# Next generation aircraft noise-mapping


Ulf Tengzelius
Aurskall Akustik AB
aurskall@gmail.com

Anders Johansson
KTH
aebjo@kth.se

Mats Åbom
CSA KTH
matsabom@kth.se

Karl Bolin
CSA KTH
kbolin@kth.se



**ABSTRACT**

*At CSA, Centre for Sustainable Aviation at KTH Stockholm, several aircraft noise related projects have run during the last 4 years. One outcome from this research is the SAFT[1]-computational program for prediction of aircraft noise contours and time-histories in receiving points on ground. SAFT is a versatile and comprehensive tool already including several computational methods such as the standard ECAC Doc.29 method but also more accurate time-stepping simulation-based representations of frequency and direction dependent aircraft sound sources and the propagation of sound in a refractive atmosphere. The computational program allows for input of "general aircraft trajectory input" in the sense that either the trajectory data of concern is fitted to the current predefined formats, or SAFT is (easily) updated to read a "new" format. Among the pre-defined formats of the current version is csv-files prepared from OpenSky historical database. From these kinds of data thrust and other noise-predictor variables may be extracted and applied for noise source establishment and then, finally, the noise-mapping. Moreover, SAFT allows for studies of aggregated air-traffic in defined areas and timespans as well as of single event flight-trajectories. And for these different scenarios almost any noise metric ($L_{Amax}$, $L_{AE}$, $L_{eq}$, $L_{den}$, ...) might be extracted together with its difference in dB, "Delta-dB, between any two scenarios or individual flights. The aim could be to see the effect on noise footprints from routing, runway-use, individual flight procedures, different weather/atmospheric situations, computational methods etc. Anticipated future implementations include drone trajectories and sound-source representations. SAFT is designed with user-friendliness in focus and a 1st time beginner can produce a noise-map in a few minutes in an interactive run.*


## 1. INTRODUCTION

SAFT (**S**imulation of **A**tmosphere and air tra**F**fic for a more silen**T** environment, or in Swedish: **S**imulering av **A**tmosfär och **F**lygtrafik för en **T**ystare omgivning) [1] is the name of a computer program for simulation and analysis of aircraft noise reaching people on ground. The program is financed by Trafikverket through CSA, Centre of Sustainable Aviation [2], and developed and applied within CSA-projects at KTH, Chalmers and LiU. SAFT is designed to be user friendly, flexible in the sense of adding new functionality, input or output. It is also aimed for education with numerous intermediate plotting possibilities during and after a finalized computation - typically ending with noise contours on a map and or noise level time histories in selected receiving points on ground.

In this presentation we try to give an overview of implemented methods and what kind of results one may achieve with SAFT, its specific features and possible computational paths, and finally what kind of methods/capabilities we would like to do add in the future. The fundamental paths of SAFT are shown below. It should be noted that all computations within SAFT follows a linear path where the user selects the type of computation, gives the needed input for this, then SAFT makes the computations and delivers intermediate results on the screen and final results on the screen and in files.

In computations regarding aggregated air-traffic, SAFT reads previous result output, either for individual flights or from already aggregated cases. SAFT is written in Matlab and can be run on a standard PC.

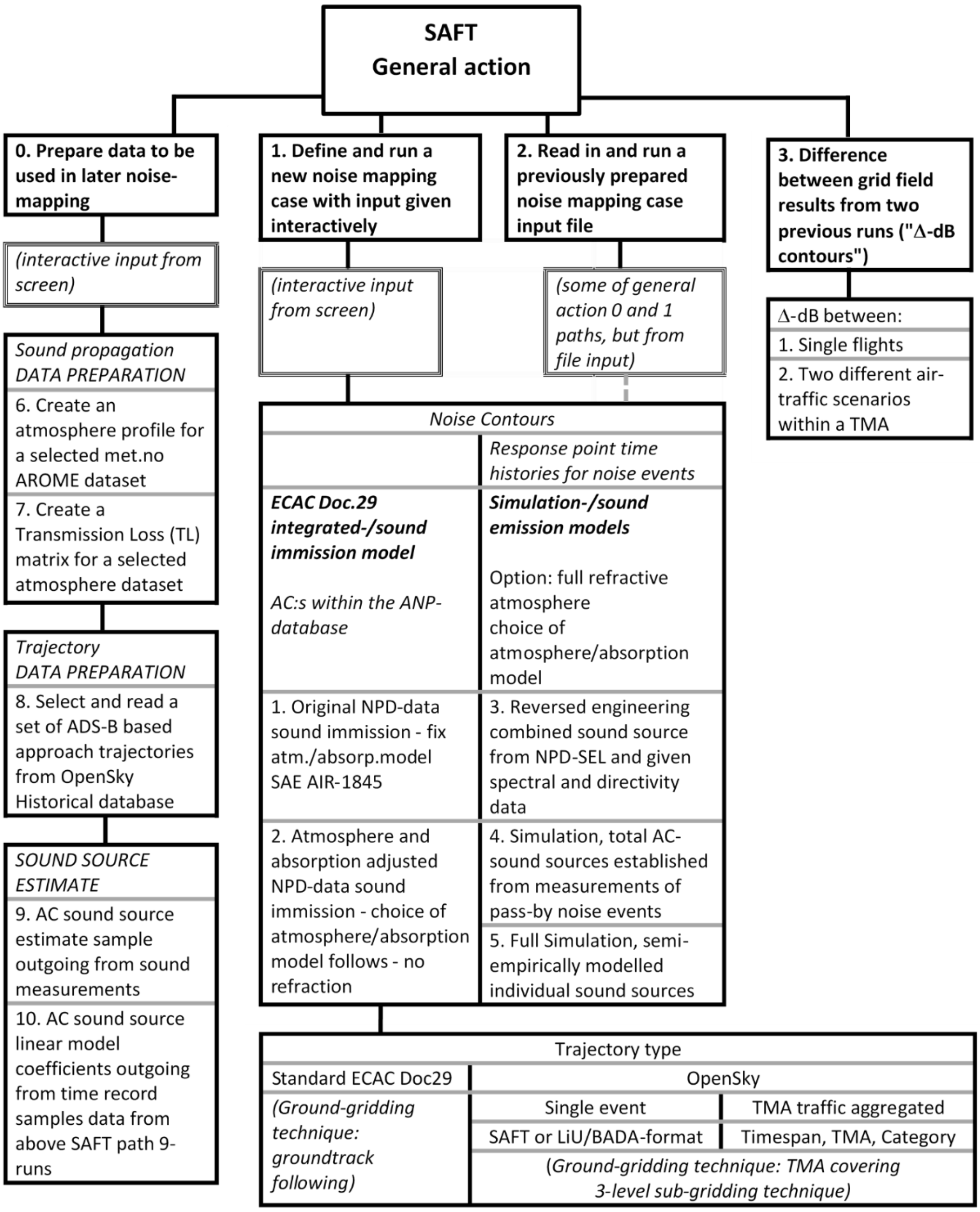


Figure 1: Outline principal computational paths in SAFT

## 2. AVAILABLE COMPUTATIONAL PATHS

### 2.1. Main Computational Paths

When it comes to noise contour-mapping SAFT give the user a choice between two different main paths, either an ECAC Doc.29 [3] based “integrated” computational path or a time-stepping

simulation and ray-tracing based path. Within each of those two main paths the user may choose between a few secondary computational branches.
NOTE: as of March 2021 only Arlanda airport and the Stockholm TMA may be selected with regard to trajectories and air-traffic areas. Though, other regions and airports is rather simple to include.

### 2.2. ECAC Doc29 Main Characteristics and Assumptions

ECAC Doc29, as well as INM, AEDT [4], are for the noise computation based on Noise-Power-Distance tables stating noise levels in a set of different noise metrics, e.g., $L_{Amax}$, $L_{AE}$, for fixed values of distance and thrust of the aircraft of concern. Given the aircraft position with regard to a set of ground points the reached noise levels in these points from a pass-by event are given by 2D interpolation from given distance and thrust. The final levels are adjusted for something called "lateral damping", assumed circumferential directivity. The lateral damping is an attempt to catch the effects of sound reflections and other effects for sound reaching ground at different angles. For the final $L_{AE}$ values also flight trajectory finite segment lengths and aircraft speed are accounted for. No attempt is made to account for longitudinal directivity in ECAC Doc29. As a result of this approximation $L_{Amax}$ is always taken for the closest distance aircraft-receiver.

The NPD-data (Noise-Power-Distance) [5] for all covered aircraft are gathered and compiled from aircraft noise certification measurements. Since the NPD-data are not directly measured for the condition they should represent, i.e., for approach 160 knots constant speed at full configuration at the stated NPD-distances and SAE AIR-1845 atmospheric absorption conditions, the measured certification noise data are adjusted to represent these specific tabulated NPD-conditions.

This situation, i.e., that the NPD-data, and thereby also the ECAC Doc29 methods, rely on only one configuration condition and is based on solely one speed, can be considered as significant model limitations. This is since the noise characteristics of an aircraft depend not only on thrust but on aircraft speed and airframe configuration, among other factors such as ambient conditions. Moreover, the "full config", is usually not activated during typical approach procedures.

These shortcomings of ECAC Doc29 resulting in increased inaccuracy away from the runway are well-known and mentioned e.g., in [6], and quantified in [7]. Conclusions from [7] below:

*"This study also shows that the AEDT model underestimates noise levels, sometimes considerably, by 4 to 7 dB(A), even when using an accurate flight path for its input. It further shows that there is no correlation between the calculated noise levels of specific aircraft to their actual, measured noise levels, even if the calculation is based on their precise flight path and speed.*

*The results of this study suggest that aircraft noise model validation should be separated into four cases; takeoffs and landings, and for each operation, a different approach should be used for close and far NMTs(=Noise Monitor Terminals"). Validation should involve correction of at least the NPD tables, as well as takeoff profiles, and a recursive process must continue until there is a match in terms of accuracy in its wider sense-trueness, and precision"*

### 2.3. ECAC Doc29 Implementations and Variants in - SAFT Path 1 and 2

Since more accurate atmospheric absorption models have been developed after the SAE AIR-1845 [8], methods to replace this with these newer ones have been introduced in ECAC Doc29. In a first step ARP866A (1975) [9] was established and later implemented in ECAC Doc29/NPD-data, then came ARP5534[2] [10] (2013), which was introduced in ECAC Doc29 2016. The SAFT computational path allows for computation of any of these two + the original narrowband/tonal absorption computation standards behind ARP5534, ANSI S1-26/ISO 9613-1 [11].

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[2] provides an empirically-determined method for applying the pure-tone absorption algorithms of ANSI S1-26/ISO 9613-1 to one-third octave band SPLs

| ***ECAC Doc.29 integrated-/sound immission model*** |
| --- |
| 1. Original NPD-data sound immission - fix atm./absorption model SAE AIR-1845 |
| 2. Atmosphere and absorption adjusted NPD-data sound immission - choice of atmosphere/absorption model follows - no refraction |

Table 1. ECAC Doc29 based computational paths in SAFT (from SAFT path outline in Figure 1)

Path 1 *Original SAE AIR-1845 NPD-data*
In the first of the ECAC Doc.29 based computational paths, SAFT Path 1, in Table 1 above, the computations are based on the original SAE AIR-1845 NPD-data and no other atmosphere data is needed as input.

Path 2 *Atmosphere and absorption adjusted NPD-data*
In SAFT Path 2, still an ECAC Doc.29 based alternative, the user has the possibility to choose between:

a) the different absorption models and
b) different atmosphere models and data

The different atmosphere models are: 1) ISA atmosphere with given ground temp, 2) a set of generic atmosphere type models with given wind and temp input or 3) met.no AROME prognosis atmospheric profile data for the hour of the flight (historical prognosis data may be found 1.5 years back in time). With regard to the chosen absorption + atmosphere model + atmosphere data, the NPD-data is updated from the original (SAE1845) figures to a new set representing the selected atmosphere/absorption sets.

## 2.4. Extended trajectory input possibilities with ECAC Doc29 - SAFT Path 2

While in path 1 the user has only one choice regarding the trajectory input, namely:

- a single flight based on ANP-data standard trajectories, to be used as a profile on top of “any” given ground track.

Path 2 offers several computational sub-branches:

“ANP-trajectories”:

- a single flight ANP-data based trajectory with “any” given ground track
- the effect of “traffic” random distribution along a “back-bone” ground track

“General (single) trajectories”:

- OpenSky [12] Historical Database ADS-B trajectory data in “SAFT”- or “LiU/BADA [13] - format” .csv-files. The main difference these two OpenSky-based trajectories is that the first type does not contain thrust estimates while the second does. The “SAFT-format” data also keep the highest possible resolution, ca 1 sec when possible, aiming for thrust computation based on accelerations and aerodynamic data, $R=C_D/C_L$ from the ANP-database. Here the configuration either is set interactively by the user based on patterns in the vertical position and velocity changes, “bumps”/”ballooning”, or has to be set based on “typical” distances from runway based on known statistical distributionsfor these.

- “Tailored” general trajectory on any of these two above formats

Aggregated traffic from “General trajectories”

- Results in terms of $L_{Amax}$ and $L_{AE}$ for flights (e.g. from OpenSky-data as above) within a timespan, input set by the user, are aggregated within a TMA
- Further aggregating of already aggregated timespans as those mentioned just above

## 2.5. Simulation Ray-tracing - SAFT Path 3 to 5

In the time-stepping simulation/ray-tracing based computational paths more accurate and versatile noise predictions are possible compared with the so-called integrated methods such as in ECAC Doc29. In these simulation models a directive sound source is moving along a trajectory in discrete time (and translation) steps. In each timestep "sound-rays" are "emitted" in discrete directions (resolution set by user) longitudinally, θ, and circumferentially, φ, with regard to the aircraft body. Depending of the orientation of the aircraft and the atmospheric conditions these emitted sound rays reach the ground at certain positions and times (= emission time + propagation time) and accounts for ground reflections.

One first benefit with the "simulation-methods" is that we get the possibility to compute noise time-histories in selected receiving points on ground. Other gains are that we, at least in principle, with regard to the noise source strength may account for: both thrust and speed related variations and configuration changes. And with regard to the sound propagation: we can include atmospheric impact from refraction and turbulence, and not only the absorption as in the integrated methods.

In this context it is interesting to note that in ECAC Doc.29 from 2016 (and in previous versions) it is anticipated that simulation methods could replace integrated methods when computing capacity becomes "enough", or in ECAC Doc29 words:

a) "integrated models represent current best practice" [authors note: referring to longtime regional averages] and
b) "This situation may change at some point in the future: 'simulation' models have greater potential and it is only (1) a shortage of the comprehensive data they require, and (2) their higher demands on computing capacity, that presently restrict them to special applications (including research)"

Here the second point under b) "higher demands on computing capacity", can be removed since it would not anymore constitute any obstacle. Though, the matter of data required is still today a problem, perhaps primarily due to a reluctance among aircraft/engine manufacturers to reveal sensitive information about their products. But possibly also due to the need for more test-flights and a more complex database, including the handling of such data in practice. Our view is though, that there are no longer any fundamental technical obstacles preventing from taking the step over to simulation methods, but rather that it could be a question about costs and proprietary matters.

In all three SAFT simulation paths we apply a concept that we believe was introduced for the first time within the development of the SAFT-program computational algorithms, namely the concept of a Transmission-Loss Interpolation Matrix (TLIM). Behind the need for this TLIM is the high computational costs linked with a straightforward implementation of a ray-tracing from a discrete trajectory to ground-grid where sound-rays from all trajectory points to all ground-grid points might be needed. A way to avoid these costly calculation operations can be by assuming that the same atmospheric conditions apply along the complete trajectory part to be studied and from these compute the TL (Transmission Loss) once and for all for: a fixed set of altitudes, horizontal distances, 2D-vertical plane directions and emission angles within these planes. With such a 4D-interpolation matrix(=TLIM) settled for the time and position (airport area) of the study it is possible to compute the receiving noise (over time) in any point on ground within the horizontal extension/radius of the TLIM (max set to 10 km in our case). The concept of the TL-interpolation matrices and the involved ray-tracing is discussed in ref. [1] chapter 4.9 p.53 and on.

NOTE: as of March 2021 the current TLIM models are only applicable for rather "flat" regions, like the Stockholm TMA. For more hilly/mountainous regions the topography has to be included in the TL-interpolation in some way.

The simulation-based noise prediction pahs in SAFT are three as outlined in Table 2 below, in terms of complexity, relation with physics and input needs ordered from 3 to 5:

| *Simulation-/sound emission models* |
|---|
| 3. Reversed engineering combined sound source from NPD-SEL and given spectral and directivity data |
| 4. Simulation, total AC-sound sources established from measurements of pass-by noise events |
| 5. Full Simulation, semi-empirically modelled individual sound sources |

Table 2. Simulation-/Ray-tracing based computational paths in SAFT (see outline in Figure 1)

In Path 3, "*Reversed engineering ...*", which is the computationally "simplest" of these three paths, the starting point is the NPD-SEL data for the given aircraft type. In order to establish a representative sound source for a specific aircraft type SAFT internally runs through a process which is equivalent to: computing SEL-data for a fixed altitude flight at 160 knots, assuming a receiving position underneath the flight path, a frequency spectrum class as of ANP-data, with an arbitrary set nominal total level, and a *user defined longitudinal directivity* of the combined total aircraft sound source. The total level of this SEL-data, computed as for a SAE 1845 atmosphere input data, is compared with the corresponding NPD-SEL level and adjusted to give same value at a selected distance. This sound source is then representing the aircraft as a directive, frequency dependent source along the trajectory where, as for ECAC Doc29/NPD, the thrust is the single independent predictor input variable. For a known trajectory, including thrust setting, the only lacking data for noise-mapping for an aircraft represented in ANP-data for a SAFT Path 3, "reversed-engineering"-run, is the longitudinal directivity. Consequently, this has to be defined by the user as input. This input source directivity is in the current SAFT implementation simplified as having the same shape over all frequency bands, 50Hz- 5kHz. As for the standard ECAC Doc29 integrated method we have also here, for each aircraft type, to rely on one single set of standard NPD data which is representing "full configuration" only.

In Path 4, "*Simulation based on total AC-sound sources established from measurements* …", the word "total" regards the combined total noise levels from all contributing individual sources, i.e., from engine: fan-, jet-exhaust mixing, combustion- and from airframe: high-lift devices and landing gear flow related noise, in each frequency band. The source strength is established from pass-by measurements during different speeds, configurations, thrust-settings and atmospheric conditions and no attempt is made to separate the different origins in this measured data. These noise sources are defined as a function of: frequency (1/3-octave bands), longitudinal and lateral directivity, thrust, TAS (True-Air-Speed) and local properties of the surrounding air at flight altitude (pressure, temperature)

In Path 5, "*Full Simulation, semi-empirically modelled individual sound sources*" the step is taken to model also the individual noise sources and their contribution to the total combined source as of Path 4. This work is carried out at Chalmers and is mainly based on empirical models found in the literature and established from parametric studies of engine/airframe component dimensions and resulting noise found in laboratory wind tunnel/noise measurements. This path will be presented in other contexts and not further discussed herein.

### 2.6. Supporting computations - SAFT Path 6 and 7, Sound propagation data preparation

| *Sound propagation DATA PREPARATION* |
|---|
| 6. Create an atmosphere profile for a selected met.no AROME dataset |
| 7. Create a Transmission Loss (TL) matrix for a selected atmosphere dataset |

Table 3. Data preparation computational paths in SAFT (see outline in Figure 1)

In SAFT noise computation as of Path 2 (Doc29 with arbitrary atmosphere model/data) and Path 3-5, simulation methods, one may use the "real" atmospheric data as of an atmospheric profile prognosis [14], [15] (for alternative atmospheric data applicable in SAFT, ISA - International/ICAO Standard Atmosphere and classes of meteo-profiles - from a set of atmosphere wind and stability, see ref. [1] chapter 4.8.1 Atmosphere model types p.40). For the simulation paths this involves possibilities to include refraction in the sound-propagation, while in the Doc29 computation (Path 2) is restricted to atmospheric absorption resulting from the atmosphere prognosis of the time of flight or selected generic atmosphere profile.

In Path 6, "*Create an atmosphere profile for a selected met.no AROME dataset*" the SAFT user has the possibility to download and view atmospheric profile data for a time between (at least) 1.5 years back in time or 1 day ahead. It should be noted that this step is not needed to run explicitly when carrying out a noise mapping run (Path 2-5), this since it is in those computational paths automatically done. The reasons to have it as a separate alternative is that it is of interest in some situations like in preparing runs, to understand the conditions etc. Sample atmospheric data plots can be found in ref. [1] figure 29-42. Together with the prognosis based atmospheric data is also an automatic collection of data from a weather station at Arlanda Airport, thought primarily thought of as a check of prognosis data with regard to wind direction and speed at ground (10m). The time for download and compilation of these two data sets, prognosis + weather station [16], is approximately 1 min. An example atmosphere prognosis and measured data comparison is shown in Table 4 below:

| Data origin (prognosis or meas.) | Temp °C | Wind Dir.° | Wind Speed m/s | $p_{sealevel}$ mbar | RH% |
|---|---|---|---|---|---|
| ***AROME prognosis*** | ***0.4*** | ***352*** | ***3.5*** | ***1015*** | ***72*** |
| **SMHI meas.10m (at AROME hour)** | **-0.4** | **350** | **4** | **1015** | **77** |

Table 4. Example comparison AROME prognosis data and SMHI measurements at 10m height

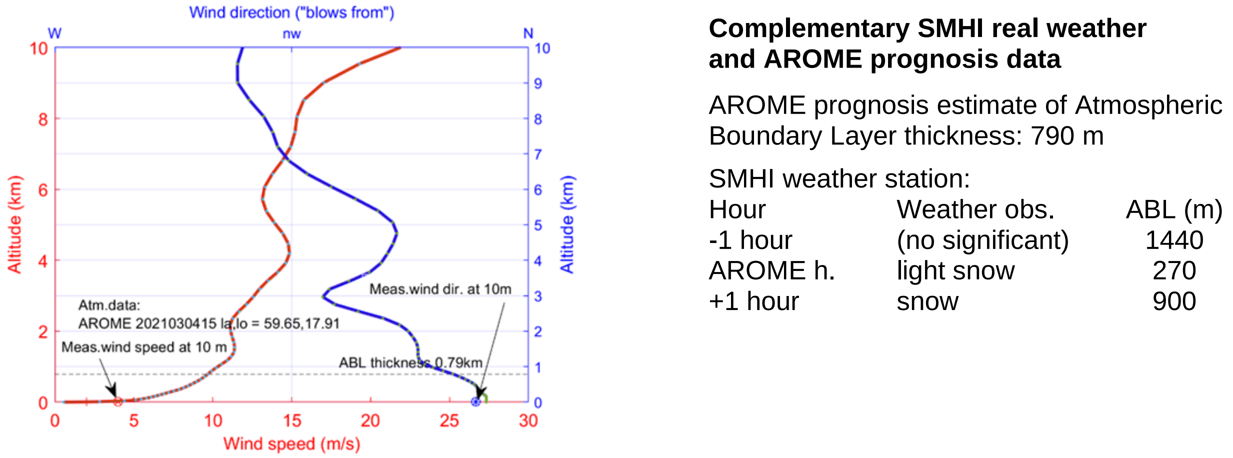


Figure 2. Example AROME prognosis winds + SMHI measurements (as in Table 4 above)

In a Path 7 - run: "*Create a Transmission Loss (TL) interpolation matrix for a selected atmosphere dataset*" the user has the possibility to pre-compute a so-called TLIM, outlined above in paragraph 2.5 (and further discussed in ref. [1] together with the ray-tracing behind its establishment).

### 2.7. Supporting computations - SAFT Path 8 - Trajectory DATA PREPARATION

| ***Trajectory DATA PREPARATION*** |
|---|
| 8. Select and read a set of ADS-B based approach trajectories from OpenSky Historical database |

SAFT preparation Path 8 "*Select and read a set of ADS-B based approach trajectories from OpenSky Historical database*" is a way to interactively select and read in air traffic from the OpenSky historical database [16]. The user defines the airport, runway and time span and gets after a few interactive input steps first a list of number of flights within selected criteria, if choosing to go on each trajectory on the list is read in. If the icao24-ID of the aircraft is not in the OpenSky database of the worlds civil aircraft the user has the opportunity to find it elsewhere before it has to be deselected (as “unknown”).

### 2.8. Supporting computations - SAFT Path 9 to 10 - Sound propagation data preparation

| ***SOUND SOURCE ESTIMATE*** |
|---|
| 9. AC sound source estimate sample outgoing from sound measurements |
| 10. AC sound source linear regression model coefficients outgoing from time record samples data from above SAFT path 9-runs |

Table 5. Sound source estimation computational paths in SAFT (see outline in Figure 1)

The aircraft type representative sound sources that are to be used in SAFT Path 4, “*Simulation based on total AC-sound sources established from measurements …*”, have to be established through previous Path 9 and 10 sound source estimations (or may be prepared “outside” SAFT and given on the wanted SAFT-readable format). Currently, as of March 2021, These SAFT computational Paths 9 and 10, focus on A321neo approaches where we have access to FDR-data and noise measurements [18] for the same flights. In the process of noise source establishment one aim is to find ways to circumvent the need for FDR-data and solely rely on ADS-B/OpenSky data for the trajectory data representing configuration and thrust, and AROME meteo-data for thermodynamic- and wind conditions at aircraft altitude. Whether FDR-data are available or not AROME-meteo data are used for the sound propagation computation down to ground. Though FDR-data can be used for validation of some AROME-data.

In SAFT computational Path 9 “*AC sound source estimate sample outgoing from sound measurements”*, an estimate of a sound intensity point source is established from noise-measurements together with a sound “back-propagation”. The estimate represents the aircraft, at each given high-lift configuration, as a sound intensity strength at 1 m as a function of: frequency, directivities, $\theta$ and $\varphi$, thrust($F$), true airspeed (*TAS)*, surrounding air temperature ($T$) and air density($\rho$) at the aircraft position.

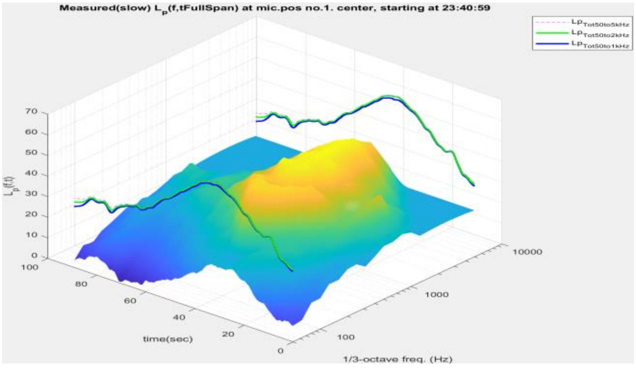


Figure 3. Aircraft pass-by noise measurement spectrogram (1/3-oct.) and sound pressure level

The “back-propagation” starts out from pass-by noise measurements such as in Figure 3 above. By accounting for the atmospheric conditions at the time of measurement and the different physical intensity reduction mechanisms with impact on the sound along the propagation path between and aircraft microphone (transmission Loss, *TL,* in dB) we may reach a sound source strength estimation record as in eq.(1):

$$\hat{L}_{I,config}(f,\theta,\varphi,F,TAS,\rho,T)|_{t_{aircraft}} = L_{p,mic}(t_{mic}) - TL_{total}(t_{aircraft},t_{mic}) \qquad (1)$$

where the $TL_{total}$ may be written as in eq.(2):

$$TL_{total} = TL_{geo} + TL_{\rho c} + TL_{absorp} + TL_{refract+turb.scat.} + TL_{EGA} \quad (2)$$

Where the TL-subscripts denote losses in dB due to:

*geo* geometrical (spherical) spreading, $TL_{geo}=10log(r_2/r_1)$, $r_1=1m$

*ρc* TL due to change of specific impedance of the air between source and receiver

*absorp* TL due to absorption in the air, sound wave energy loss to friction and relaxation processes in the air

*refract+turb.scat* with regard to spherical propagation: sound rays displacement, compression/expansion due to sound speed gradients and scattering due to turbulence

*EGA* Excess Ground Attenuation, impact of ground reflections in relation to a free field

All these TL contributions are in principle the same as for simulation-based noise-mapping/forward sound-propagation as in SAFT path 3-5. Each of them, as well as the sound measurement itself, has an uncertainty which together with the randomly fluctuating character of the involved aircraft noise sources brings in a need for a statistical analysis before reaching a sound source strength model. The step taken here is a multiple regression analysis similar to the approach found in [19] with the total, i.e., all individual sources combined, sound intensity level $L_I$ as the dependent (response) variable. And *f, θ, φ, F, TAS, ρ* and *T* as predictor/independent variables. In order to establish the regression analysis input for one time-record (1 sec time steps applied in SAFT), as of Figure 3 and equation 1 and 2 above, one critical step is the EGA resulting from the microphone positions (at 1.2 m above ground in most cases [18]) and the surrounding ground conditions. The other TL-contributions described in, e.g., [1]. The method applied here to remove the EGA from the aircraft pass-by noise measurements, in order to reach free-field estimates, has been an "engineering" trick where the dips in the measured spectrum have been interpreted as ground-reflection cancelling, i.e. λ/2 match between the direct vs reflected wave, and simply replaced with a spectrum envelope creating a first intermediate $L_I$ time-spectrum (spectrogram) with only the amplifying part of the EGA effects left. See Figure 5 sample spectra of this type. In a second step a similar trimming is applied on the theoretical 3D EGA time-spectrum. Here we concentrate on the EGA as seen in Figure 6

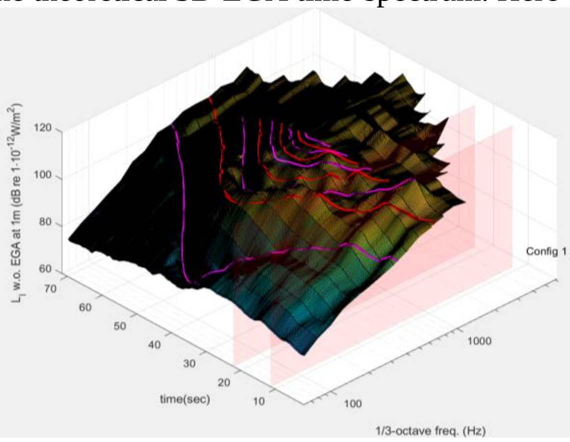


Figure 4. $L_I$ estimate before removal of EGA
*Red lines = theory +/- interference red=peak +interference*
*Magenta lines = destructive, λ/2-interference*

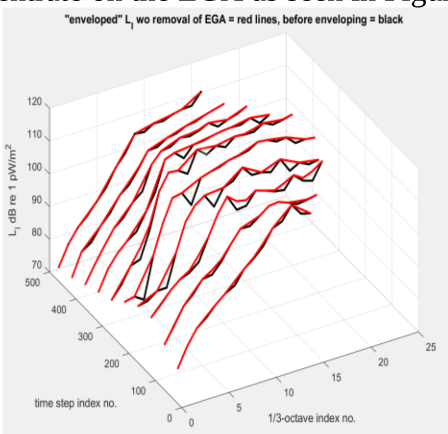


Figure 5. Example enveloped $L_I$ estimate
*Black lines = $L_I$ with EGA included, Red lines = "enveloped, destructive interference removed"*

and Figure 7 of the theoretical 3D EGA time-spectrum, presented as -EGA. In the Figure 6 an

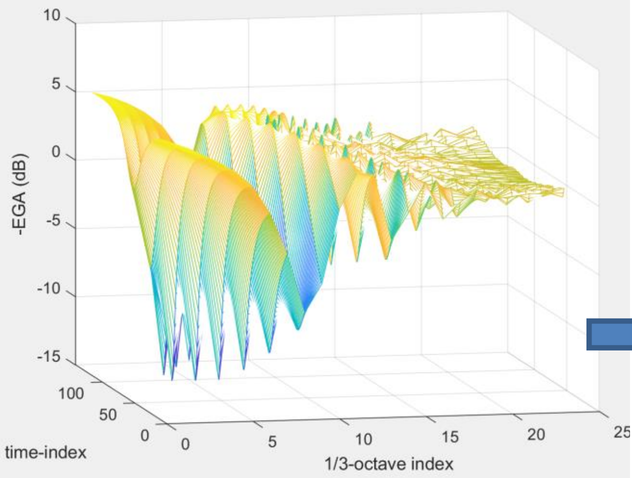


Figure 6. -TL<sub></sub>

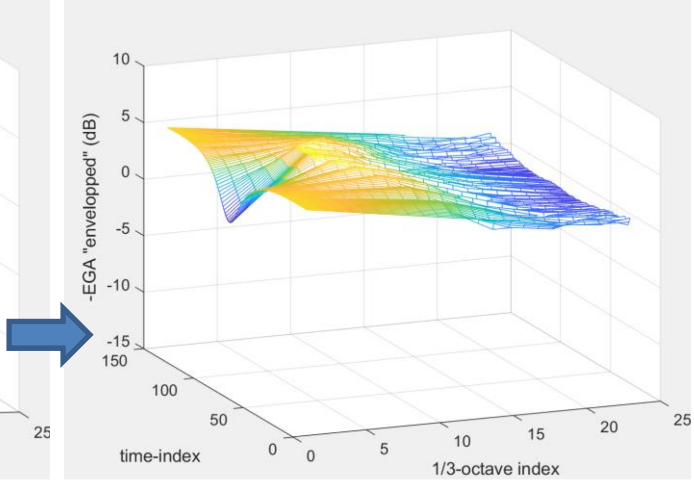


Figure 7. "envelopped" -$TL_{EGA}$ as of Figure 6

EGA-model [20] for wide-band (here 1/3-octaves), plane waves, for the example flight passage is presented. The time-frequency result of this model is then "enveloped" in a similar manner as spectra in Figure 5, i.e. leaving the amplified regions, but lifting up destructive, λ/2-interference-regions to the levels of the amplified ones. Now we compute approximate free-field $L_I$ as:

$$\hat{L}_{I,config}(t_{aircraft}) = env(L_{p,mic}(t_{mic})) - TL_{geo} - TL_{\rho c} - env(TL_{EGA}) \qquad (3)$$

Where "env" denotes the enveloping procedures outlined above. It should be noted that the TL term $TL_{refract+turb.scat.}$ from eq.(1) is left out here in eq.(3) since it has not yet been applied in source estimations (only in sound propagation /noise mapping sofar). Such a time record sample $\hat{L}_{I,config2LGup}$ for a specific microphone pass-by flight might look like in Figure 8-10 below:

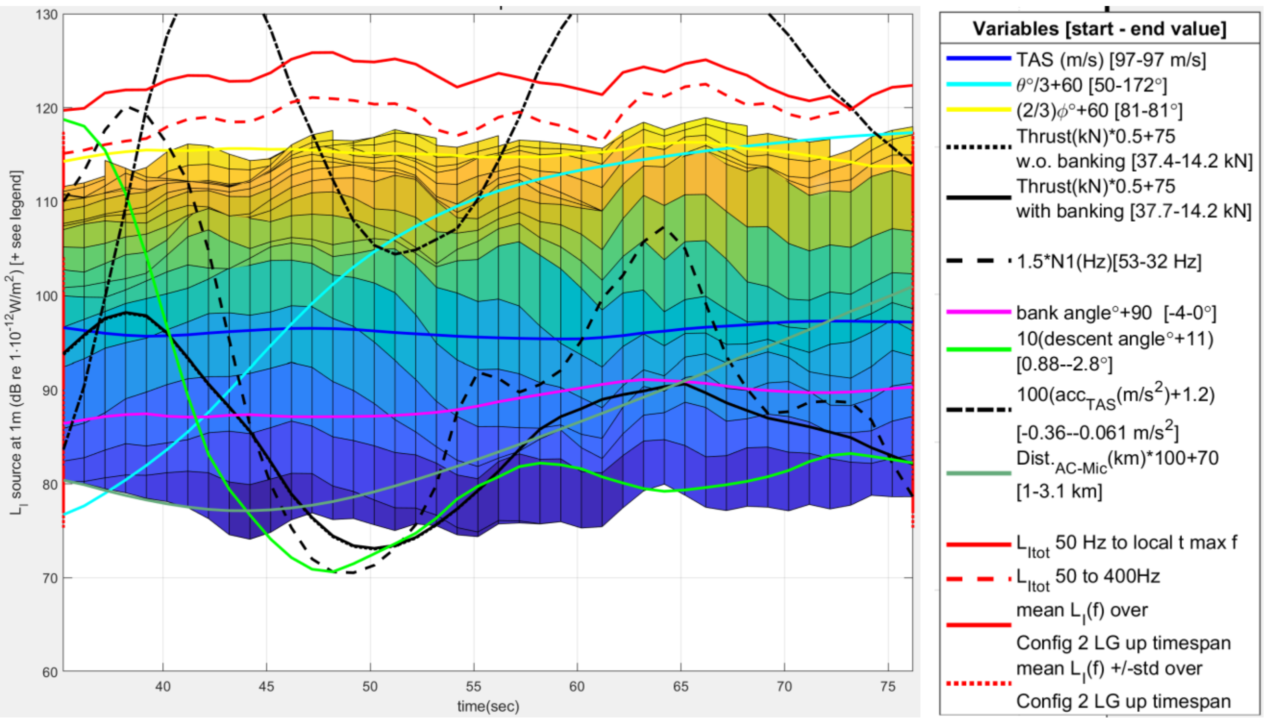


Figure 8. Sample time record aircraft sound source strength estimate $\hat{L}_{I,config2LGup}$, time view

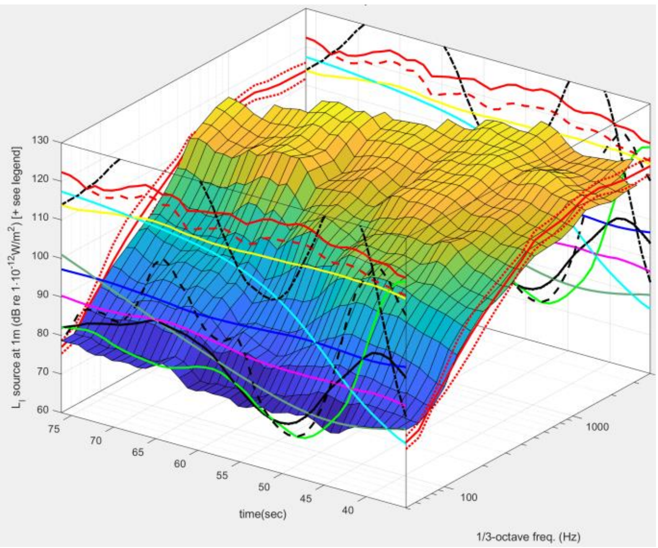


Figure 9 Sound source strength estimate $\hat{L}_{I,config2LGup}$, time and frequency view

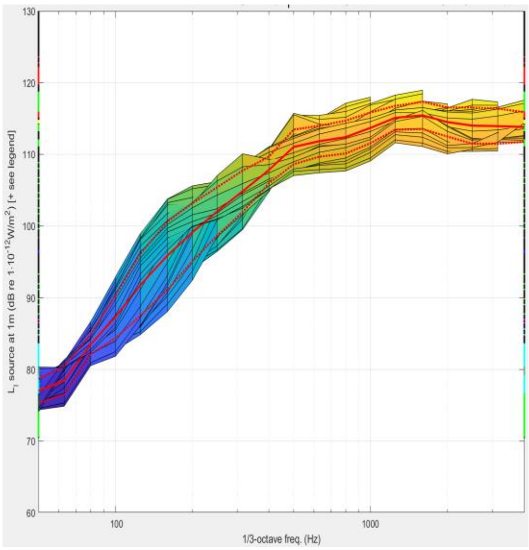


Figure 10 Sound source strength estimate $\hat{L}_{I,config2LGup}$, frequency view

In SAFT Path 10. Runs, "*AC sound source linear regression model coefficients outgoing from time record*" sound source estimates created in previous Path 9 runs are gathered and the multivariate linear regression analysis is carried out for the individual configurations. Currently these estimations are partly based on FDR data from A321neo but the idea is to be able to do about the same analysis based on only OpenSky ADS-B data for the trajectory and thrust estimates. Figure 11 below shows input for a regression analysis based on 11 gathered time records from Path 9 runs, representing 11 different mic/flight-combinations for which $\hat{L}_{I,config1}$ at 1m is estimated (upper left subfigure) together with simultaneous value of (candidate) predictor variables

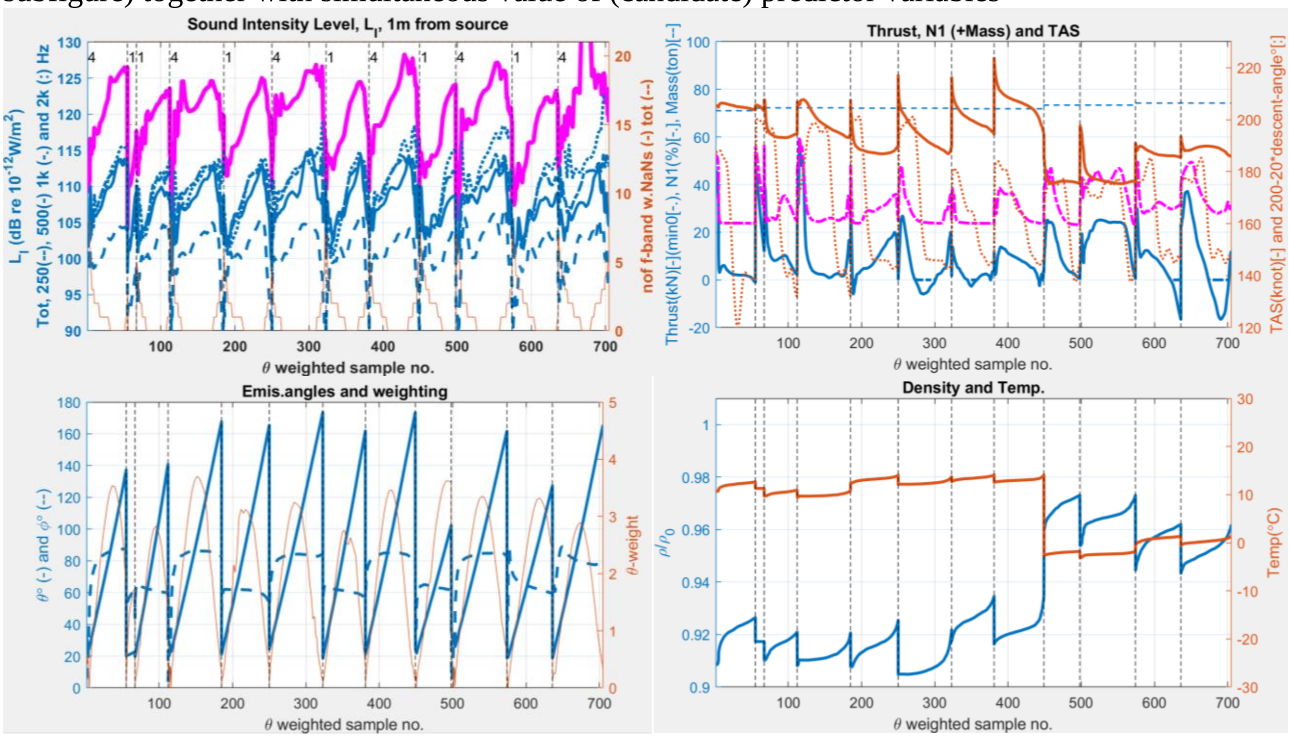


Figure 11. Input to regression analysis.

*Upper Left:* $\hat{L}_{I,config1}$ 1/3-oct. 250, 500, 1k and 2kHz blue --,-,-. and : resp. total level =magenta

*Lower Left:* $\theta$, $\varphi$ and sample weighting. *Upper Right:* TAS=red, Thrust=blue, engine low pressure fan rotational speed, N1=magenta(--), *Lower Right:* air density rel. 1 atm at aircraft alt.= blue, Temperature at aircraft altitude = red colour

(sorry no more space …)

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