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VALIDATION OF NOISE FOOTPRINT CALCULATION MODEL FOR A HIGH PERFORMANCE MILITARY AIRCRAFT

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This paper gives a survey of the performance and results of a validation process for a noise footprint calculation model which is being developed within the framework of a medium-term initiative at Airbus Defence and Space GmbH to reduce the noise produced by high performance military aircraft. It comprises the validation of according noise source emission models by evaluation of a dedicated noise measurement flight test campaign using beamforming techniques as well as the validation of the developed noise propagation algorithm by comparison with a well established and validated noise calculation software. Based on a modular approach models for the different noise sources identified (e.g. jet, fan, landing gear) have been developed mainly based on theoretical/textbook approaches inducing the need for according refinements based on noise data measured during dedicated flight tests and subsequent validation. Accordingly in a dedicated flight test campaign at Neuburg/Germany airfield aircraft noise measurements and data gathering has been performed supported by Brüel & Kjær which then provided information on noise emission and directivity characteristics for the different noise sources modelled. The system used for this was a fly-over beamforming system with 135 microphones deployed on the ground. Using these data the existing noise source models and accordingly the overall aircraft noise emission model could be refined in order to better reflect reality and thus building a reliable basis for calculating the overall noise emitted. In parallel the dedicatedly developed noise propagation algorithm has been refined/corrected and finally validated by comparison with an actual standard noise calculation program. These activities being harmonized in the framework of a dedicatedly defined overall validation strategy and approach give way for the complete validation of the developed noise footprint calculation program.
Keywords: aircraft noise, noise reduction, noise sources, validation, flight test

1. Introduction

Noise reduction for civil aircraft has been an important issue for aircraft manufacturers as well as for airport operators within the last decades. Meanwhile a huge set of requirements and rules coming from annoyed residents, legal regulations, and customers, i.e. airline companies have to be taken into consideration.

However for a long time less emphasis has been placed on noise reduction for military aircraft, but this seems to be subject to change over the past years and consequently also military aircraft noise becomes more important as e.g. the over the years increasing number of respective papers in scientific article databases exemplarily shows.

Additionally the respective international regulations [1] have been tightened in two steps in 1985 and more recently in 2006. Similar regulations on European and national (e.g. German) level exist. Accordingly the relevant regulations are

- ICAO Annex 16, Volume 1, Para 12.2 and 3.4.1.2a (international)
- EC Reg. 1592/2002, Articles 6&13 (European)
- LuftVZO, Article 3 (German).

For military aircraft specifically there is also a certain shift in emphasis with respect to the relevance of noise emissions to be observed. Whereas in the past national fighter acquisition programs usually contained no requirements with respect to noise emission/immission, especially in the last decade the according Requests for Information or Proposal (RfI/RfP) more frequently ask for respective data and information. This can be illustrated e.g. by an article [2] in the Swiss public journal ‘Cockpit’ on the latest Swiss Air Force Fighter acquisition program. Therefore obviously strategies and technical solutions for (military) aircraft noise abatement have to be developed.

In the paper proposed here the overall approach and actual status of an industrial noise reduction initiative for a specific high performance military aircraft is presented. However as the according processes and techniques developed are by their very nature generic to a large extent, application to other aircraft (types) would be straightforward in principle.

As aspects of noise reduction nevertheless still are of minor importance for the design and development of military aircraft especially compared to operational requirements the focus for the approach presented here has been mainly placed on noise immission rather than emission. As obviously the predominant nuisance generated by aircraft is in the vicinity of the respective airfields the overall goal defined is the

Reduction of aircraft noise ground immission by optimisation of the according takeoff climb (and landing approach) flight paths.

2. Overall approach

Pursuing the above goal it is finally necessary to implement an optimisation algorithm which generates noise optimal (i.e. minimal) flight paths. Main focus has to be put on allowance of a broad variety of possible flight paths and easy observance of boundary conditions (e.g. flight mechanical and performance restrictions, terrain information, and residential or prohibited areas respectively) whereas accuracy of the solution will be only a subordinate goal.

From the current point of view therefore e.g. the use of the principles of genetic optimisation (e.g. including a respective niching concept) seems to be appropriate. For the time being yet the definition and construction of operationally reasonable flight paths ‘by hand’ e.g. based on operational manual or flight test data or a combination of both should be sufficient. An overview over the main elements of the general overall approach for noise minimisation can be found in Fig. 1.

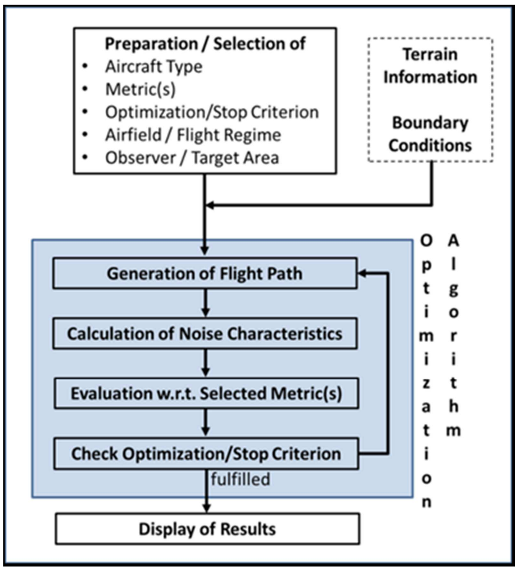

Figure1 – Logic of overall approach.

3. Noise calculation model

However, as a basis for the above mentioned optimisation approach obviously a dedicated validated aircraft noise calculation model has to be provided. Accordingly a dedicated generic modular approach has been developed.

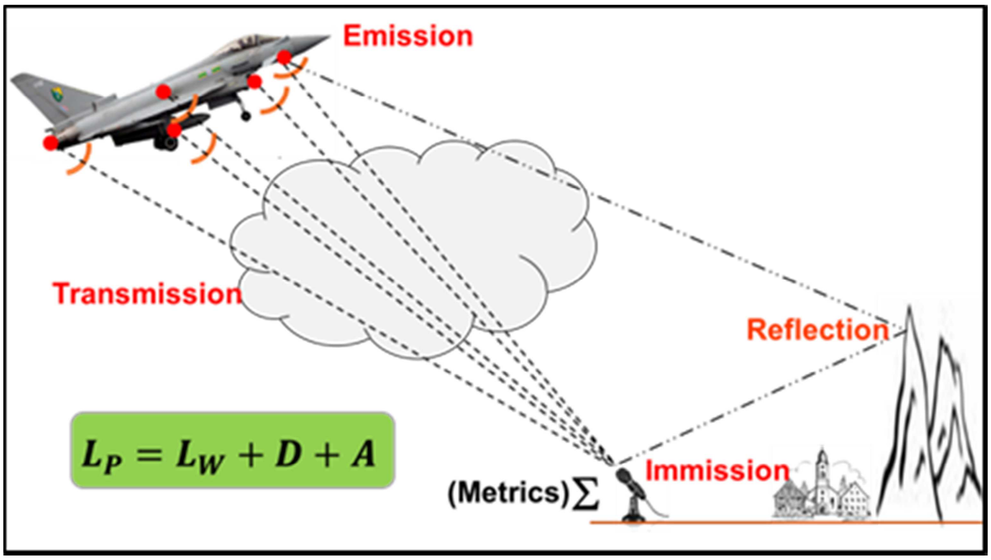

Figure 2 – Modular aircraft noise model.

As shown in Fig. 2 this approach mainly consists of a combination of the three components

- emission (analytic modular approach)
- transmission (modified/simplified ray tracing)
- immission (metrics and refraction).

This is also formally reflected in the common equation for aircraft noise propagation

$$L_P = L_W + D + A \tag{1}$$

according to [3] where L_P denotes the sound pressure level, L_W the sound power level, D the directivity correction, and A the absorption during propagation.

The above breakdown which is defined analogously to [4] has the advantage that the three components can be encapsulated to a large extent which eases development of the three models independently from each other. This process and the respective current status will be described in more detail in the following subsections.

3.1 Noise emission

The basic principles and current status of the noise emission model used for the approach described in this paper are outlined in detail in [5], [6], and [7], yet only an overview is given in the following. As also depicted in Fig. 3 The basic approach consists in a reasonable splitting of the overall noise source ‘aircraft’ into the following distinct noise source components.

- engine jet (incl. combustion and afterburner)
- engine fan (broadband and discrete-tone)
- undercarriage (nose and main landing gear)
- vertical tail
- foreplane
- leading and trailing edge
- airframe
- stores

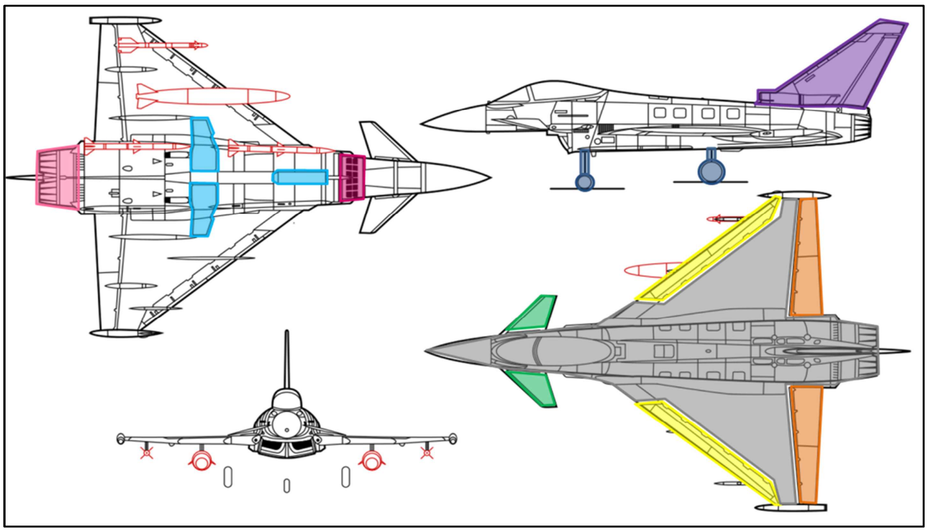

Figure 3 – Aircraft noise emission components.

For each of these noise sources a dedicated noise emission model as well as a respective directivity correction has to be provided. As a start the above noise sources initially are modelled using primarily analytical formulas (e.g. provided in [4]) and will be subject to according corrections based on the results of validation flight test measurements. Having modelled the noise emissions itself at the several sources the second component of the complete emission model consists of the near-field behaviour of the noise i.e. the directivity corrections for all sources.

It is well known that fan and jet noise emissions (at least vertically) do not show a homogenous expansion. Analogously a similar phenomenon also is expected horizontally especially in the case of a twin engine aircraft with two parallel engines mutually influencing the exhaust airflow. It is therefore essential at least for engine noise to consider a three-dimensional directivity correction. All other noise sources are modelled as monopoles with uniform propagation (D=0).

3.2 Noise transmission (propagation)

As described in [8] for noise propagation a simplified (linearized) Ray Tracing method has been established to be of sufficient accuracy in this case and subsequently implemented. A general characteristic of noise propagation through the atmosphere is the phenomenon of attenuation/absorption (‘A’ in Eq. (1)). Usually the following three different types of absorption are distinguished.

- **geometric** (sound power per area unit decreases proportionally to the square of the distance)
- **atmospheric** (reduction of the sound intensity due to molecular air absorption)
- **ground** (for a/c-ground angle < 15°, i.e. mainly for airfield operation or low level flight)

Following the modular approach also the noise propagation is modelled separately for the several sources. Therefore combination of the noise components is not performed before the end of the transmission phase, i.e. impact at observer point.

3.3 Noise immission (observer perception)

As shown in Eq. (1), for the characterisation of the noise perceived by an observer on ground the sound pressure level $\mathbf{L_P}$ is crucial in contrast to the sound power level $\mathbf{L_W}$ describing the noise emitted by the aircraft. Accordingly for noise impacting on ground the most important effects are

- **ground absorption** (as described in the preceding subsection)
- **reflection** (important e.g. in case of the airfield being in the vicinity of mountains)
- **bending** (deflection due to obstacles)

As a start the latter two effects are currently not modelled but will be taken into account in future program versions. Furthermore the current model of the ground as planar surface will then be replaced by a proper ground modelling based on a terrain database. Further refined modelling up to a level of detail also containing buildings is currently not planned.

4. General validation approach

Following the (modular) general overall approach for the noise model described above all three components (Fig. 2) will be validated separately by the following dedicated validation strategies.

- **emission**: comparison of (analytical/textbook) model based calculated noise values (frequency dependent) with sound power spectra as well as directivity patterns derived from data gathered during dedicated flight tests [9] using beamforming techniques [10]
- **transmission**: comparison of the underlying transmission algorithm with a validated widely used standard software [11] dedicatedly developed for noise propagation calculation
- **immission**: subsequent to refinement and validation of emission and transmission models/algorithms, comparison of model based calculated noise values with sound pressure levels measured during dedicated flight tests

As indicated above for substantiation, refinement, and validation of the noise emission models respective noise measurement flight tests are essential. Accordingly in a 2-day campaign appropriate flight tests have been performed in November 2015 at Neuburg airfield with the support of the Danish company Brüel&Kjær which provided the noise measurement equipment (135 microphone array, recording hardware, etc.) and as well conducted the noise recording and post processing.

A total of 20 test points (fly-overs) have been performed in different configurations (with & without under wing tanks, undercarriage up and down) and with varying power settings (Part Dry / Max Dry / Max Afterburner) at altitudes between 150 and 200 ft above airfield.

5. Validation results / model refinements

Up to now most of the noise sources (emission) could be refined/validated using results from the above described flight tests [12]. The transmission algorithm has been validated by comparison with SOPRANO [11]. The overall validation of the calculation model based on measured sound pressure levels from flight tests will be performed subsequent to completion of emission validation.

5.1 Emission models

For **undercarriage** model validation a detailed analysis based on the sound power spectrum has been performed. As shown in Fig. 4 the curves for model and flight test data vary in a constant shift. Accordingly model validation (aligned curves) can be achieved by adapting model parameters.

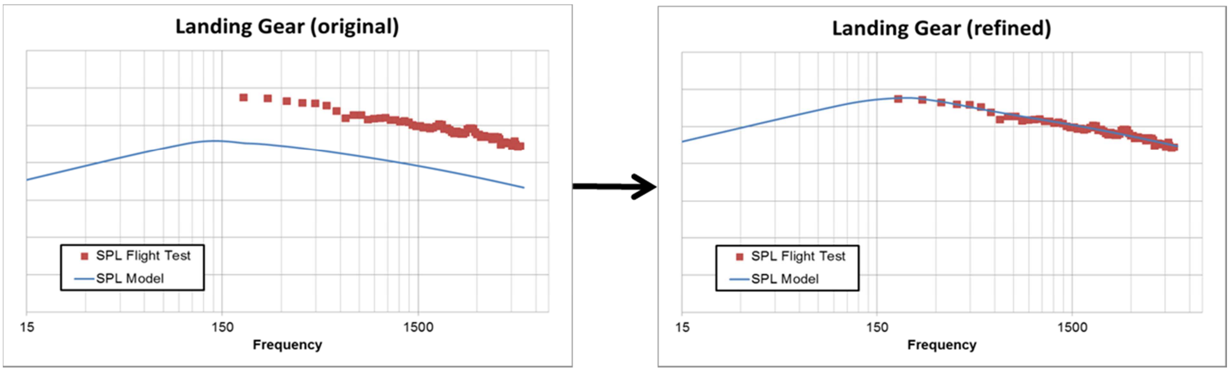

Figure 4 – Undercarriage noise model refinement.

A similar approach has been performed for the validation of **surface** noise. In this case however, also a qualitative discrepancy of the model and test data curve (Fig. 5) appears. Accordingly not only certain model parameters have to be adapted but the model function itself to achieve curve matching and thus validation.

As additionally test data showed that the actual **leading edge** noise modelling is not realistic, further investigations proved that the noise for retracted leading edge can be covered with the surface model by an increment on the roughness height. Extended leading edge noise yet is not covered.

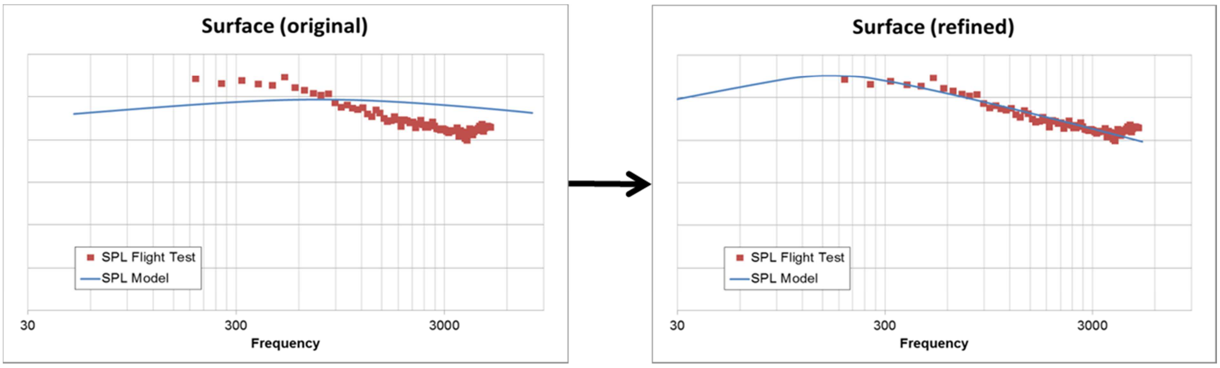

Figure 5 – Surface noise model refinement.

For **foreplane** noise significant quantitative as well as qualitative differences between the noise model and flight test data (Fig. 6) can be observed. The original emission model qualitatively (with a certain constant offset) only describes the noise for higher frequency. Detailed analysis has shown that additionally the noise generated by the tip vortex has to be taken into account. An according model has been implemented and together with a modified constant offset finally provides good matching of the noise model with flight test data (Fig. 6).

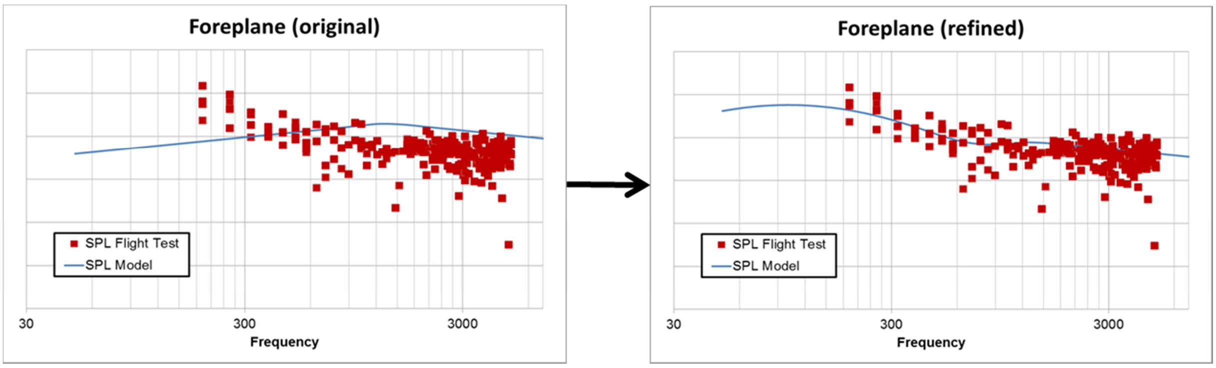

Figure 6 – Foreplane noise model refinement.

As it is not possible to isolate **trailing edge** noise characteristics from flight test measured data, instead the results from foreplane noise analysis are read across with suitable adaption.

No characteristics for **vertical tail** noise could be extracted from the flight test measured data. As the noise emitted by this surface is not of significant magnitude and anyway shadowed in most cases with respect to reception on ground, it is neglected further on and validation can be omitted.

Detailed analysis of the measured noise characteristics for **stores** (tanks) showed that the predominant contribution for this component comes from the trailing edge of the tank rather than from the surface. Accordingly in a similar way as for the trailing edge the results from foreplane validation are transferred to the stores with an additional correction for smaller fittings (e.g. fins).

As the flight test results for the **engine jet** showed completely different noise characteristics compared to the model a complete re-design of the engine noise model has been decided. This model has been designed mainly based on flight test results as a piecewise linear function dependent on the thrust lever position. Dependent on this function according spectral forms (frequency dependent representations) have been derived based on so-called similarity spectra.

In addition to that, for the engine jet also a dedicated directivity characteristic has to be defined. As the current directivity model is mainly based on data derived from commercial aircraft (due to a general lack of commonly available noise data for military aircraft) an appropriate model for military aircraft has been defined mainly based on flight test data. As for the engine jet, a strong dependency on thrust lever position has been detected and is implemented accordingly.

Validation of **engine fan** noise characteristics has not been performed yet but respective flight test noise measurement data are available and accordingly this task is currently under progress.

5.2 Transmission model

The noise transmission algorithm of the noise calculation model described above has been validated against the yet validated standard software SOPRANO for calculation of noise propagation. In order to avoid as far as possible eventual contributions from differing noise sources to the evaluated differences between SOPRANO and the new method, the validation process has been performed using fan noise as the only emission source [13]. Accordingly the fan noise model in SOPRANO and the new method have been aligned in a way that they both provided identical results if provided with matching input parameters.

Besides the additional implementation of dedicated algorithm for the Doppler effect into the new software mainly the modelling of attenuation phenomena like geometric and atmospheric absorption had to be analysed in order to eliminate differences between SOPRANO and the new method.

Accordingly in a first step the differences emerging from differences in the models for geometric absorption (Fig. 7) have been analysed in more detail.

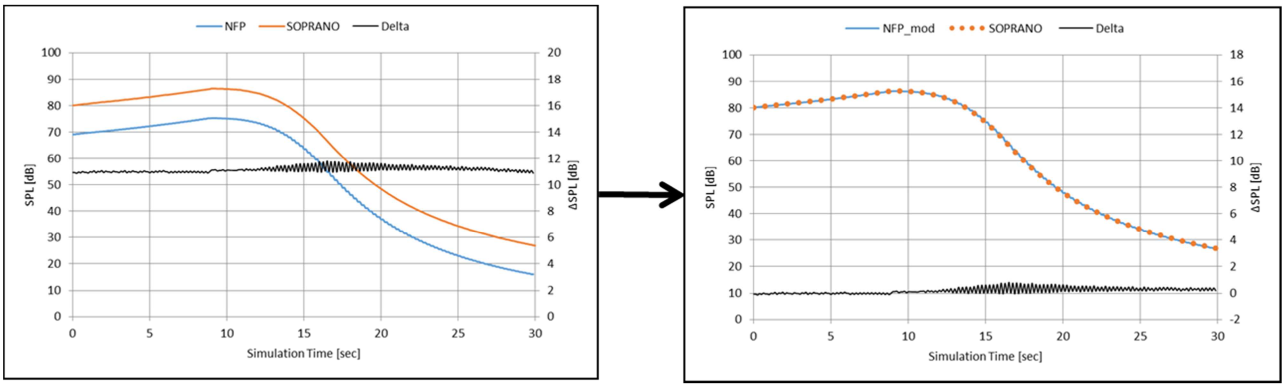

Figure 7 – Validation of model for geometric absorption.

Finally it has been detected that the differences found in the sound pressure level are due to the definition of the geometric reference point for sound propagation and its distance to the noise source at the aircraft. Correction of this different approach results in almost congruent curves for SPL (Fig. 7) showing a maximum difference of less than 0.2dB.

Subsequently the differences in atmospheric absorption (Fig. 8) have been evaluated which obviously again indicated the need for deeper analysis.

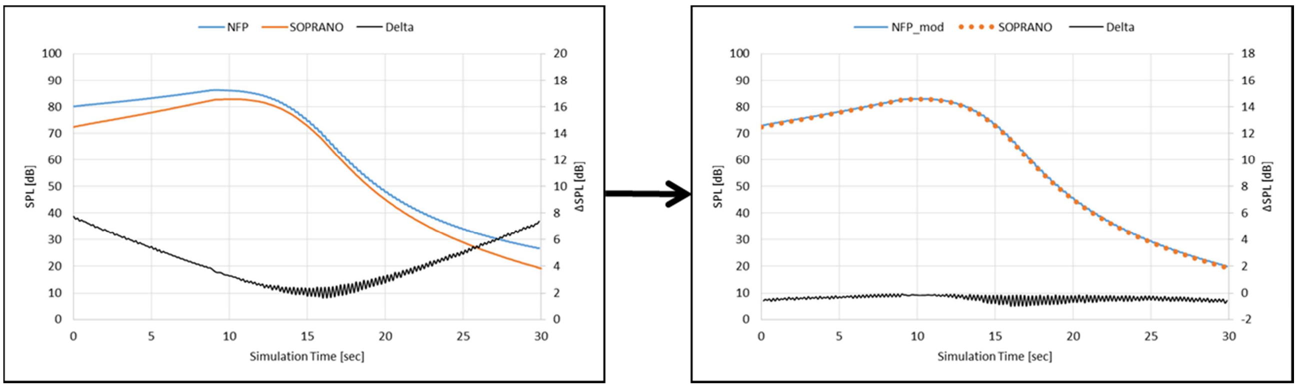

Figure 8 – Validation of model for atmospheric absorption.

Detailed analysis of the source code showed that for atmospheric absorption there are two different methods based on distinct approaches implemented. As the method applied in SOPRANO (based on the standard ARP866B published by SAE International) proved to be yet validated it has decided to replace the current algorithm in the new method by this approach. As expected this leads to an excellent matching (Fig. 8) showing a maximum difference of less than 0.4dB.

6. Summary and conclusion

A generic approach for noise modelling of high performance military aircraft substantiated by a corresponding validation flight test campaign has been presented. Due to the modular structure of the aircraft noise model each noise source as well as the propagation algorithm can be modelled and validated separately thus giving way to flexibility for a wide variety of applications.

A dedicated validation strategy has been developed and an according flight test campaign with subsequent evaluation phase has been performed. Accordingly based on this up to now most of the modelled noise sources could be refined and validated using the flight test results. The noise propagation algorithm used in the described noise calculation model has been refined, improved and validated by comparison with a well-established standard software for noise transmission calculation.

Future planned activities with respect to enhancement of the described aircraft noise calculation program comprise the completion of the validation process, the integration of a feasible terrain data base, the development of a comfortable graphical user interface, and finally the embedding of the noise calculation model into a flight path optimisation algorithm.

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