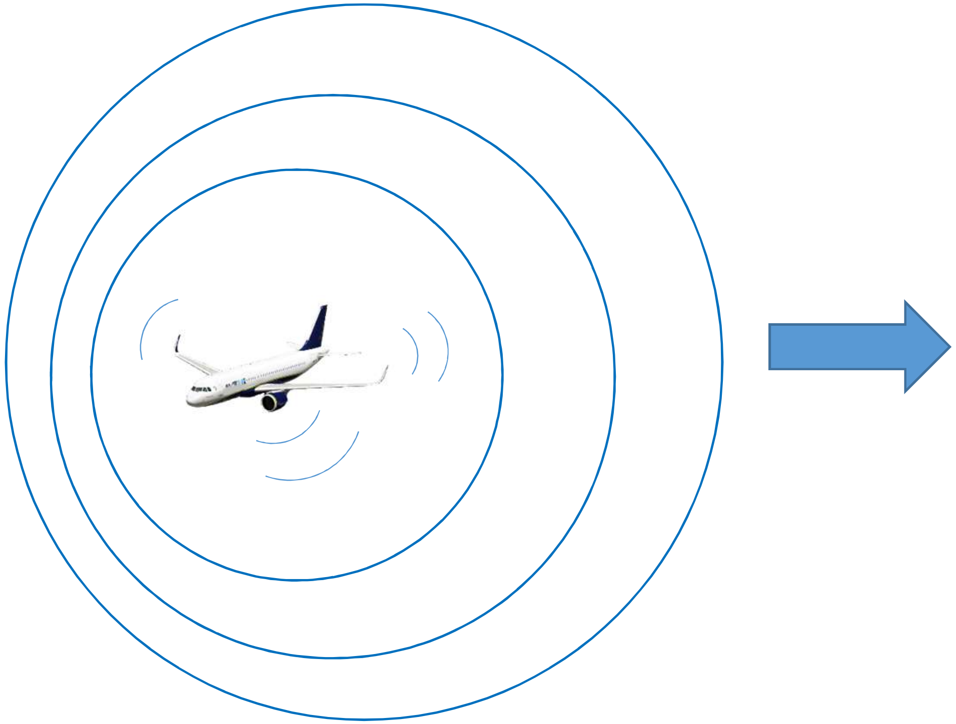
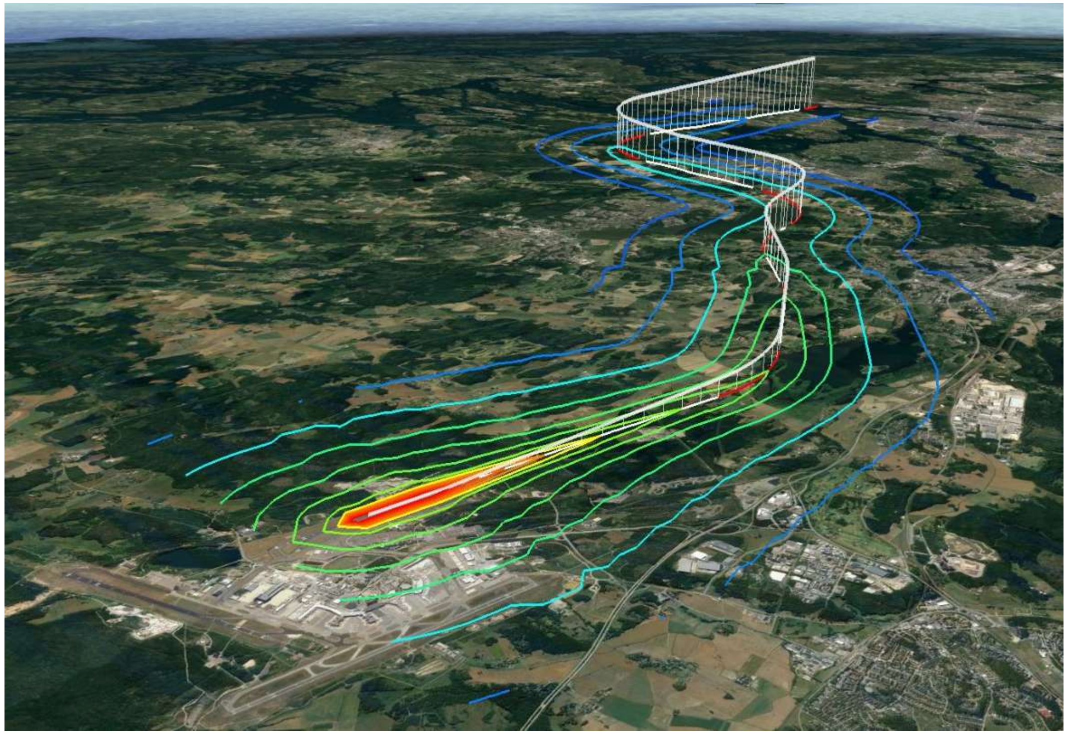
Aircraft noise simulation with the SAFT-program

(SAFT = Simulation of atmosphere and Air traffic For a quieter environmenT)





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1. **Aircraft noise mapping of today integrated vs simulation methods**
2. **SAFT outline**
3. **Case examples and conclusions**
4. **SAFT applications in coming CSA-projects and beyond**

1. Aircraft noise mapping of today and the SAFT simulation code

- SAFT is a computer code for aircraft noise mapping of single event aircraft pass byes + a CSA-project (2.5 year 2016-2019 ended in June)
- Financed by Trafikverket and administrated by CSA (Centre for Sustainable Aviation) at KTH
- Partners: KTH-MWL and Chalmers

- Noise mapping around airports:

  traditionally by "integrated methods" ECAC Doc.29, AEDT(INM successor in the US)

- ECAC Doc.29/integrated methods **lacks:**

  sound source frequency and directivity dependencies, configuration and speed dependencies and possibilities to study noise time-histories for general atmospheres

- The strength of ECAC Doc.29/integrated methods are:

  NPD-database covering most existing aircraft wrt noise level/power setting

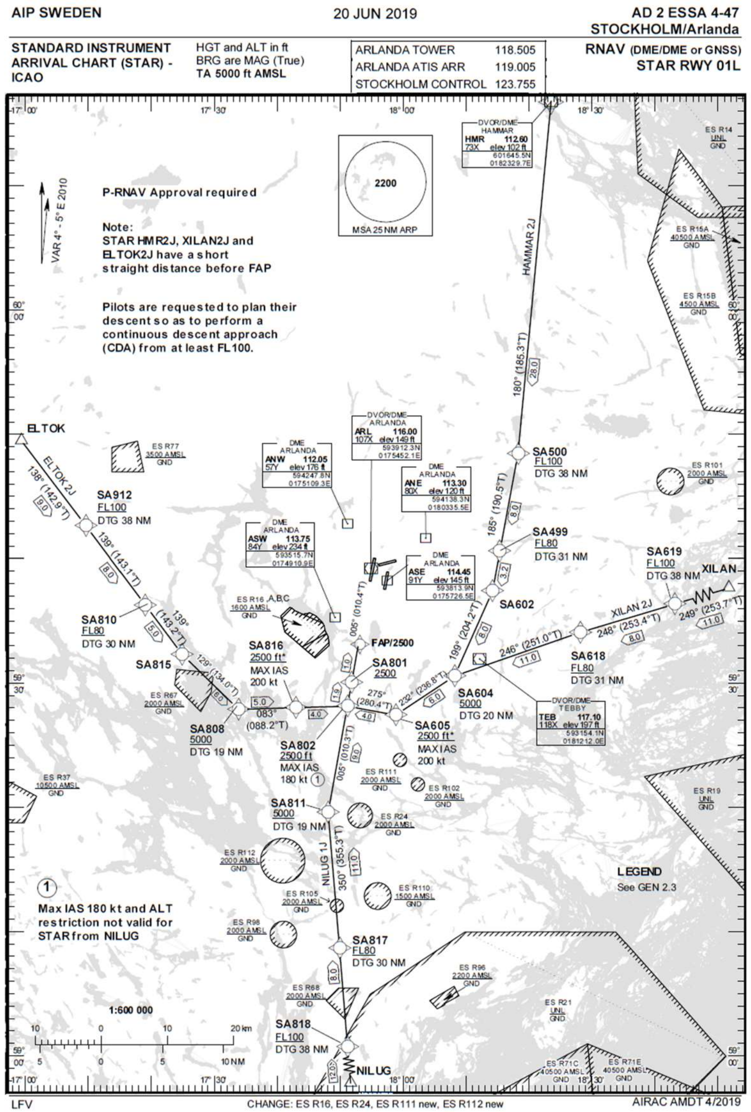
Though:

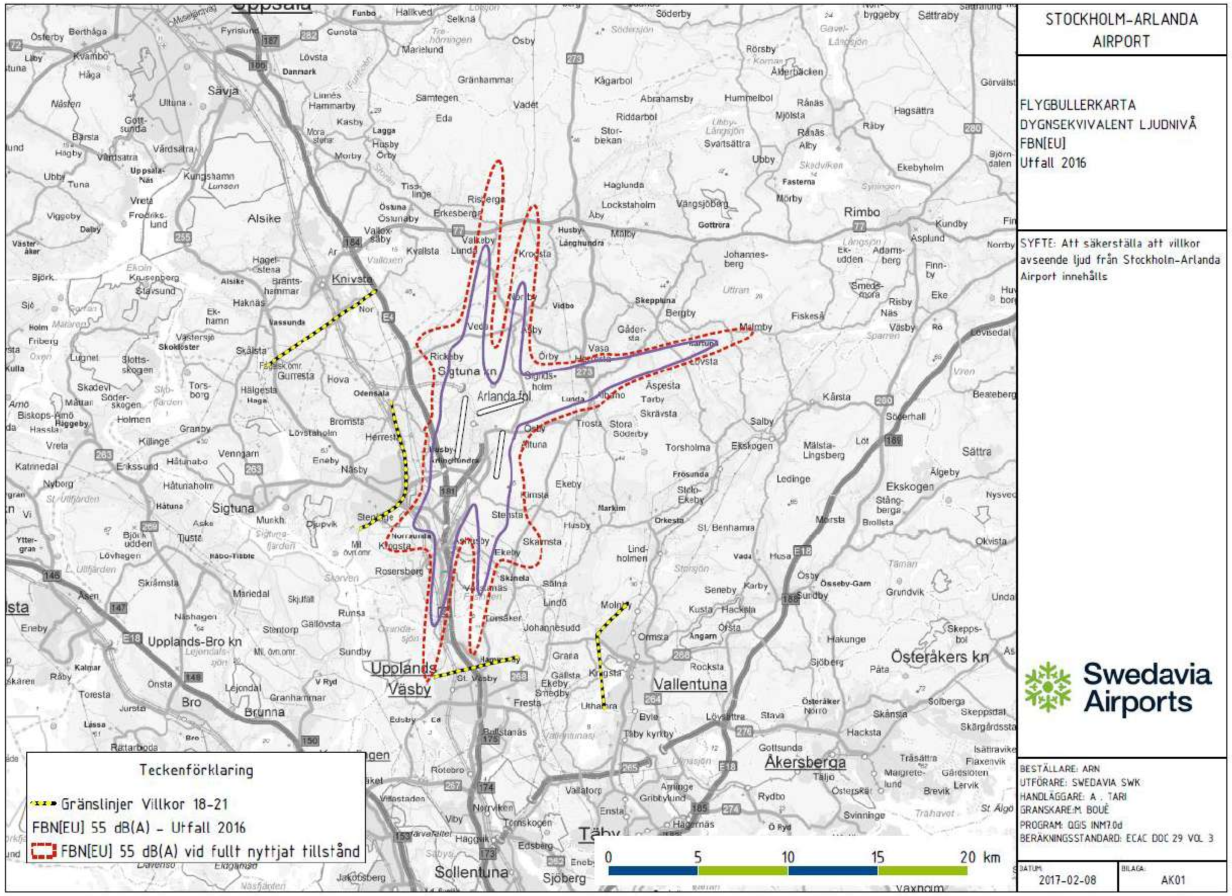
due to the limitation in covered dependencies and information at the same time a strong drawback!

Swedavia: ”Flygbullerkarta som visar beräknad FBN 55 dB(A) (lila kurva) för utfallet år 2017 tillsammans med gränslinjer för villkoren 18-21 som visas i gula streckade linjer. I figuren visas också FBN 55 dB(A) vid fullt nyttjat tillstånd (röd kurva)”

https://www.swedavia.se/contentassets/3ccd5eee926149979ca1c7a96d7fba72/miljorapport-2017.pdf

LFV: https://www.aro.lfv.se/Editorial/View/6272/ES_AD_2_ESSA_4-47_en





- SAFT - a time-stepping aircraft noise simulation code, allowing for general, time and frequency dependent noise sources and atmosphere/weather impact + resulting noise time histories on ground

- Difficulties:

  lack of open aircraft noise source data – industrial proprietary, unwillingness to share

- Possibilities with regard to modelling of noise sources:

  a. NPD-database + "back propagation" with SAFT (or similar) involving an assumed spectra and source directivity

  b. semi-empirical modelling based on engine + airframe design size and performance

  c. based on real flight noise measurements close to airports + "back propagation"

  ~~d. CAA/aeroacoustic modelling~~ (only as support to semi-empirical model testing)

- (up to now) Different focus and applications of integrated vs simulation methods:

  <u>integrated methods (like ECAC Doc.29</u>) – yearly means of sound exposure levels, changing route design, (procedures)

  <u>simulation methods (like SAFT</u>) – single aircraft pass-by events, trends when changing aircraft/engine or design or procedures (not much research found in literature)

- Already 10 years ago it was anticipated in ECAC Doc.29:

  "... integrated models represent current best practice. 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)"

<u>We believe that these two points are not valid arguments anymore!</u>

... our view is that:

- Simulation methods and computer codes like SAFT are, together with coupled noise measurements/aircraft sound source estimates, very well ready to take over from the older integrated methods.

- Moreover: it could be a matter of awareness and/or reluctance (?) among involved organisations and stakeholders when this change, to more powerful methods in noise-mapping, is to come.

- Some ongoing initiatives towards simulation methods (or at least a more comprehensive extension of the NPD-data to more than one speed/configuration) can be found in:

P. Houtave and J.-P. Clairbois , "Single aircraft pass-by: Modelling relevant noise at ground", in *Euronoise 2018*, Crete, 2018.

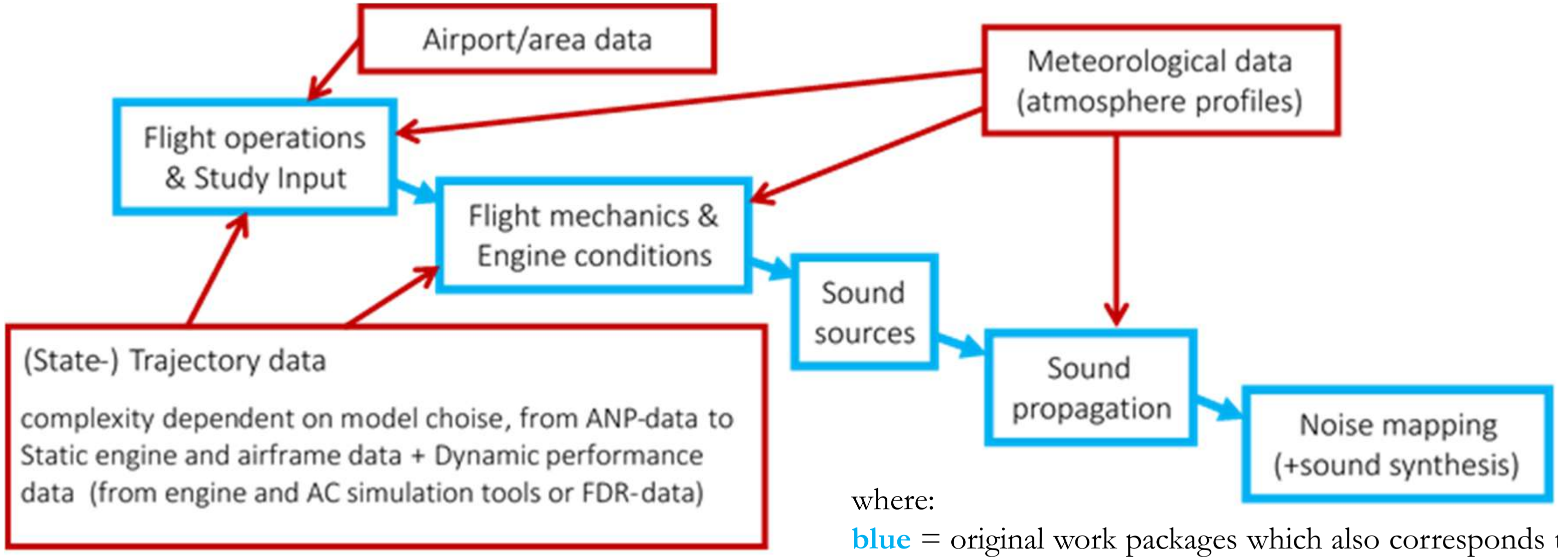
C. Zellman, "Dr.Thesis: Development of an Aircraft Noise Emission Model Accounting for Flight Parameters," Technischen Universität Berlin, Berlin, 2017.

D. Mavris and C. Perullo, "Noise Power Distance Re-Evaluation, FAA Project 043," 2018. https://ascent.aero/documents/2018/06/ascent-043-2017-annual-report.pdf

2. SAFT outline

The current SAFT simulation code – single event

(draft final SAFT report at:
https://www.kth.se/polopoly_fs/1.926212.1568982611!/Slutrapport_SAFT_draftversion1.pdf)



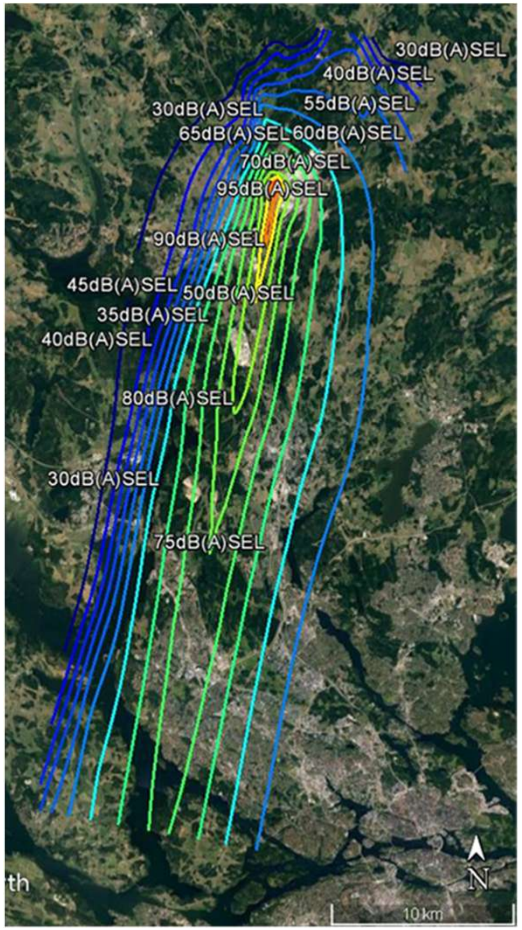
where:
blue = original work packages which also corresponds to the main blocks in the SAFT computer code
red = user input data

SAFT enables prediction of:

- **noise time histories** in any ground point along a flightpath
- **noise level contour lines on ground for "any" aircraft,** i.e. existing and future aircraft, given aircraft/engine performance along a trajectory (ground track + profile)

... by accounting for:

- the **atmospheric profile** ("real weather") by involving SMHI/met.no prognosis data (or other, e.g. simpler standard type profiles)
- **sound propagation models**, selected within a set of implemented ones **of different complexity/accuracy** (from "integrated" over "straight rays" to "refracted rays")



... and this made possible:

- ... in a comprehensive, user friendly way while keeping the computational times short
- User screen view when running SAFT interactively:

Decide the type of noise computation n you want to run among the following SAFT run-paths:

NOISE MAPPING

-- **ECAC Doc.29 integrated-/sound immission model, AC's within the ANP-database** Output: Noise Contours --
1. Original NPD-data sound immission - fix atm./absorp.model SAE-ARP-1845 (Default)
2. Atmosphere and absorption adjusted NPD-data sound immission - choice of atm./absorp.model follows - no refraction

-- **Simulation-/sound emission models** Output: Noise and/or Noise Event Time Histories --
3. Reversed engineering combined sound source from NPD-SEL and given spectral and directivity data (i.e. merged individual, fan+jet+...) --
[4. Simulation, total AC-sound sources established from measurements of pass-by noise events. NOT YET IMPLEMENTED !]
5. Full Simulation, semi-empirically modelled individual sound sources. AC: A321-V2533

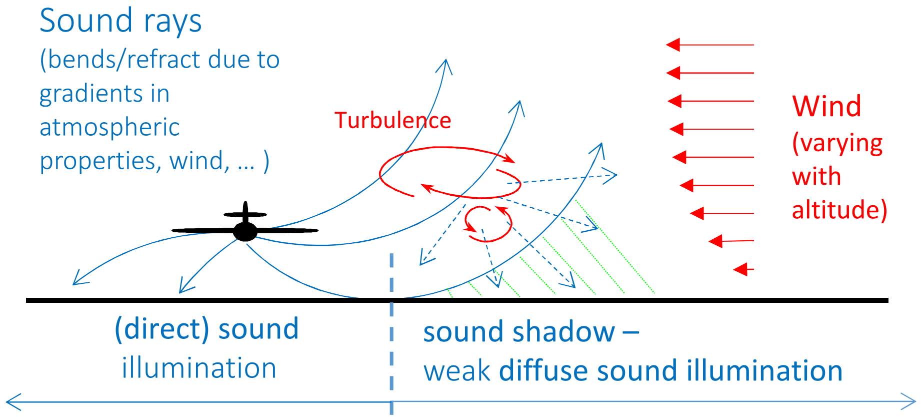
DATA PREPARATION - for later use in noise mapping

-- AROME atmosphere data only, for later use Output: atmosphere profile(s)saved in file --
6. Creation of an atmosphere profile for a selected met.no AROME dataset (to be applied in later SAFT-runs)
-- TL only (no AC involved) for later use Output: TL interpolant matrix saved in file --
7. Creation of a Transmission Loss (TL) matrix for a selected atmosphere dataset (to be applied in later SAFT-runs)
-- Establish an AC sound source sample for later use Output: frequency, directivity, speed- and AC configuration dependent sound source saved in file --
8. AC sound source estimate outgoing from sound measurements on ground and related trajectory data (to be applied in later SAFT-runs)

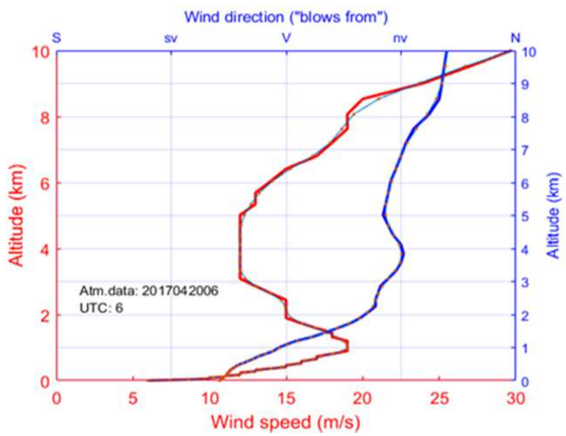
Please give a number between 1 and 8:

SAFT three alternative atmosphere models/data sources:

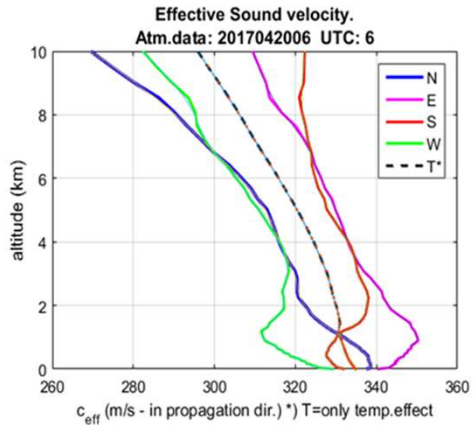
1. ISA atmosphere + wind
2. Typical atmospheres wrt cloud cover, stability, temp + wind as of IMAGINE project
3. Forecast data (AROME/met.no/SMHI - covering Scandinavia each hour one day ahead, or historical data over years)



Atmospheric data



⇒ Effective sound velocity



Versatile in terms of possible studies, e.g:

- **new aircraft concepts** or modification of existing types
- **noise prognoses**
- **new routing** and **runway use pattern with regard to weather and noise distribution**
- noise pattern input into the **planning process for new runways**

Due to the easy understanding and running of SAFT:

- pedagogical tool in the process of **learning about aircraft noise, "ready to run by beginners"**
- **supporting knowledge dissemination and cooperation with experts other fields,** such as aeronautics, ATM and emissions

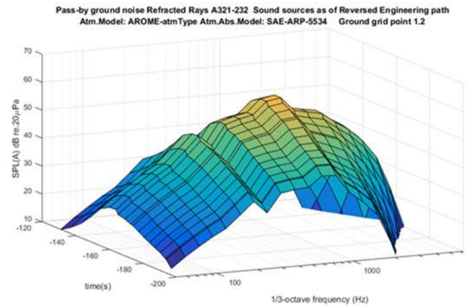
3. Case examples and conclusions

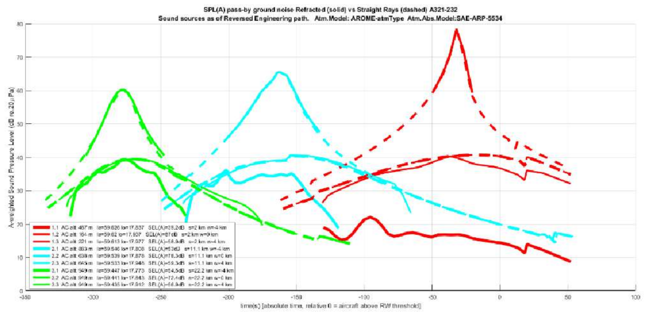
- **Time event analyses possible in any ground point** (either in selected grid points or in other specific receiving pts)

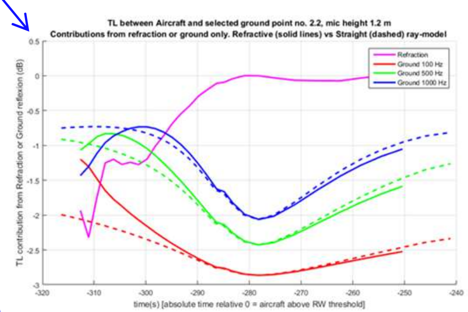
- **Sub-division in separate TL contributions** based on the physics behind the sound propagation to any ground point

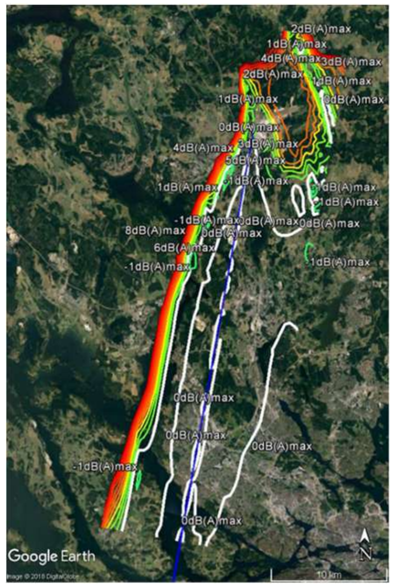
- **Direct grid comparisons possible – contours of "ΔdB",** e.g. between different propagation models, different weather data, different aircraft, procedures,…

- **"Real" weather prognoses** – allow for **forecasting of noise patterns,** including different forecasts with various probability

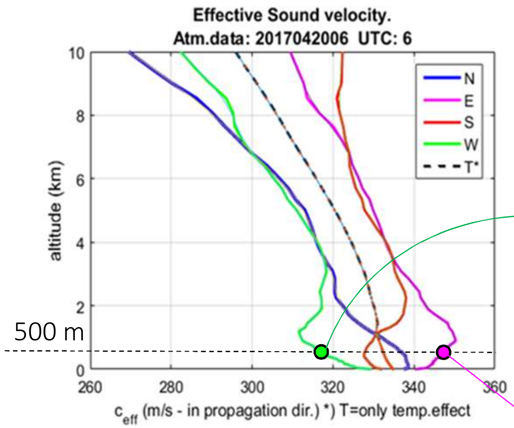


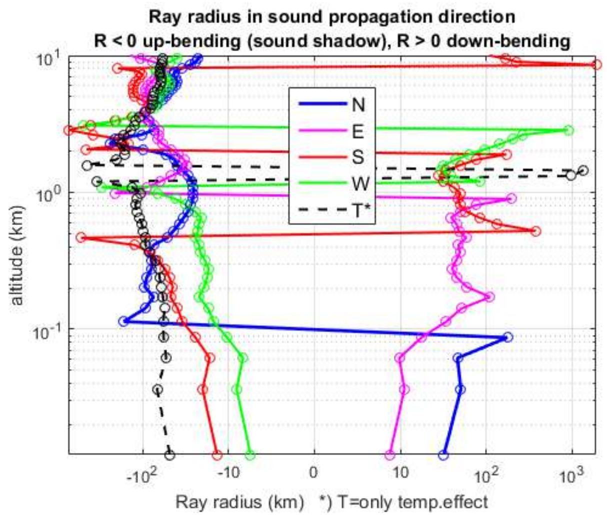






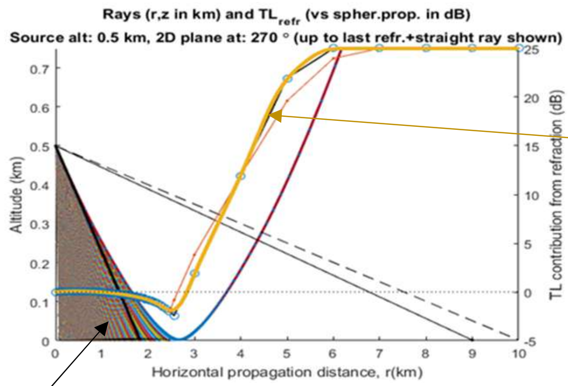
Sound propagation, ray-tracing. Transmission Loss (TL*)





Sound rays and computed Transmission Loss (TL) due to refraction only:

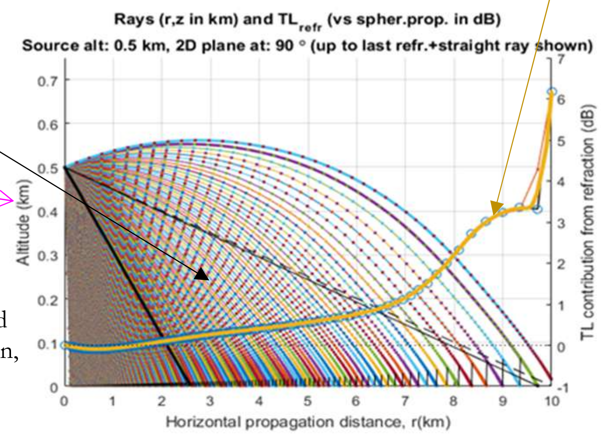
Ex. Source at alt. 500 m, sound propagation to the west, headwind



$TL_{refraction}$

Sound rays

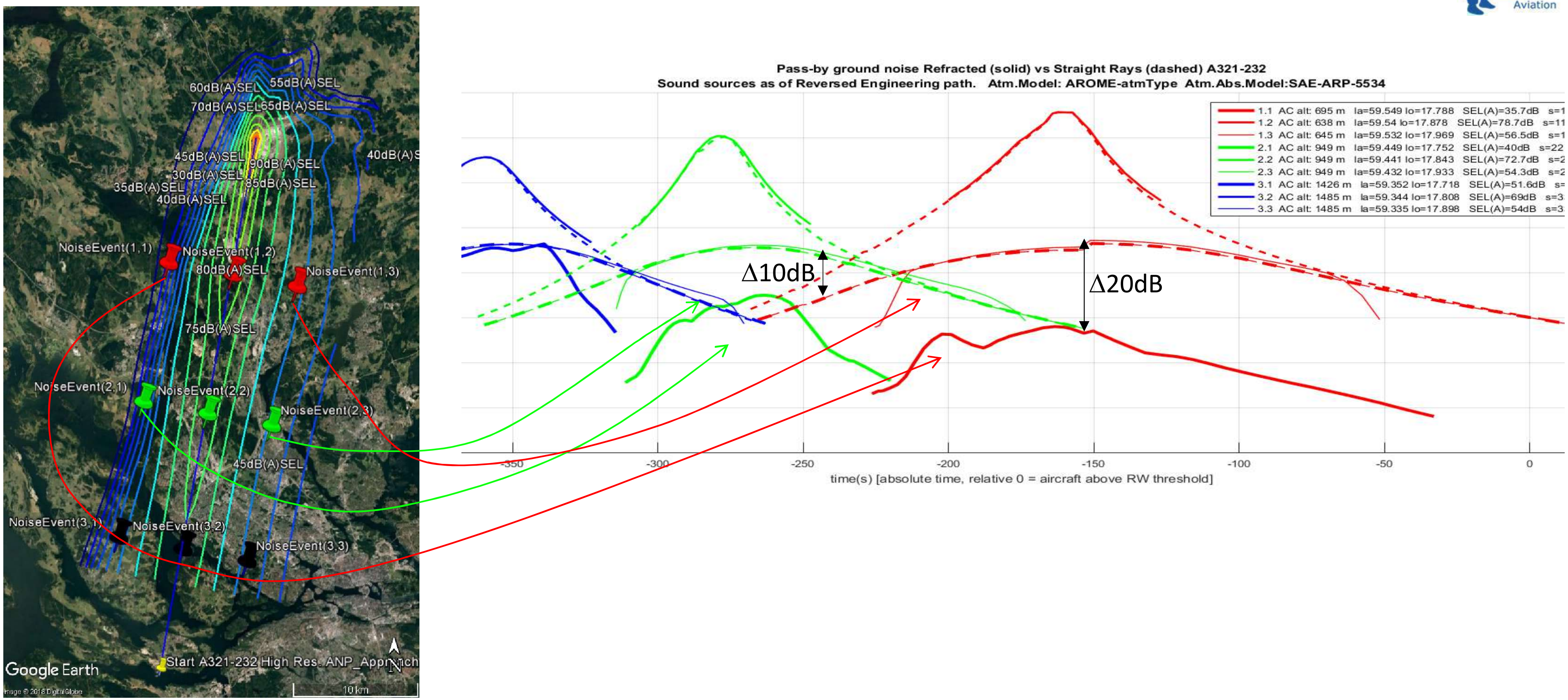
Ex. Source at alt. 500 m, sound propagation to the east, tailwind



*) TL = Transmission Loss, the loss in dB between source and receiver due to physical mechanisms, e.g. refraction, absorption, ground reflection etc.

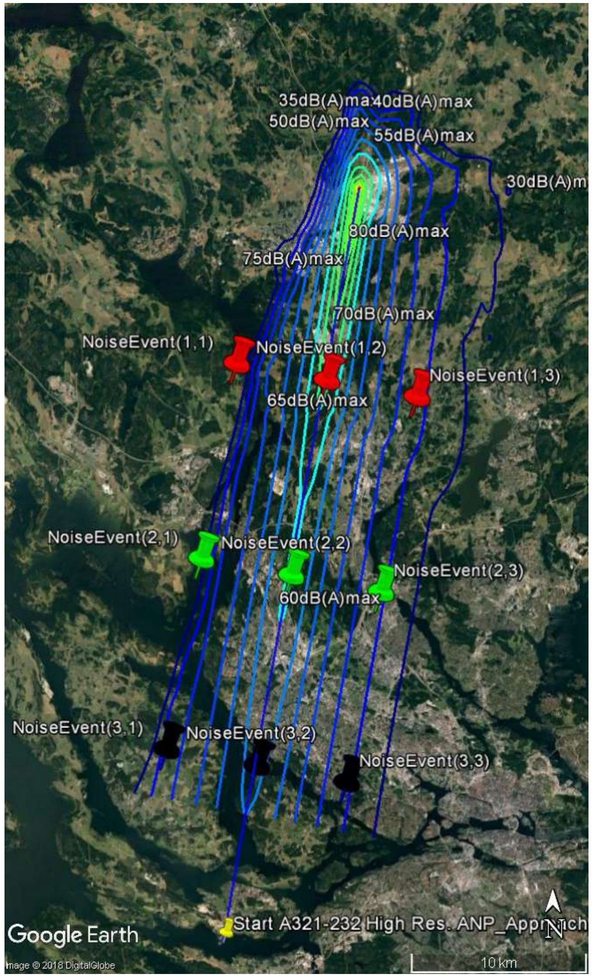
More sample runs output …

Example Landing in side wind ⇒ ***significant asymmetry for lateral ground positions***



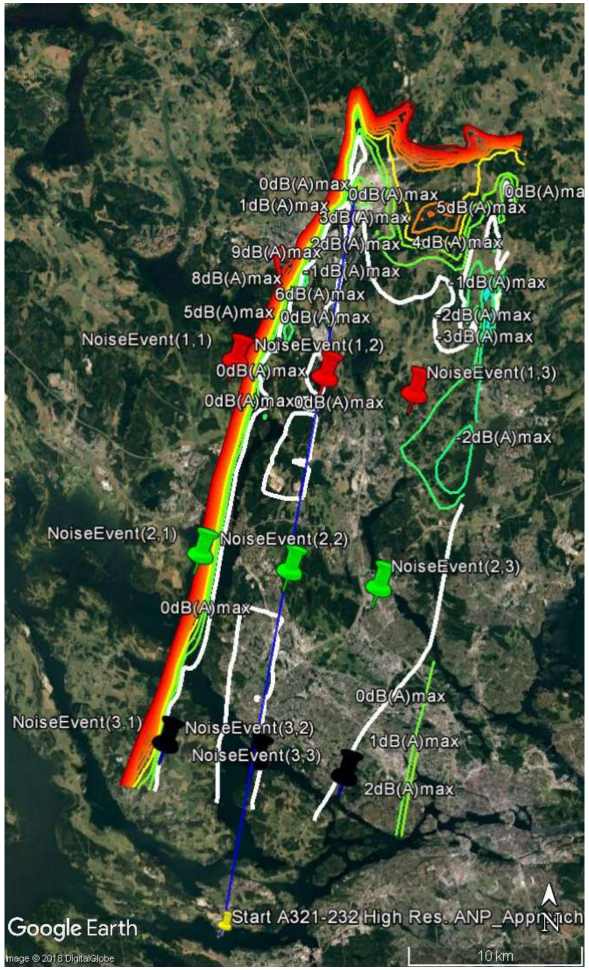
… cont. More sample runs output

$L_{pmax(A)}$ contours (refr.rays)

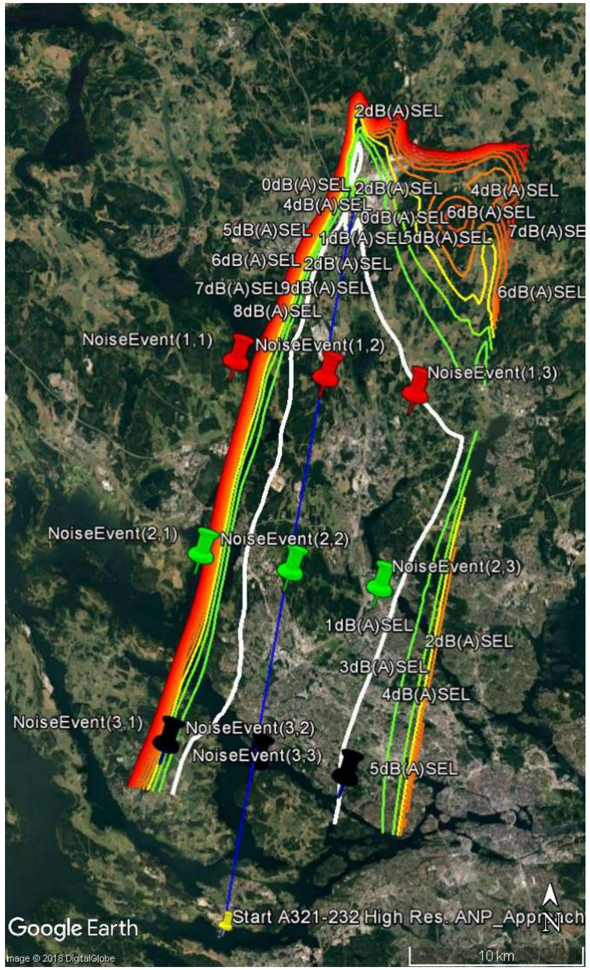


Difference (dB) Straight vs Refracted rays model

$\Delta dB_{Str.-Refr.}$ L_{Amax}



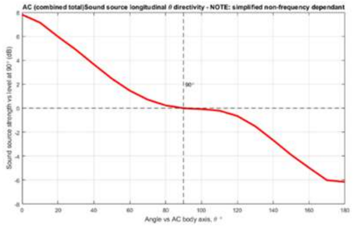
$\Delta dB_{Str.-Refr.}$ SEL(A)



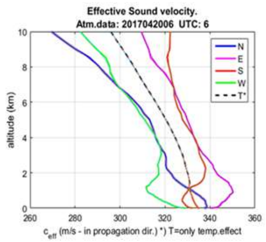
... cont. More sample runs output

Example runs ΔdB$_{\text{ECACdoc.29.- Refr.Rays}}$($L_{Amax}$)

longitudinal directivity
8,0,-6 dB 0,90,180° =



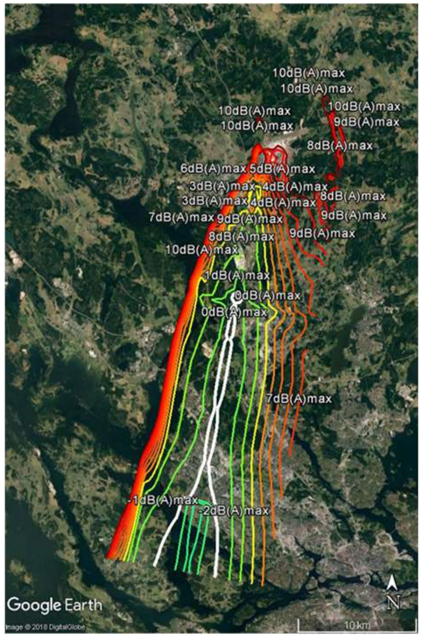
(same sample atmosphere data profile as above)



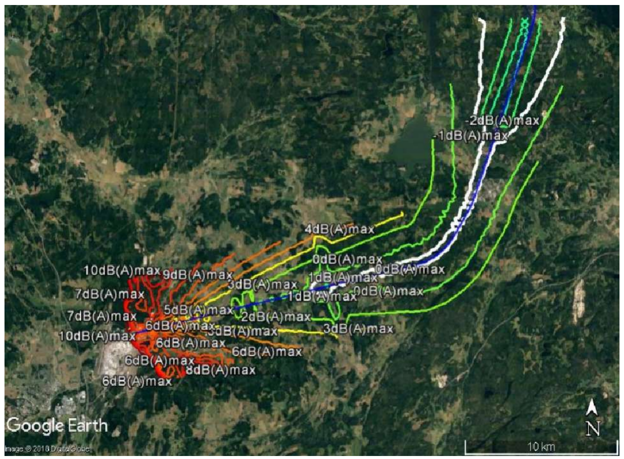
Tendencies in L_{Amax} example:

- ***For zero directivity and close to the ground track, similar noise levels*** are found for ECAC Doc.29 and simulation methods, ***both for side- and headwind conditions***
- ***Further out laterally***, difference tend to increase, ***ECAC Doc.29 overestimate(?)***
- ***For headwind conditions and longitudinal directivity*** 8,0,-6 dB at 0,90,180° rather large differences also close to the ground track, ***ECAC Doc.29 tend to overestimate(?)***

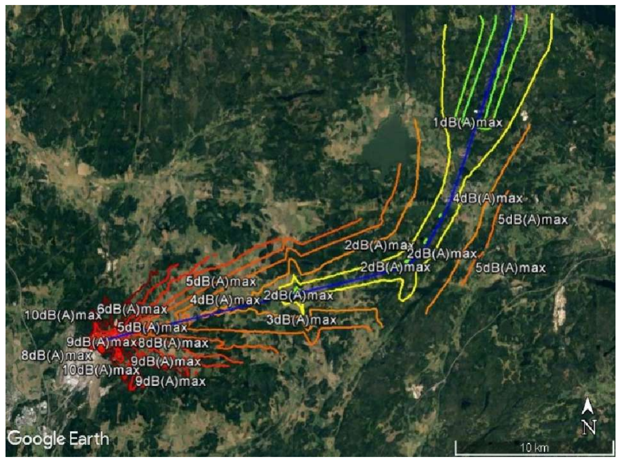
RW01L side wind
(longitudinal directivity 8,0,-6 dB 0,90,180°)



RW26 headwind
(zero directivity)



RW26 headwind
(longitudinal directivity 8,0,-6 dB 0,90,180°)



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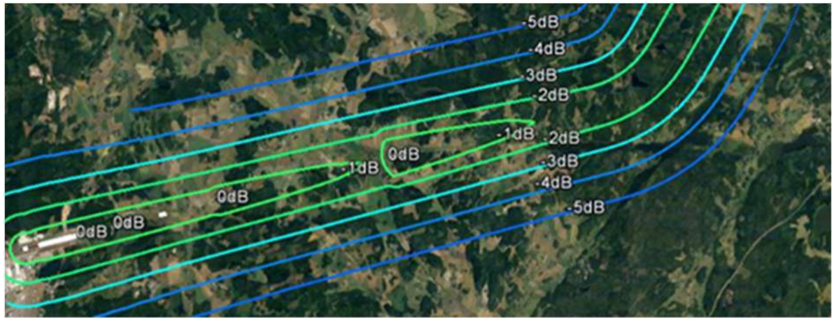
Absorption – examples ECAC Doc29 with different atmosphere data

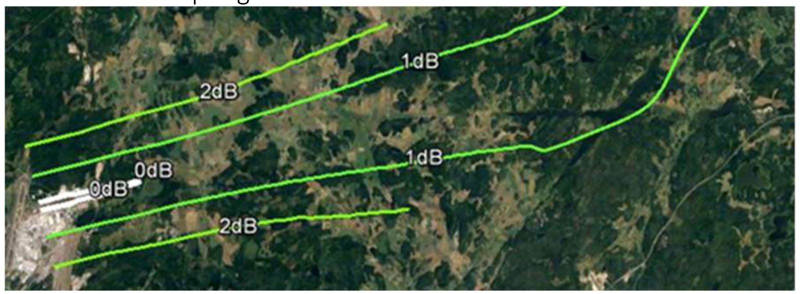
Comparison SAE AIR1845 and ARP866A
ΔL_{Amax} $dB_{1845\text{-}866A}$ sample day atmosphere data



Comparison SAE ARP866A and new ARP5534
ΔL_{Amax} $dB_{866A\text{–}5534}$ sample day atmosphere data

Comparison ISA atm and sample day atm. (ARP5534)
ΔL_{Amax} $dB_{ISA\text{–}SMHI}$ sample day atmosphere data

Comparison two sample days atmosphere
ΔL_{Amax} $dB_{'spring'\text{–}'summer'}$ (SMHI/ARP5534)



Some conclusions from SAFT work wrt traffic scenario/noise modelling

1. ***CPU time for time-stepping aircraft noise simulation is no more any principle obstacle*** (in contrary to what is expressed in e.g. ECAC Doc29 documents) even for air traffic over, say, a year.

2. ***Semi-empirical, physically based, noise source models*** for airframe and aero-engines is a good tool for looking at trends in noise levels - but **not yet ready for predicting absolute noise levels, especially for air-traffic** involving a large number of AC types and flight conditions.

3. ***The strength of the integrated methods is the NPD-database, covering most active AC-types***

4. ***These NPD-data is at the same time one limiting factor of the integrated methods since it only covers a fictive 160-knots + config "full" situation*** (e.g. due to ECAC Doc29 for SEL a ***higher speed results in a lower sound level*** due to the shorter time of the event, though **in reality there is a strong opposite effect from speed on noise level** instead giving a higher levels both due to higher airframe and engine noise)

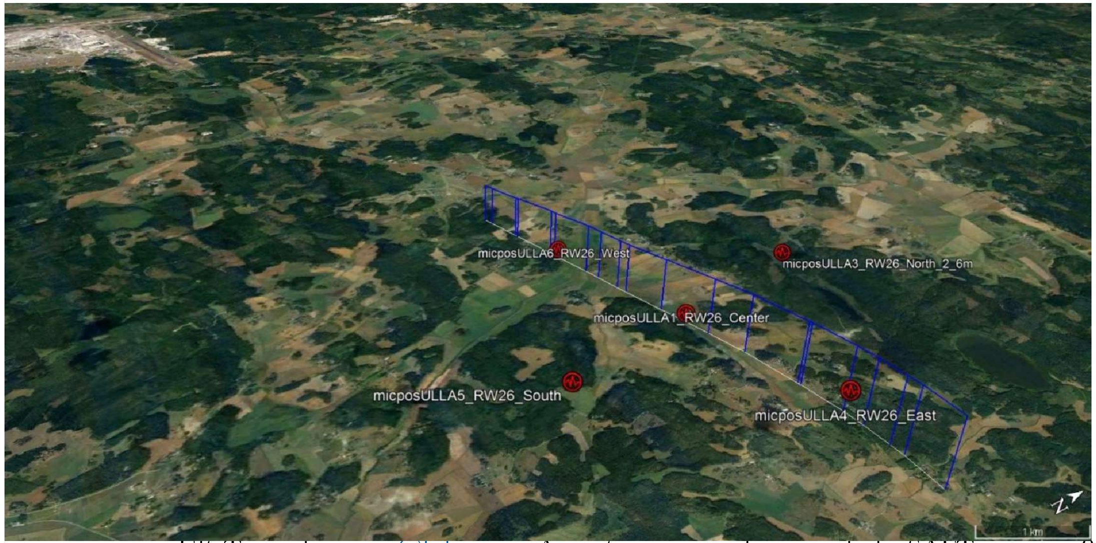
5. ***The best suited approach for establishing AC noise sources*** (freq, directive, config and speed dependent) for a number of aircraft types and conditions ***would today be noise measurements in combination with a time-stepping code*** ("back-propagation") , FDR and ADS-B data + meteo/atmospheric profile data.

4. SAFT applications in coming CSA-projects and beyond

A. A new multi-level gridding technique covering Stockholm TMA

B. Establish noise sources for most common aircraft through measurements

- Cooperation with CSA-project ULLA carrying out aircraft pass-by measurements around Arlanda airport in Stockholm
- ULLA-project: Establish aircraft pass-by noise data from several noise measurements stations together with OpenSky* ADS-B trajectory data, validation with FDR-data.



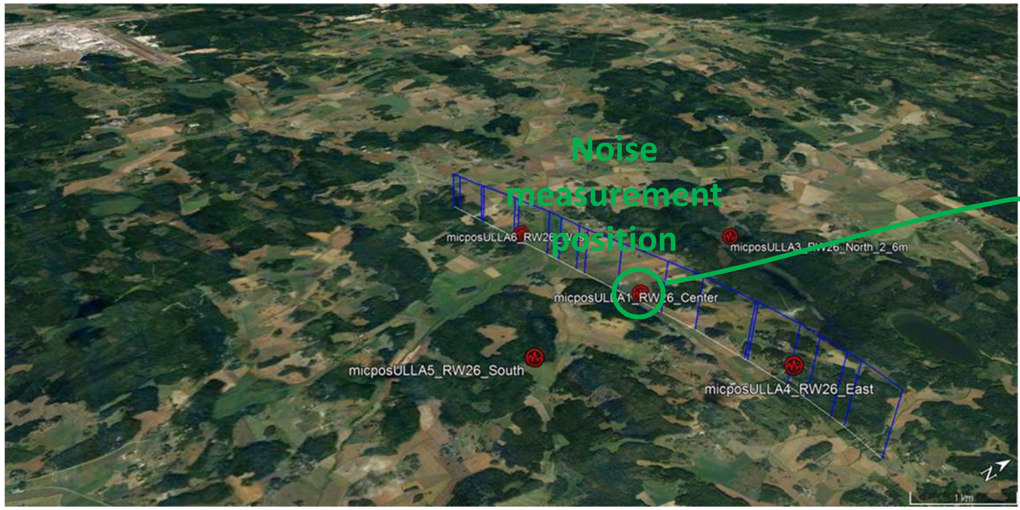
*) *http://www.opensky-network.org*

- Independent weather resilient measurement stations with: microphone, computer (Raspberry Pi), internet connection and solar power/battery support
- Triggers noise measurement for aircraft movement within certain area supported by OpenSky ADS-B trajectory data
- Together with meteorological data* (atmospheric profile variables) and a time stepping code such as SAFT one have all resources for an aircraft (total) sound source strength estimation as a function frequency and directivity through "back propagation"
- Open matters:
  - variation, uncertainties along complete computational chain ?
  - identification of independent variables, thrust, configuration/LG, speed, static pressure and temperature at aircraft altitude, ... ?
  - optimal positioning of microphones wrt axial directivity and else?

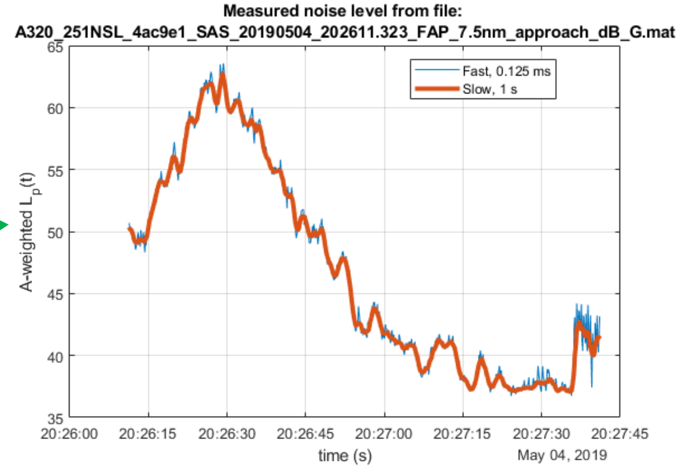
Price per station ca 500 Euro
(commercial equipment ca 20 000!)

*) from met.no/SMHI, i.e. the Norwegian or Swedish meteorological institutes

Example correlated noise measurement and ADS-B trajectory data



Noise:

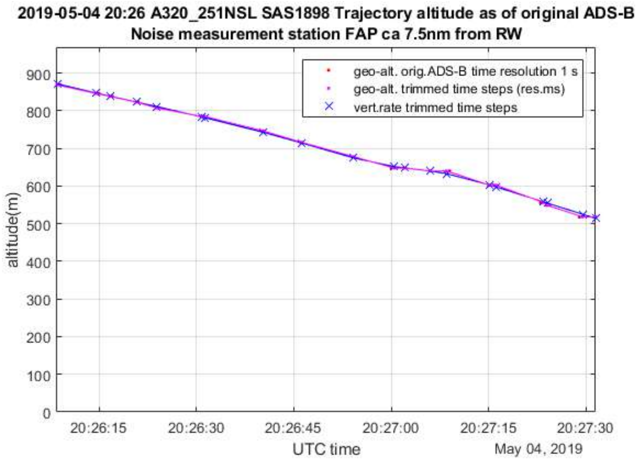


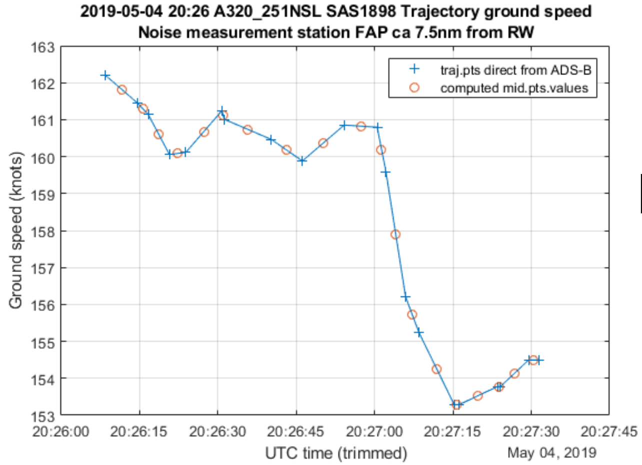
Below, computed acceleration:

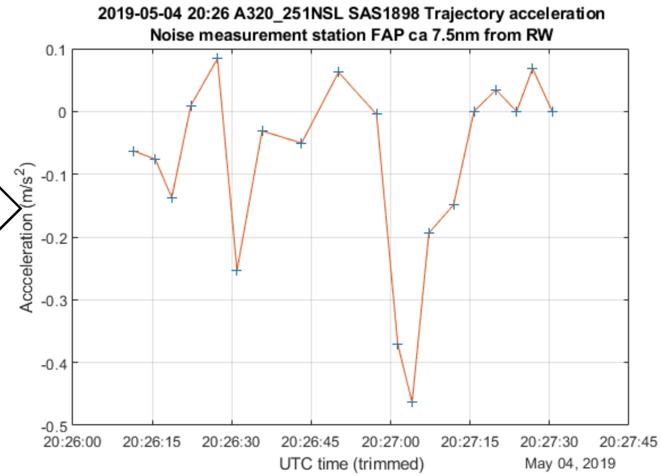
Is this information enough for finding configuration and thrust ?

(with support of Lift/Drag estimates)

Some ADS-B trajectory data, altitude and ground speed as a fcn of time:







CSA projects starting 2019/2010:

SAFT development and studies

- ODESTA - Optimizing Aircraft Descent for Environmentally Sustainable Aviation, LiU
- CIDER - CorrelatIon- and physics based preDiction of noisE scenaRios Chalmers

SAFT studies (+"trimming")

- TREVOL - Aircraft Trajectory Analysis for Reduced Environmental Impact KTH
- OPNOP - Operational Noise Optimization Huvudsökande: KTH/Vernamack
- ERAS - Evaluation of Realistic Approach Scenarios KTH/Vernamack