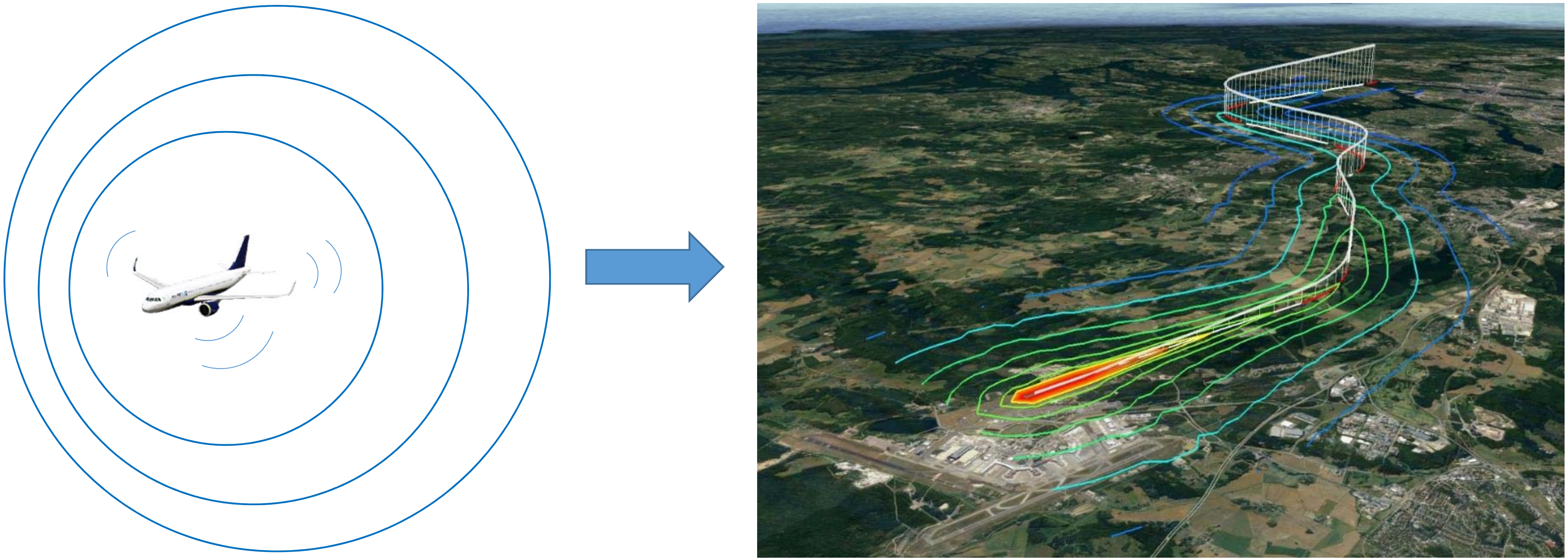
Slutrapport från CSA:s projekt SAFT

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



Ulf Tengzelius + Tomas Grönstedt/Olivier Petit Slutrapport från CSA:s Projekt SAFT 10 oktober 2019

1. **SAFT – a simulation code for noise mapping**

   - Outline, Capabilities

   - Full Simulation, semi-empirically individual sound sources (Chalmers)

   - Alternative atmosphere models/data sources

   - Some features

2. **Case examples**

3. **Conclusions**

4. **SAFT links with running and coming CSA-projects**

1. SAFT – a simulation code for noise mapping

- SAFT - a computer code for aircraft noise mapping of single event aircraft pass by + a CSA-project (2.5 year 2016-2019 ended in June)

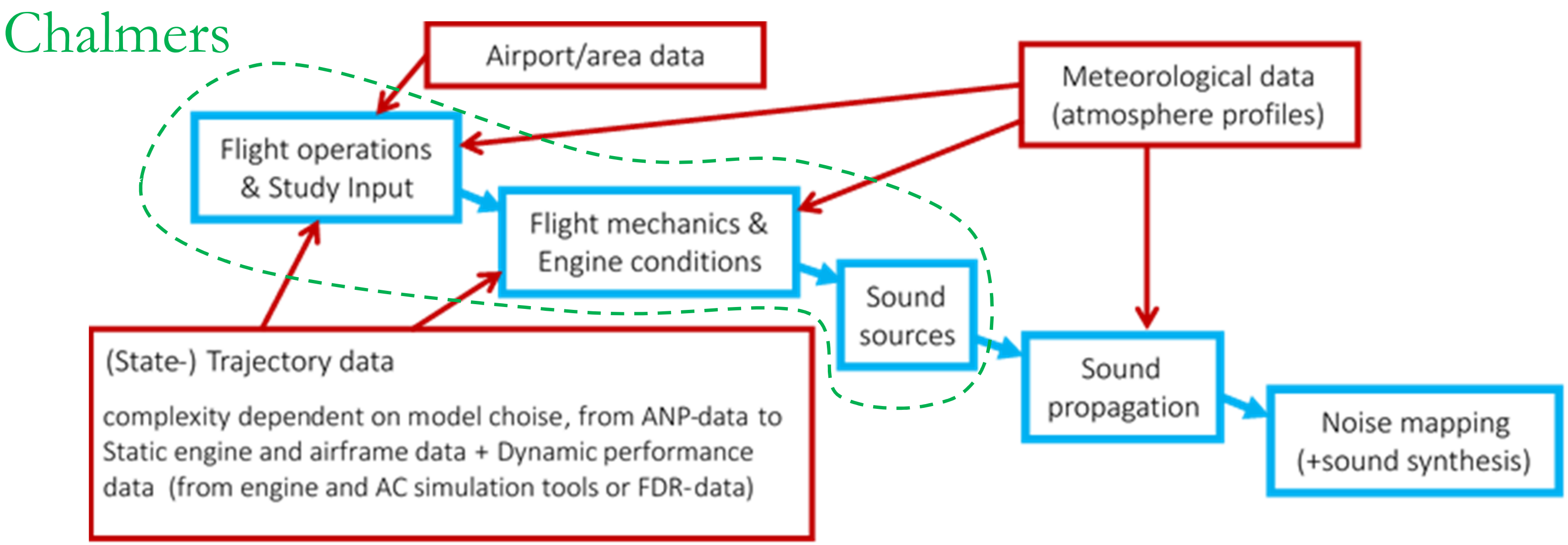
- Partners: KTH-MWL and Chalmers

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

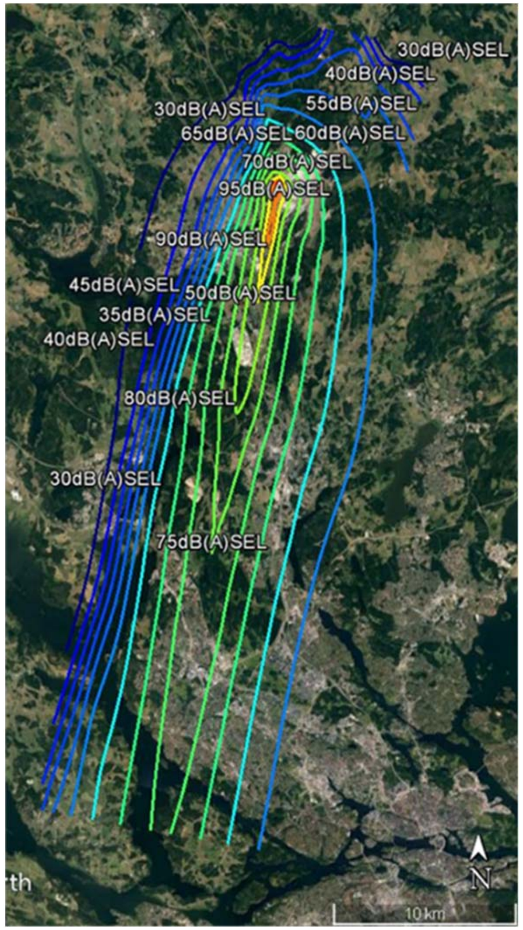


SAFT capabilities:

- **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")



- 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

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 – Needs input preparation outside SAFT!!!

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 run type :

-- Simulation-/sound emission models Output: Noise and/or Noise Event Time Histories --

5. Full Simulation, semi-empirically modelled individual sound sources. AC: A321-V2533

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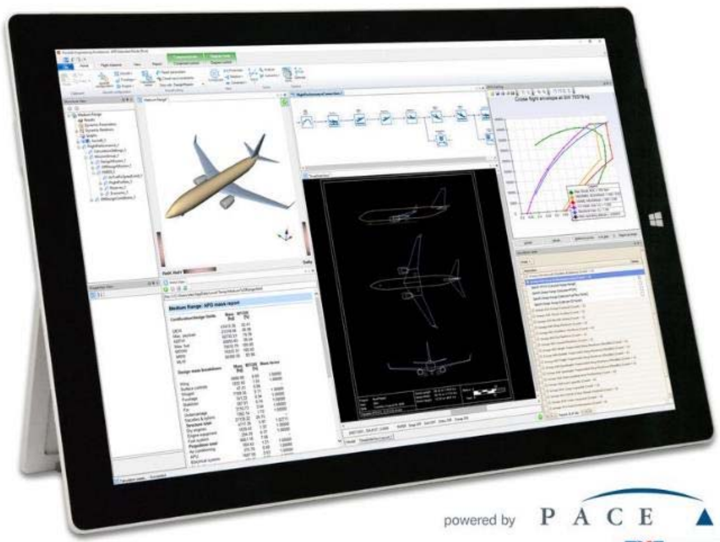
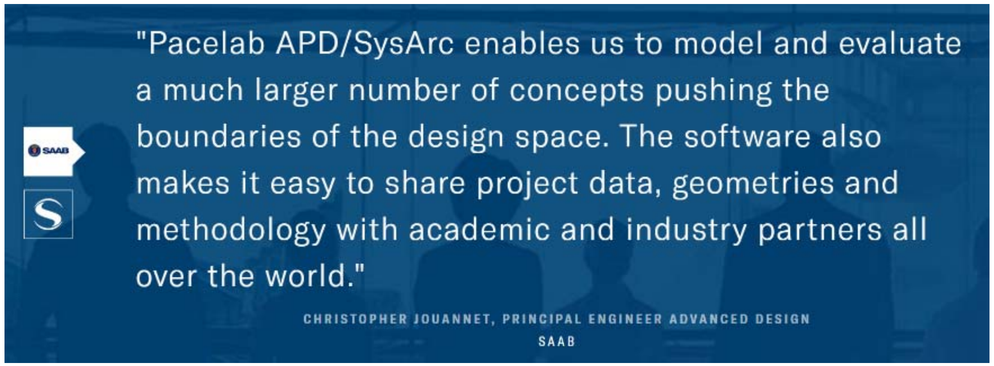
Pacelab APD



powered by PACE a TXT company

- Commercial software for aircraft design
- Supplement with in-house methods (to be developed)
- We are going in this direction

https://www.txtgroup.com/markets/solutions/pacelab-apd/, cited October 7th, 2019



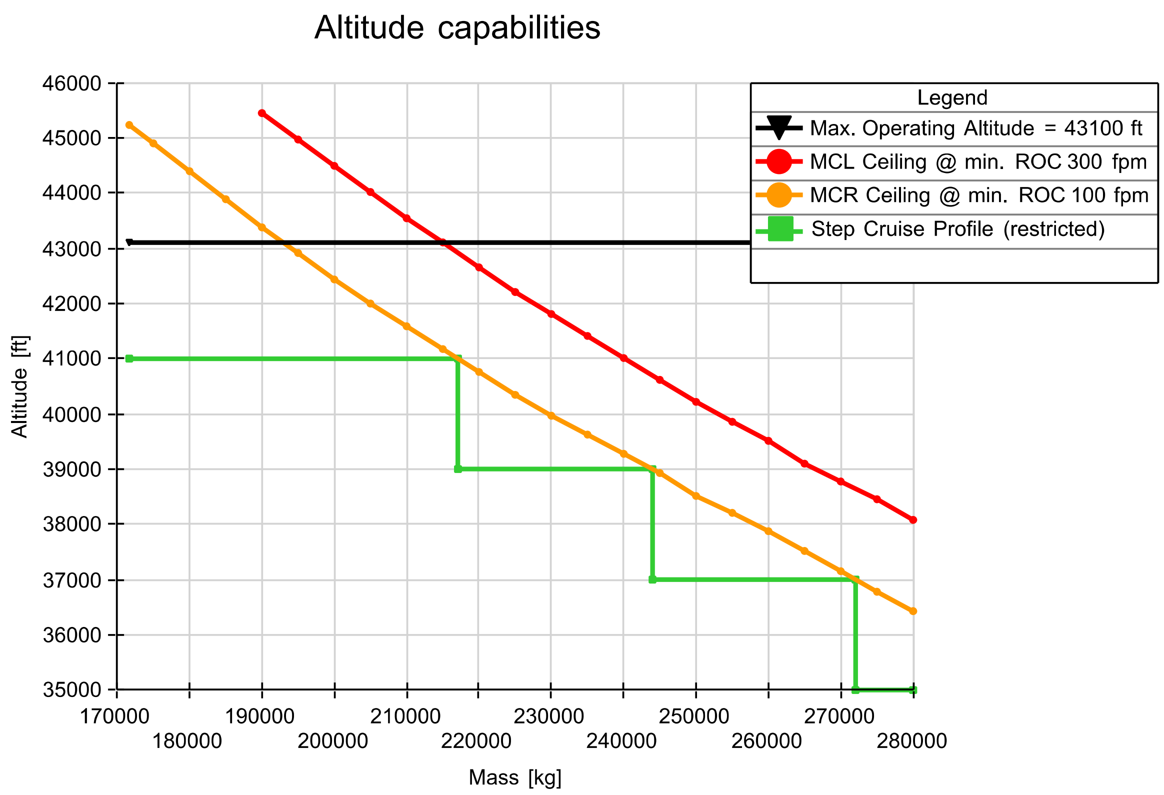
AIRCRAFT INPUT

- Airbus A350-XWB Pacelab APD model.
- Design requirements:
  - Range 8100 NM
  - 325 PAX
  - Initial cruise at 35,000 ft
  - Climb to 35,000 ft in less than 25 min (TOC M0.84)
    - Air traffic control limits CAS = 250 kts up to 10,000 ft
    - After 10,000 ft climb at optimum CAS = 300 kts
  - Take of field length, 3200 m
  - Landing field length, 1600 m
  - Fuel reserves: 5% contingency fuel, 100NM diversion @20,000 ft, 30 min hold

AIRBUS A350-900 Specifications	
Characteristics	
Wing loading	640.5 kg/m^2
PAX	48J + 277Y
Cruise Mach	0.85
Thrust	
Engine	2 Rolls-Royce XWB-84
Output/Flat Rating	2 x 84,200 lbf / ISA+15 C
Weights	**Kg**
Max Ramp Weight	280,900
Max TO Weight	280,000
Max Land. Weight	207,000
Max Zero Fuel Weight	195,000
OEW	141,000 (*calculated*)
Max Payload Structure	54,000
Max Fuel	113,000
Limits	
Ceiling certification	43,100 ft
Max operating Mach	0.89

AIRCRAFT ENGINE MATCHING

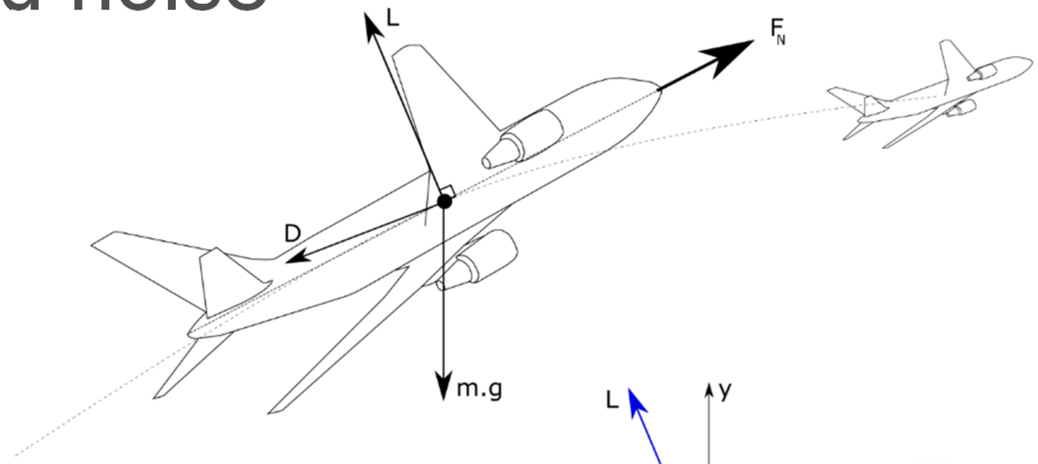
- Match engine propulsion system
- Update mission specification
- In SAFT we developed a A321-200 model with a V2533-A5 engine
- We used in-house propulsion understanding and discussed aircraft performance assumptions based on current APD-model and Novair expertise

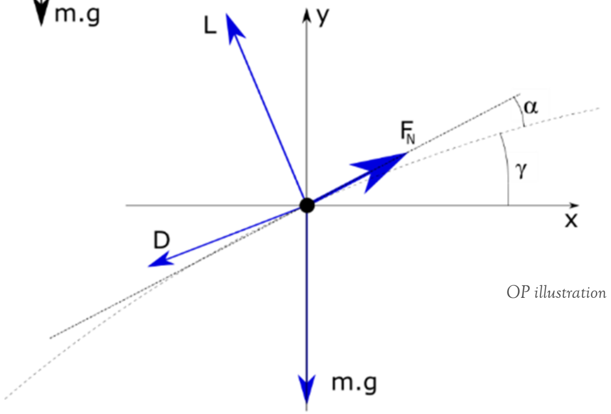


Cruise @ CAS/Mach 320/0.85 | Climb @ CAS/Mach 300/0.84 | ISA Dev. = 0.0 K | FlightLevels = RVSM East

Aircraft performance and noise

- To build a simple dynamic aircraft model project forces in x- and y- direction
- Again we simplify by setting the engine orientation in the flight direction.





OP illustration

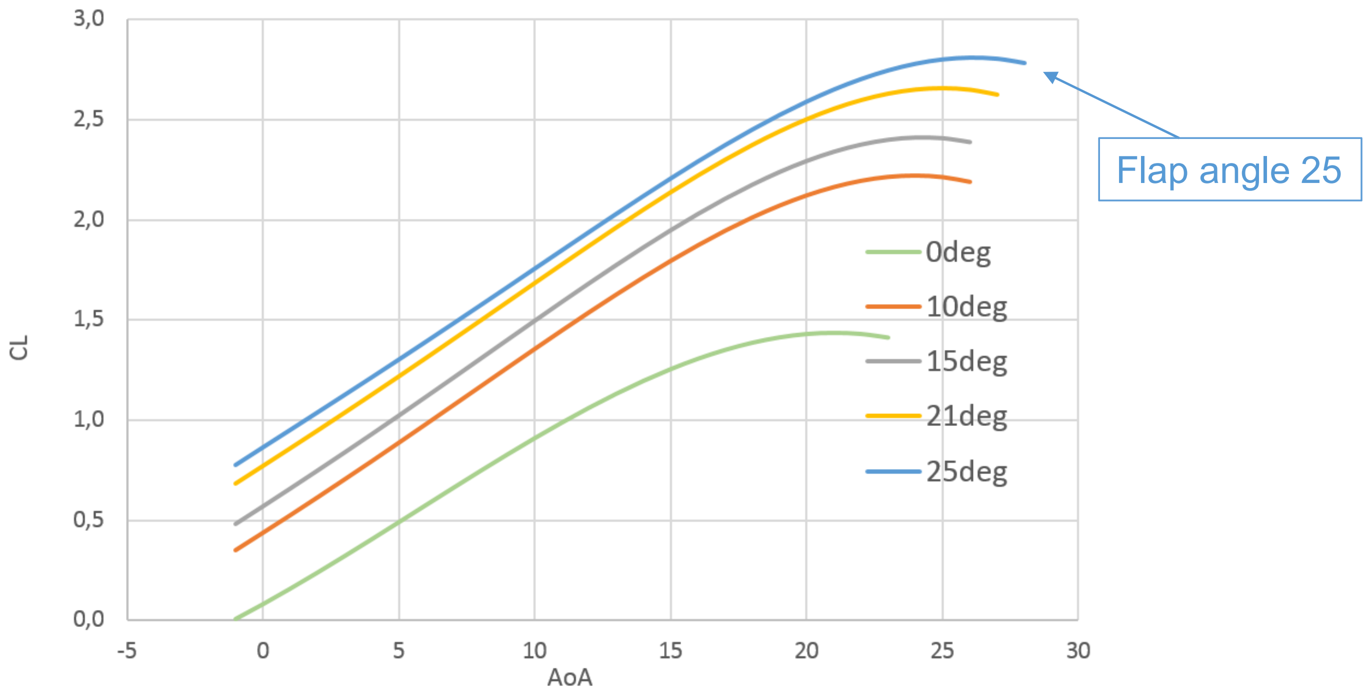
$$F_x = -L\sin\gamma - D\cos\gamma + F_N\cos(\alpha + \gamma)$$

$$F_y = L\cos\gamma - D\sin\gamma + F_N\sin(\alpha + \gamma) - mg$$

- Lift and drag are obtained from previously derived expressions.

During approach flap settings are changing

- Under normal approach conditions net thrust can be predicted from aerodynamics only
- Climb-out & fly-over are more difficult



AoA = angle of attack = α

Landing gear is down

ENGINE PERFORMANCE SIMULATION

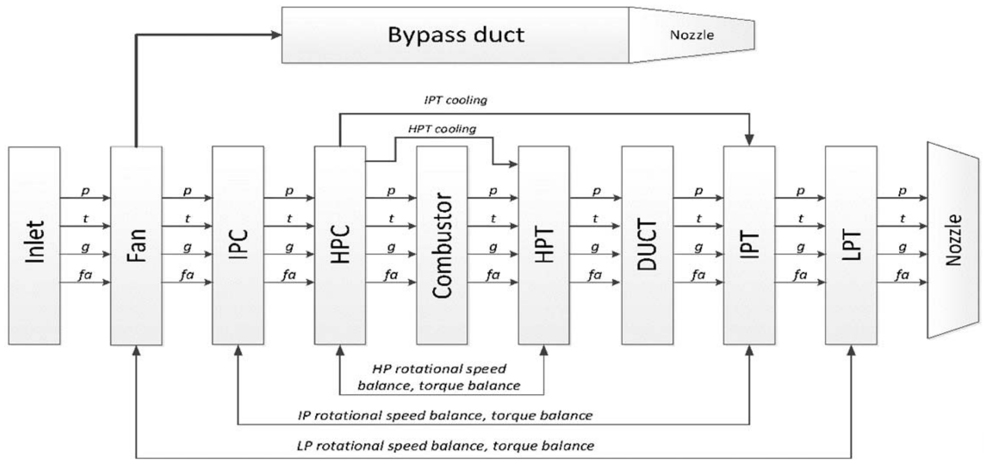
GESTPAN – General Stationary and Transient Propulsion Analysis

- Zero-dimensional aero-thermodynamic analysis employing discrete component maps
- Solves for the mass and energy balance between the various engine components
- Ability to simulate a wide range of aero-engines as well as industrial gas turbines

Image courtesy of CFM.

Key Capabilities

- Ability to introduce customised (user defined) component characteristics.
- Design, Off design and transient performance calculations

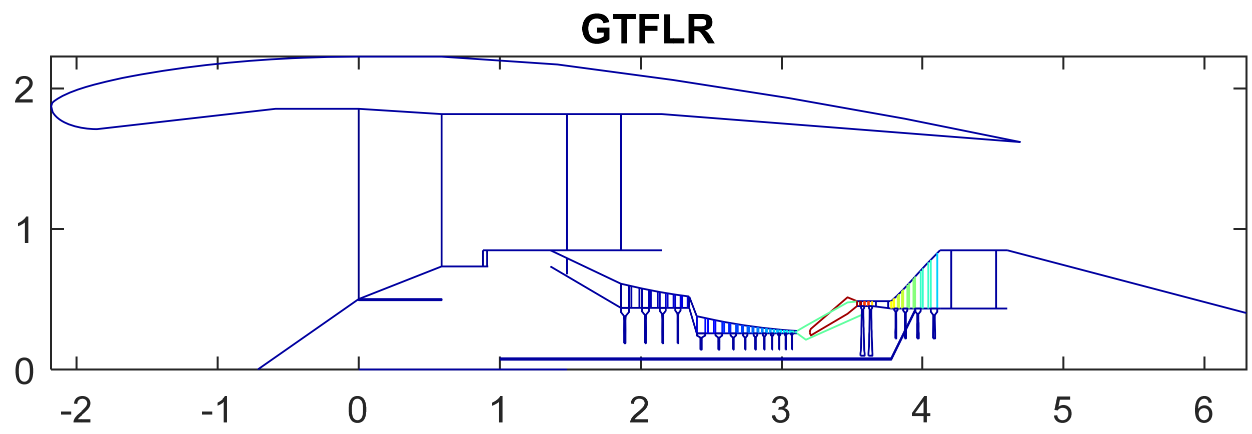


GESTPAN - Interconnected Engine Component Schematic of Turbofan

*Grönstedt, T., "Development of Methods for Analysis and Optimization of Complex Jet Engine Systems", PhD Thesis, Department of Thermo and Fluid Dynamics, Chalmers University of Technology, 2000.

WEIGHT AND DIMENSIONS PREDICTIONS

- Geometry needed to define data in noise sources



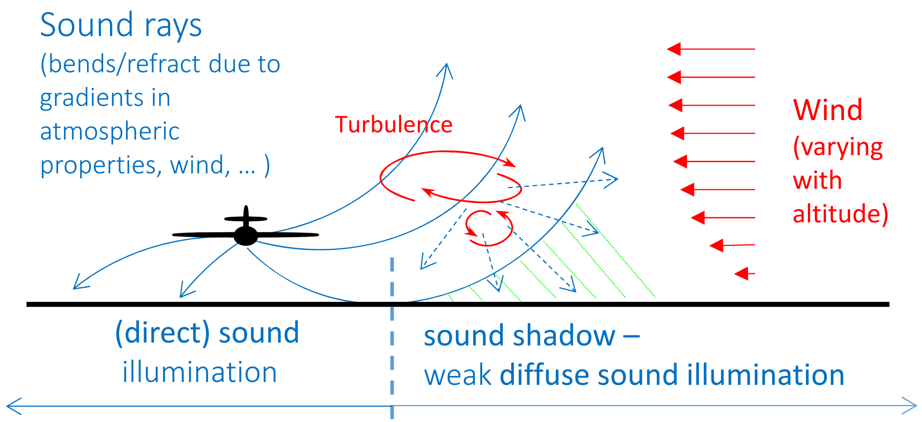
- Interesting to cross breed these methods with estimation based methods planned in follow up project CIDER.
- Turbomachinery flow and blade speeds available to calculate noise sources

SAFT three alternative atmosphere models/data sources:

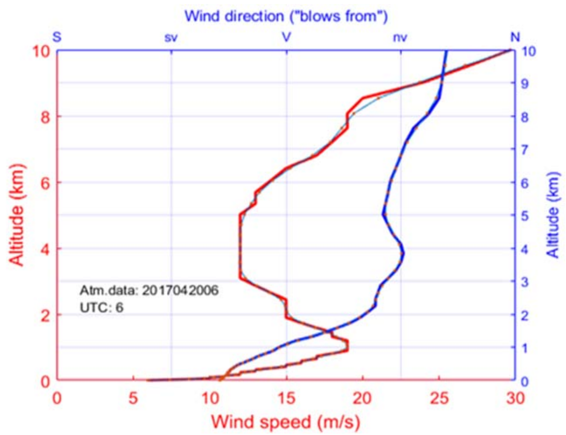
1. ISA atmosphere + wind

2. Typical atmospheres wrt cloud cover, stability, temp + wind as of IMAGINE project

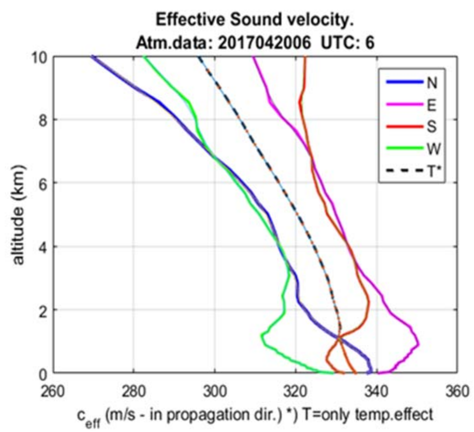
3. Forecast data (AROME/met.no/SMHI - covering Scandinavia each hour one day ahead, or historical data over years)



Atmospheric data



⇒ Effective sound velocity



Special SAFT features with regard to sound propagation:

- **Fast: TL-interpolant matrix approach** – time and lat, long invariant TL matrix used for all trajectory grid points (fcn of source alt, horizontal distance and propagation heading, 0-360°, also emission- and incident angles are interpolated in the same way)
- Simple selection or generation of new **ground tracks**
- "Automatic" **effective gridding** around any ground track
- **Time event analyses possible in any grid point**, including sub-division in separate TL contributions based on the physics behind
- **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 noise patterns** including different forecasts with various probability

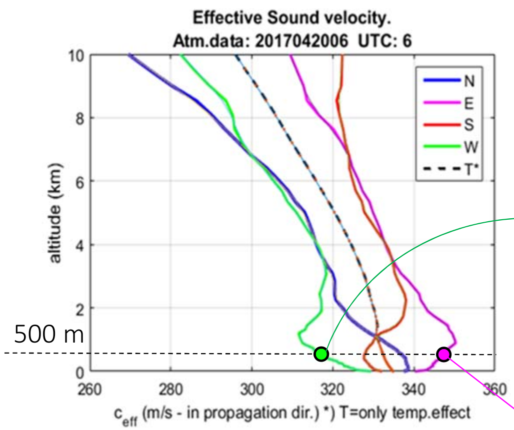
Versatile in terms of possible studies, e.g:

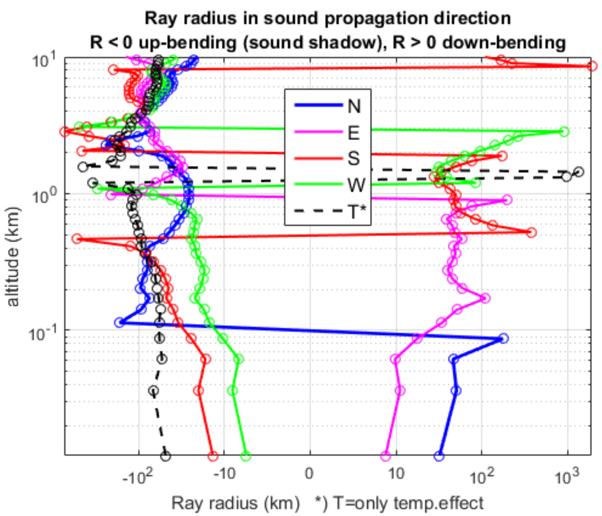
- **new aircraft concepts** or modification of existing types
- **noise prognoses**
- **new routing** and **runway use pattern with regard to weather and noise distribution**
- noise pattern input into the **planning process for new runways**

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

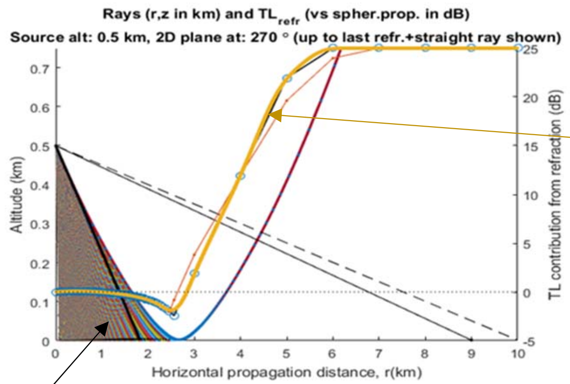
Sound propagation, ray-tracing. Transmission Loss (TL*)





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

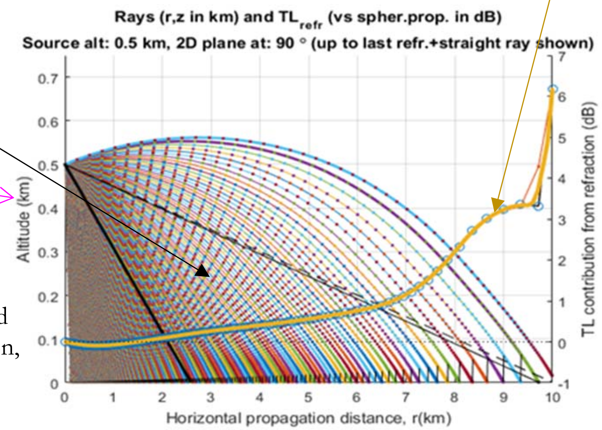
Ex. Source at alt. 500 m, sound propagation to the west, headwind



$TL_{refraction}$

Sound rays

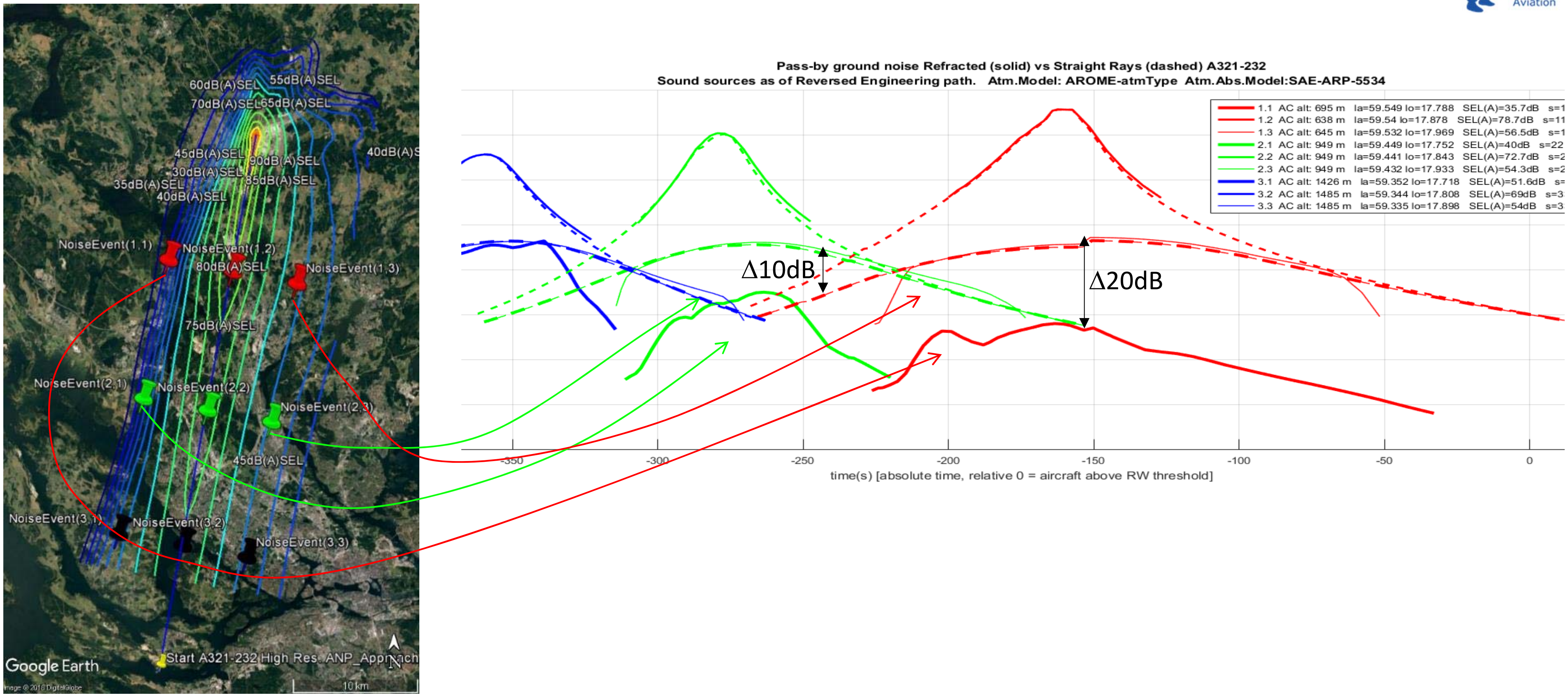
Ex. Source at alt. 500 m, sound propagation to the east, tailwind



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

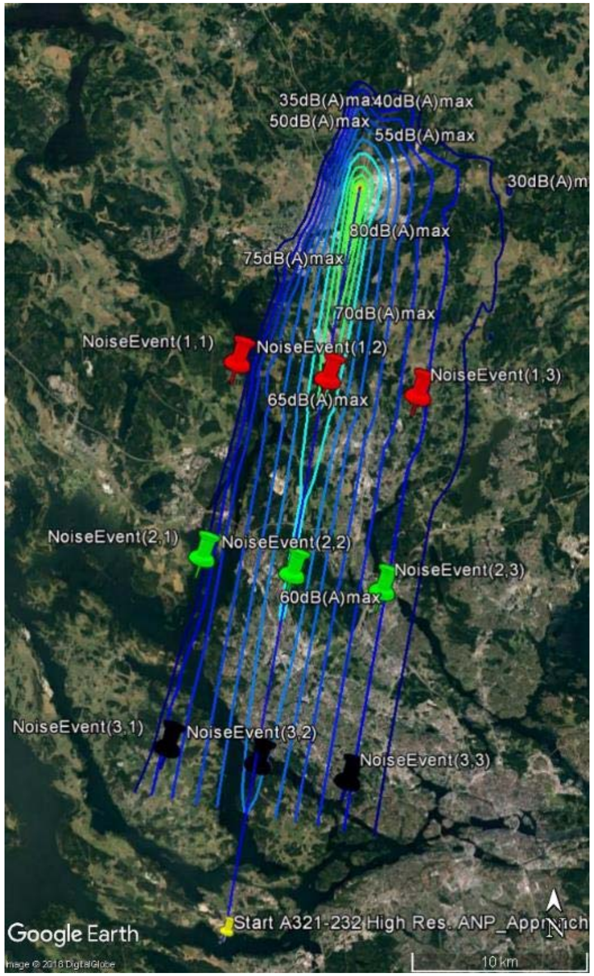
2. Case examples

Example Landing in side wind $\Rightarrow$ ***significant asymmetry for lateral ground positions***



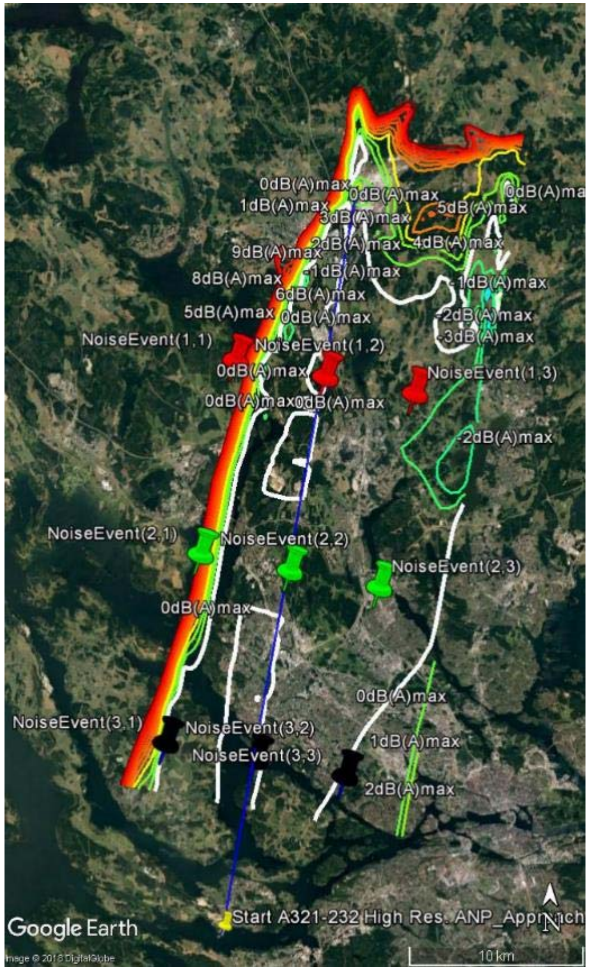
… cont. More sample runs output

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

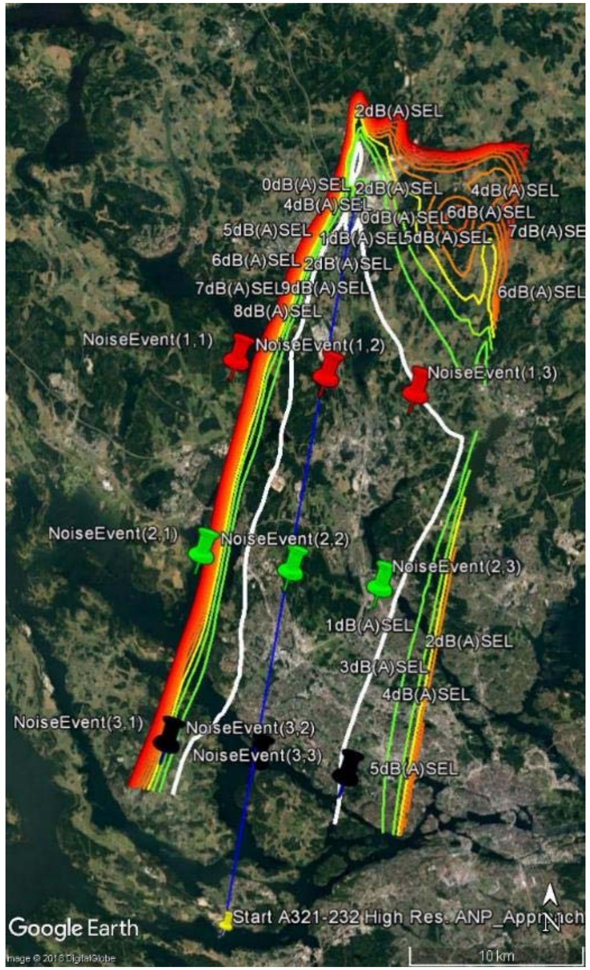


Difference (dB) Straight vs Refracted rays model

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



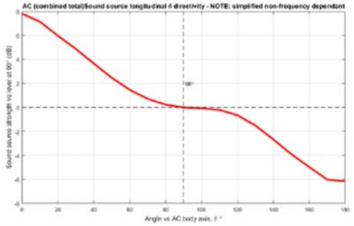
$\Delta dB_{Str.-Refr.}$ SEL(A)



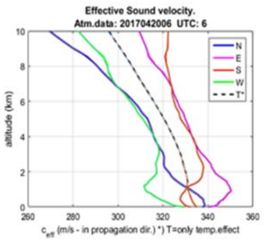
... cont. More sample runs output

Example runs $\Delta dB_{ECACdoc.29.- Refr.Rays}(L_{Amax})$

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



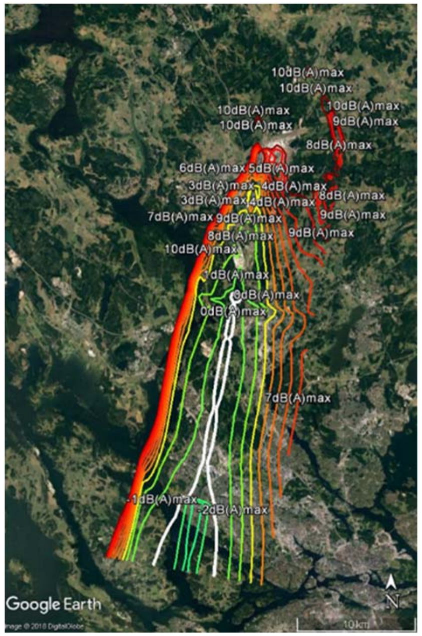
(same sample atmosphere data profile as above)



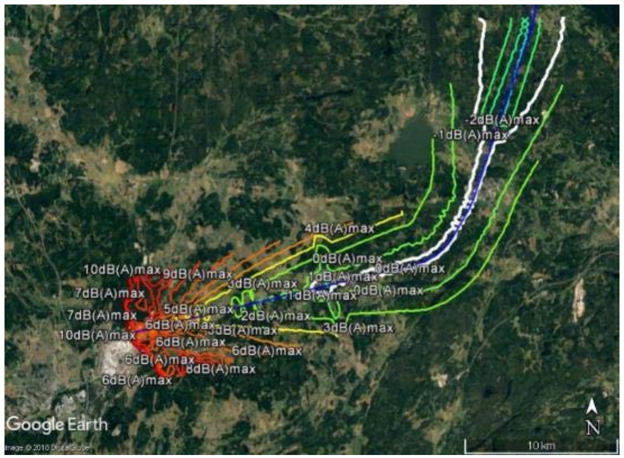
Tendencies in L_{Amax} example:

- ***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(?)***

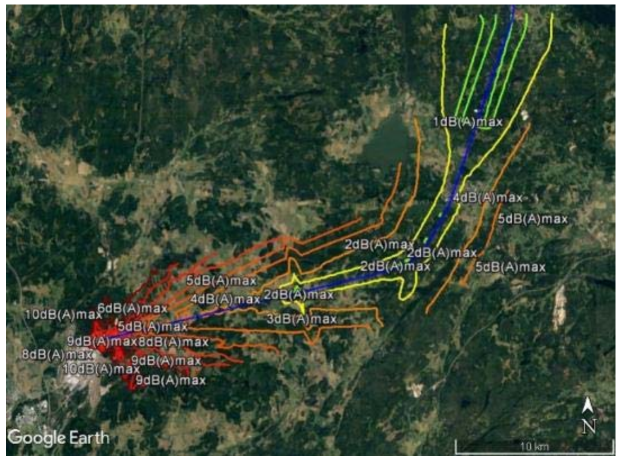
RW01L side wind
(longitudinal directivity 8,0,-6 dB 0,90,180°)



RW26 headwind
(zero directivity)



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



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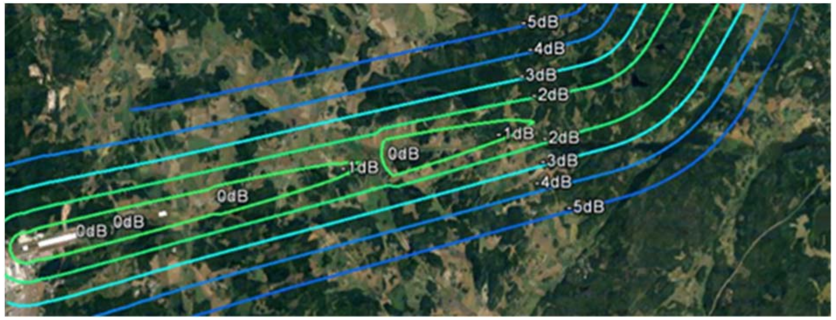
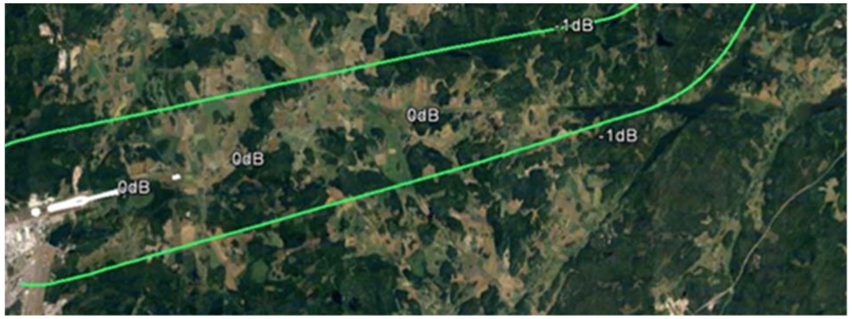
Absorption – examples ECAC Doc29 with different atmosphere data

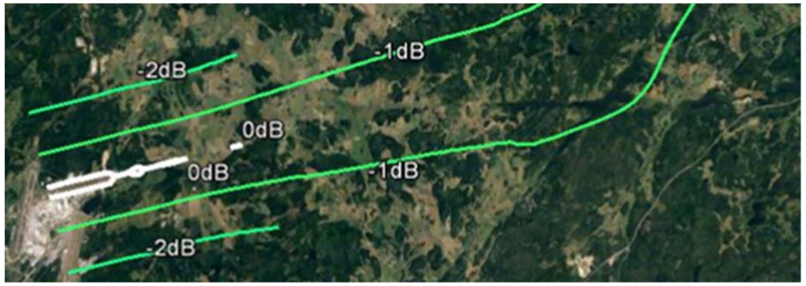
Comparison SAE AIR1845 and ARP866A
ΔL_{Amax} $dB_{1845\text{-}866A}$ sample day atmosphere data



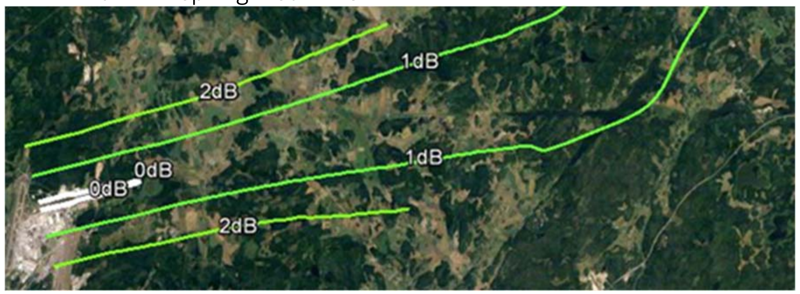
Comparison SAE ARP866A and new ARP5534
ΔL_{Amax} $dB_{866A\text{–}5534}$ sample day atmosphere data



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} $dB_{\text{'spring'–'summer'}}$ (SMHI/ARP5534)



3. 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 longer time spans

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*

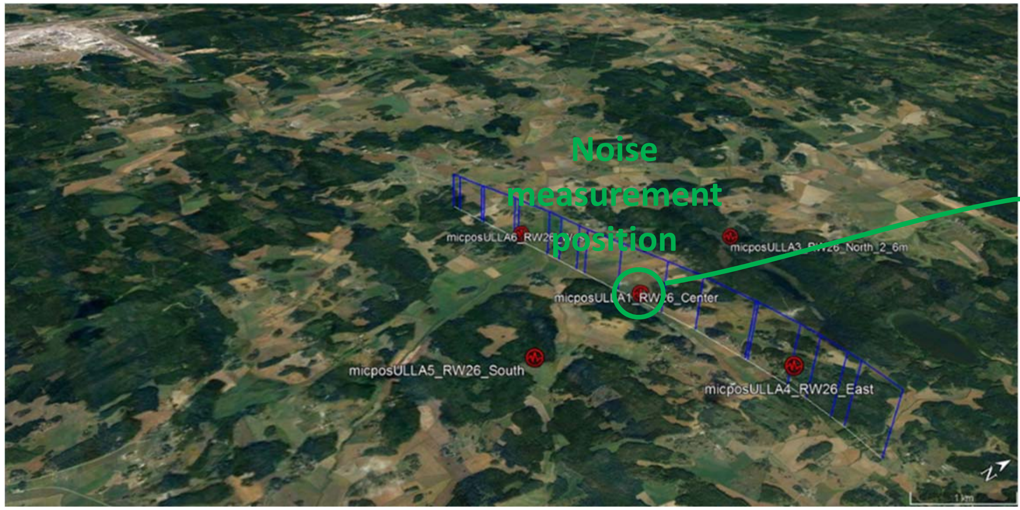
Ulf Tengzelius + Tomas Grönstedt/Olivier Petit Slutrapport från CSA:s Projekt SAFT 10 oktober 2019

- 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?

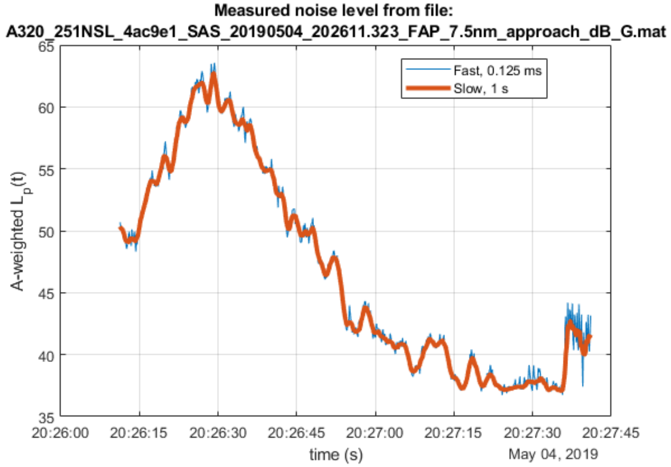
Price per station ca 500 Euro
(commercial equipment ca 20 000!)

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

Example correlated noise measurement and ADS-B trajectory data

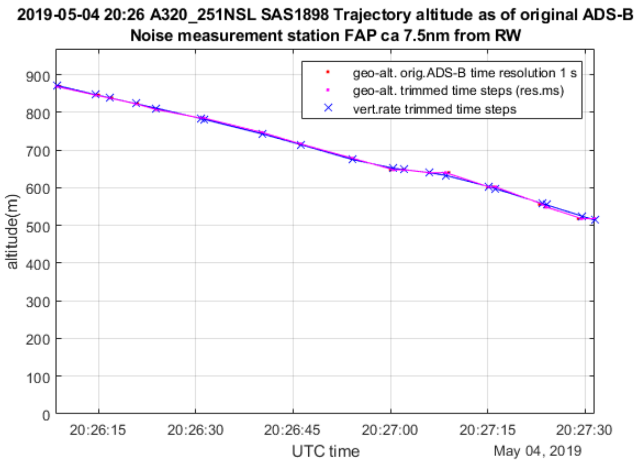


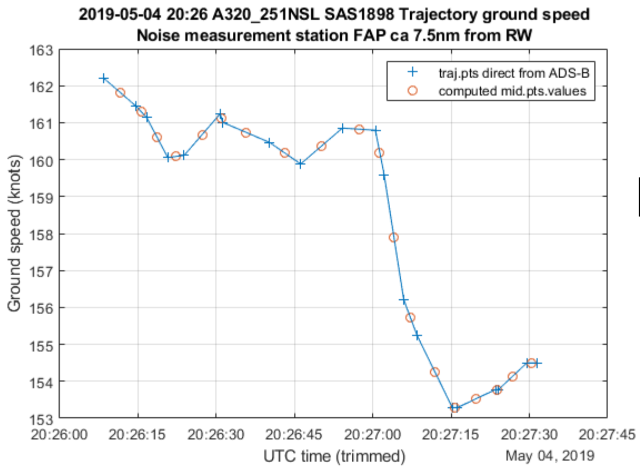
Noise:

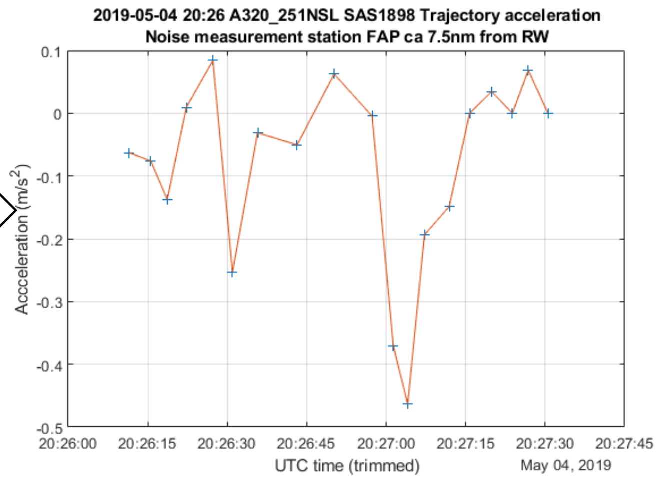


Below, computed acceleration:
Is this information enough for finding configuration and thrust ?
(with support of Lift/Drag estimates)

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







Principle for finding aircraft noise source estimates with support of *1. time stepping noise source + propagation simulation (SAFT), 2. Noise measurements (ULLA), 3. Trajectory (OpenSky) and 4. meteo-data (met.no)*

Sound pressure level at ground: $L_p = L_{I,source,i} + TL_{tot}$

Sound source: $L_{I,source,i}(t, f, □, □, \text{config}, \text{"thrust"}, Mach\ no, \text{"}AC - type\text{"}, p(z), T(z), \ldots)$

Transmission Loss: $TL = TL_{Sphere} + TL_{Refr} + TL_{GrRefl} + TL_{AirAtt} + TL_{\rho c}$

Since we have from measurements (green = knowns, red = unknowns):

$$L_{p,mic,i}^{meas} = L_{I,source,i} + TL_{tot}$$

.... and from SAFT: $L_{p,mic,i}^{SAFT} = L_{I,source,i}^{SAFT} + TL_{tot}^{SAFT}$

We can get sound source estimates: $\hat{L}_{I,source,i} = L_{p,mic,i}^{meas} - TL_{tot}^{SAFT}$

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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

The end!

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