Noise Reduction for a High Performance Military Aircraft – General Approach and Current Status

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Summary

This paper gives an overview and current status of a medium-term initiative at Airbus Defence and Space GmbH to reduce the noise produced by high performance military aircraft. Based on a modular approach a widely generic model for aircraft noise estimation, evaluation, and measurement is being developed. Based on dedicated metrics the effect (annoyance) of aircraft noise with respect to an observer on ground is quantified thus providing the basis for a planned future optimization of military aircraft climb and descent schedules and flight paths. Accordingly the general approach as well as the current status of the project is described and subsequently recent results are presented leading to an outlook on planned future enhancements of the model.

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1. Introduction / Motivation

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 due to several reasons. As can be depicted from Fig. 1 this seems to be subject to change over the past years and also military aircraft noise becomes more important as the number of hits for the search expressions “Aircraft Noise” and “Military Aircraft noise” in a scientific article database exemplarily shows.

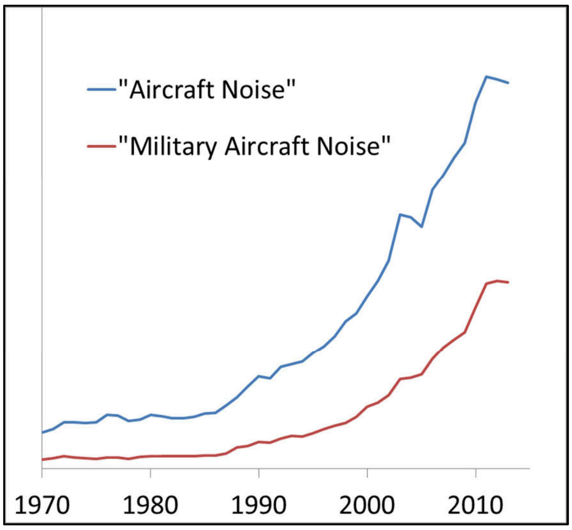

Figure 1. Search results in scientific article database.

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

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 where finally armasuisse together with the respective tenderers performed according flight tests which subsequently were evaluated by the Swiss institute EMPA (Fig. 2).

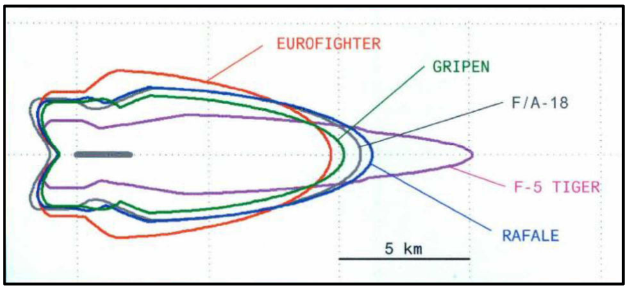

Figure 2. EMPA flight test noise immission evaluation.

These facts finally lead obviously to the necessity of developing strategies and technical solutions for (military) aircraft noise abatement.

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 optimization of the according takeoff climb (and landing approach) flight paths.

2. Overall Approach

Pursuing the above goal it is finally necessary to implement an optimization algorithm which generates noise optimal (minimal) flight paths based on dedicated suitable optimization criterions (noise metrics). 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/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 optimization seems to be appropriate. Developing and subsequently implementing an according algorithm is however a very time consuming task and will therefore be accomplished towards the end of the whole program development cycle. For the time being the definition and construction of operationally reasonable flight paths "by hand" should be sufficient. An overview over the main elements of the general overall approach for noise minimization can be found in Fig. 3.

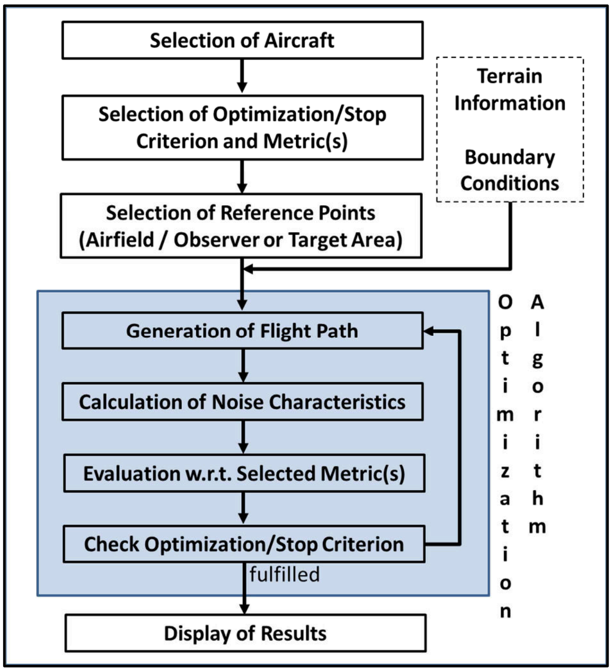

Figure 3. Logic of overall approach.

Obviously the central function consists of the calculation of aircraft noise which will be described in more detail in the following section.

The starting point "Selection of Aircraft" stresses the modular nature of the approach presented here. All aircraft specific parameters (e.g. for engine or aerodynamics) are not hard-coded but are provided to the program by dedicatedly defined external datasets. Respective interfaces had been set up.

In "Selection of Optimization/Stop Criterion and Metric(s)" it is fixed whether one single optimal solution or rather a set of feasible flight paths fulfilling e.g. according accuracy requirements is searched for. As well the maximum number of iterations is set and -most important- one or more appropriate metrics for the evaluation of noise on ground is selected.

Furthermore in "Selection of Reference Points" the local coordinate system is fixed by choosing a geographic point (in WGS 84 / NAVSTAR GPS coordinates) representing the airfield the takeoff (or landing) is performed on. Additionally the position of the observer or an appropriate area on ground is defined for which the chosen noise metric(s) shall be evaluated.

Prior to the start of the actual optimization algorithm additional information on terrain specifics and possible boundary conditions (e.g. residential or restricted areas) represented by accordingly defined data bases are fed into the program via respective modularly designed interfaces.

The first step within the optimization algorithm will be the selection or generation of a dedicated flight path being a candidate for the optimum solution to be found. After the calculation of the noise characteristics along the flight path the above chosen on-ground noise metrics have to be evaluated thus providing a basis for the subsequent decision on continuation of the optimization iteration. In case optimization will continued a new "candidate" flight path has to be constructed based on previous results (feedback loop). The methods and principles which are applied for this purpose are constituting the very core of an optimization approach/algorithm.

If the stop criterion is fulfilled the results will be displayed using a dedicated user interface. Furthermore all relevant and necessary data for a potential post processing (e.g. detailed analysis of feasible flight paths or evaluation of additional metrics) are store in accordingly designed data bases.

3. Noise Calculation Model

However, basis for the above mentioned optimization approach has to be obviously a validated (modular) aircraft noise calculation model consisting of the three main 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

$$L_P = L_W + D + A \quad (1)$$

according to [3] where L_P denotes the sound pressure level, L_W the sound power level, C 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 according following subsections.

3.1. Noise Emission (Aircraft Noise)

The basic principles and current status of the noise emission model used for the approach described in this paper are described in detail in [5] and [6], yet only an overview is given in the following.

The basic approach consists in a reasonable splitting of the overall noise source "aircraft" into the following distinct noise source components

- engine jet
- engine fan
- undercarriage
- airframe.

For each of these four noise sources a dedicated noise emission model as well as respective directivity correction has to be provided. As shown in a subsequent section also the noise propagation is modelled separately for the several sources. Therefore combination of the noise components is not performed until impact at observer point.

As outlined in [5] especially for the takeoff case which is currently the most relevant use case the engine jet and fan represent the by far dominant noise source components (exemplarily in Fig. 4). Therefore for the following discussions undercarriage and airframe noise is neglected and will be considered for other flight phases.

	Landing				Take-Off			
Rank	Item	$EPNL_c$	+dB	−dB	Item	$EPNL_c$	+dB	−dB
1	MLG	97.37	1.508	−1.354	FAN	99.55	1.685	−1.590
2	SLAT	88.80	0.291	−0.221	JET	88.18	0.404	−0.325
3	FAN	84.25	0.072	−0.087	LPT	83.30	0.056	−0.034
4	NLG	83.38	0.020	−0.053	COMB	78.42	0.030	−0.012
5	COMB	82.47	0.019	−0.050	Wing	63.52	0.005	−0.003
6	FLAP	77.50	−0.005	−0.039	MLG	63.30	0.000	0.000
7	HPC	77.18	0.086	−0.123	HSTAB	62.81	0.002	−0.001
8	Wing	74.29	−0.037	−0.015	LPC	61.16	0.001	
9	HSTAB	74.24	−0.047	−0.009	HPC	58.46	0.001	
10	LPC	64.65	−0.060	−0.001	NLG	48.17		
11	JET	46.01	−0.062		SLAT	47.09		
12	VSTAB	44.82	−0.062		APUC	19.53		
13	APUC	38.37	−0.062		APUJ			
14	LPT		−0.062		VSTAB			
15	APUJ		−0.062		HPT			
16	HPT		−0.062		FLAP			

Figure 4. Breakdown of noise for civil aircraft [4].

Engine jet noise (Fig. 5) is modelled using analytical formulas e.g. provided in [4] and will be subject to according corrections based on the results of validation flight test measurements. Analytical models are synthesized for

- jet
- combustion chamber
- afterburner.

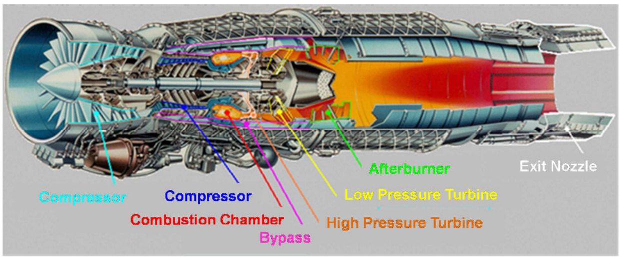

Figure 5. Engine Components.

Analogously also for the fan noise an analytical model represented by a respective complex formula is synthesized.

Having modelled the noise emissions itself at the several sources the second component of the complete emission model consists of the near-field behavior of the noise i.e. the directivity corrections for all sources. Again for the time being airframe and undercarriage are neglected in this context and models are built up for jet and fan only.

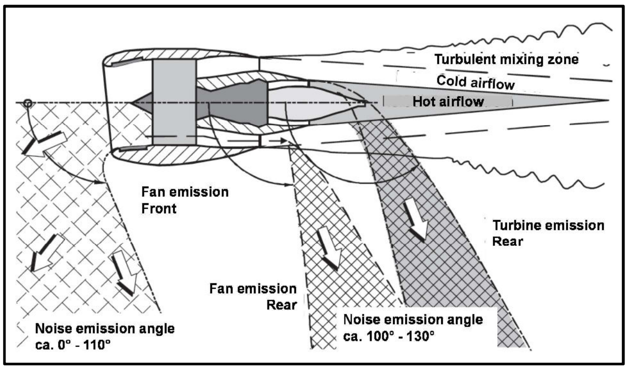

Figure 6. Principle noise emission characteristics.

As it can be observed from Fig. 6 (and as it also could be expected) the 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 to consider a three-dimensional directivity correction. In Fig. 7 a descriptive example for horizontal and vertical directivity characteristics (for a civil aircraft) is given.

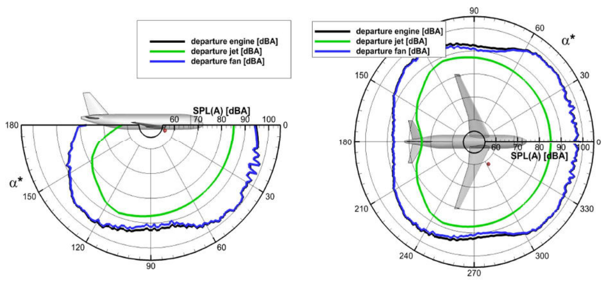

Figure 7. Example for directivity characteristics.

For the synthesis of these corrections however no straightforward analytical approach exists thus inducing the need for modelling respective directivity functions basically derived from dedicated tests i.e. noise measurements. As according tests are very expensive and time consuming they are often avoided thus preventing a proper modelling of directivity corrections.

Therefore in practice it is often necessary to model the directivity corrections by cross-reading from data for generalized or related problems or to use heuristics. For the approach presented here directivity data for the fan have been taken based on data derived in [4], for the jet estimates compiled in [5] have been used. Yet naturally these (currently best-guess) values will be subject to checking, refinement, and finally validation during further progress of the project.

3.2. Noise Transmission (Propagation)

Having modelled the noise emitted in the near-field of the aircraft the proximate task consists of specifying the propagation to (an observer on) the ground. As described in [7] a simplified (linearized) Ray Tracing method has been established to be of sufficient accuracy in this case and subsequently implemented. Based on the principles of geometric acoustics the method developed here mainly introduces the aspect of the time dependency to noise propagation.

A general characteristic of noise (or more generally sound) propagation through the atmosphere is the phenomenon of attenuation (or absorption) as also contained in Eq. 1. Usually the following three different types of absorption are distinguished.

- **geometric** (radially expanding the sound power is distributed over an area increasing with distance from the source and therefore the 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** (additional sound attenuation for observer location with an aircraft-ground angle lower than 15°, i.e. mainly applicable for airfield operation or very low flight altitudes)

The noise transmission phase ends with the sound impact at the observer which is described in the following subsection.

3.3. Noise Immission (Observer perception)

As it can be seen e.g. in Eq. 1 for the characterization and measurement of the noise perceived by an observer on ground the so called sound pressure level L_P is crucial in contrast to the sound power level L_W which describes the noise emitted by the aircraft. Though L_P is for most problems the standard noise measurement parameter there are for a vast variety of different applications numerous alternative measures or metrics [8] which cannot be described in more detail here due to space restrictions.

For noise impacting on ground the most important effects are

- **ground absorption** (as described in the preceding subsection)
- **reflection** (of utmost importance especially in the case of the airfield and observer being in the vicinity of mountains, e.g. Switzerland, or in an area with many buildings around; it is also contributing to ground absorption)
- **bending** (deflection due to obstacles)

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. Refined modelling up to a level of detail also containing buildings is currently not planned.

4. Current Status / Recent Results

The noise calculation model as described in the preceding sections according to its actual state has been applied to a dedicatedly provided high performance military aircraft climb path being of generic nature.

Accordingly as shown in Fig. 8 a takeoff from Manching airfield near the town Ingolstadt in Upper Bavaria is simulated (capitals A-K) and respective environmental conditions have been chosen. In the map below starting point and immission spot (observer location) are marked by the symbol ∇.

Emphasizing the very advantages of the strict modular approach outlined here in [6] also an alternative climb path noise calculation and analysis for a small passenger plane (not shown here) is presented which has been relatively easy to implement once the aircraft specific characteristics and data are known.

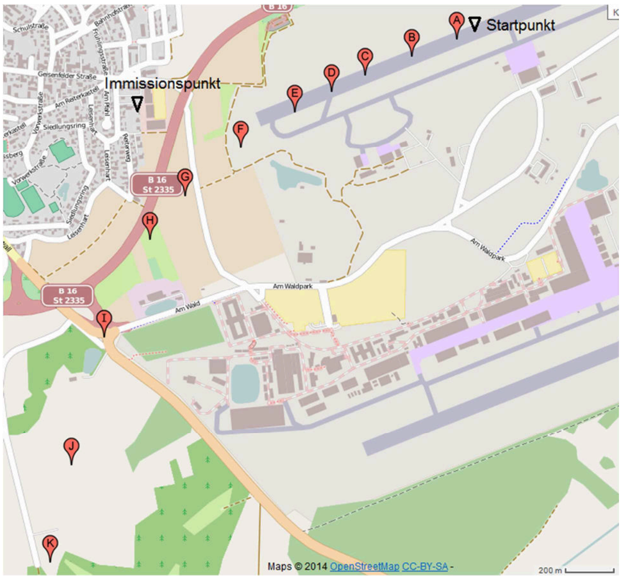

Figure 8. T/O climb flight path from Manching airfield.

Noise calculations have been performed based on a reference frequency of 1000Hz. As it can be observed from Fig. 9 the maximum SPL is not reached for the minimum distance but during receding from the observer location. Furthermore the reduction in SPL during further receding from reference point happens much slower than the increase during approach which all together is a good indication at least for a principally proper implementation of noise and directivity characteristics.

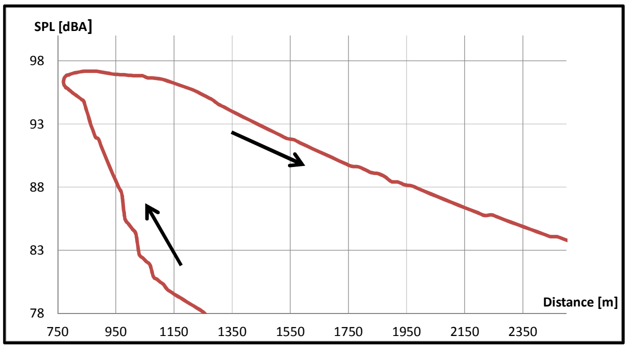

Figure 9. SPL over distance for takeoff climb.

In Fig. 10 a simplified noise footprint for this takeoff climb simulation (aircraft position marked by the star) is shown for that instance when the maximum SPL (97.2 dB) at the observer location is attained.

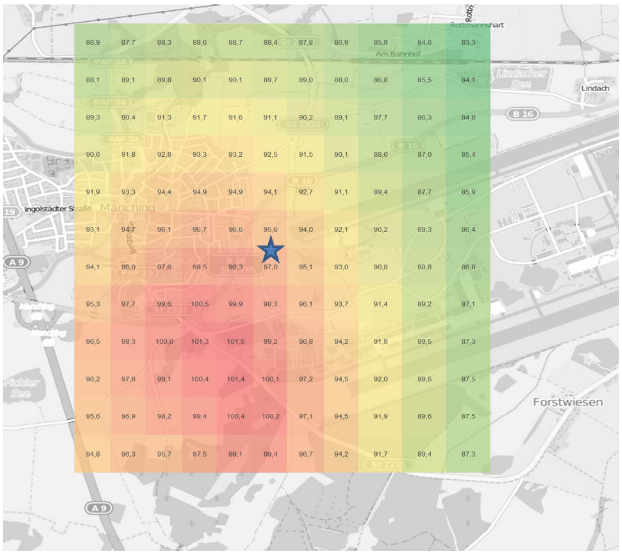

Figure 10. Simplified noise footprint.

At the first glance the result seems to be astonishing as the area of overall maximum SPL immission on the ground lies well ahead of the actual aircraft position, but this can be easily explained as an effect produced by a combination of a relatively steep flight path angle of about 45° and the rather downward deflection of the noise emissions especially at the engine jet as shown in preceding sections.

5. Summary and Outlook

The general approach and current status of an Airbus Defence and Space internally started initiative for reducing aircraft noise immissions by optimizing takeoff/climb (and descent/landing) flight paths has been presented. Though due to significant constraints a number of simplifications and assumptions were necessary the first simulation results look promising. Basically a first prototype for an aircraft noise calculation model has been developed which will constitute the core for a minimum noise flight path optimization program in the future. Additionally also some theoretical foundations for future developments are yet provided.

However as it can obviously be seen going through this paper a lot of work is still to be done. In order to give a short overview only the most important tasks are listed in the following.

- Emission model refinements (undercarriage, airframe, flaps, external stores, etc.) including provision of according directivity corrections
- Refinement of directivity correction for jet and fan (e.g. by explicit noise measurements)
- Implementation and integration of a terrain data base including obstacles
- Graphics based comfortable user interface
- Simulation of approach and landing cases (including descent phase)
- Comparison with other aircraft models (in case according data are available)
- Development and implementation of a dedicated flight path optimization algorithm based on the aircraft noise model described in this context. This of course is a comparatively huge task which will take a longer time and has to be coordinated closely with possible parallel model improvement activities.

The primary aim for the nearer future is to realize this set out of the above tasks that is essential for the overall goal of providing noise minimal flight paths. As one of the next steps in the nearer future (sufficient maturity of the model assumed) a flight test based validation process is planned to be started which then is expected in turn to provide valuable information for further improvements of the overall model.

References

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