependencies are adequately captured by the simulation. The feasibility and reliability of the simulation depends on (1) input data quality (aircraft and engine), (2) noise source modeling (especially source dominance), (3) effects of a moving source, (4) sound propagation effects, and (5) ground noise impact.

The results of the comparison are presented as follows: a.) code-to-code comparison of the airframe noise; b.) comparison of both codes and experimental data. We have considered four different trajectories: two approach/landing trajectories (named `rec002` and `rec004`) and two take-off and climb-out trajectories (named `rec013` and `rec015`). Only the data from the microphones below the flight path are presented. These data are shown in Figure 2 to Figure 5. Recordings of the A-weighted sound pressure level are selected for this initial comparison. Experimental data can be subject to inherent atmospheric disturbances and additional foreign noise sources (e.g. wind). These disturbances are visible as rapid pressure fluctuations in the experimental data and are not captured by any simplified simulation method. Differences can be attributed to a number of factors beyond the acoustic modeling; specifically, we refer to the airframe model, to the engine model and to all ancillary sub-models. With this caveat in mind, we consider first the differences between noise signatures provided by two different codes, and then address the problem of comparison with the experimental data. Therefore, not all differences can be attributed to the noise itself.

Consider the results shown in Figure 2. The comparison of the airframe noise is satisfactory at microphones 21 and 18, but there are differences at the closer microphones 15 and 13. This difference is attributed to the mechanism of deployment of the landing gear and the flaps/slats. PANAM takes into account the actual deflection angle, as extracted from the flight recorder data. FLIGHT associates the deflection to an integer operator. Each value of this operator corresponds to a fixed value of the deflection angles, which is taken from the airplane's flight manual. More critical is the precise deployment time within the simulation. Significant differences can be experienced if the simulations account for different event times for the full deployment of the high-lift system. A few seconds time difference can cause relevant variations in flight speed, thus expose the high-lift system to different flow conditions which cause variation in the predicted noise generation. These

discrepancies are experienced at microphone locations close to configuration changes.

Figure 2: Time-level-history predictions and comparisons with measured data for observers along the ground track, trajectory rec002 (arrival). Flap/Slat deployment sequence and landing gear deployment shown.

Figure 3: Time-level-history predictions and comparisons with measured data for observers along the ground track, trajectory rec013 (departure).

Conclusions

This contribution has addressed the problem of aircraft noise prediction by using comprehensive models, as well as the comparison with fly-over data. The underlying strategy was to make an assessment of the state-of-the-art of aircraft noise prediction, and to propose a standard for code validation and verification. Having different underlying models leads to differences in noise prediction. Other differences may arise in the way the changes in configurations are handled. Comparisons

Figure 4: Time-level-history predictions and comparisons with measured data for observers along the ground track, trajectory rec004 (arrival). Flap/Slat deployment sequence and landing gear deployment shown.

have been shown for a set of microphones, both on the approach and departure side, below the flight track and at sideline locations. Comparisons were shown both for the airframe and propulsion contributions. The final comparison with the noise measurements shows some agreement with a few discrepancies, either between numerical simulations and experimental data, or between numerical simulations.

Figure 5: Time-level-history predictions and comparisons with measured data for observers along the ground track, trajectory rec015 (departure).

There are three important areas of future investigation: the effect of noise directivities; the noise footprints; the effects of system integration. We know that some sources contribute more than

others, in a way that depends on the flight condition and on the position of the ground microphone. Therefore, a noise breakdown analysis is required to identify the critical components. Code-to-code comparisons for comprehensive prediction codes have not been attempted before, the standards are not established and the goals are not yet agreed. This is a novel area of research, lagging behind best-practice noise modelling with dedicated validation cases and reliable measurements. Standards for noise comparisons and code-to-code comparisons have to be established on a rigorous basis.

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