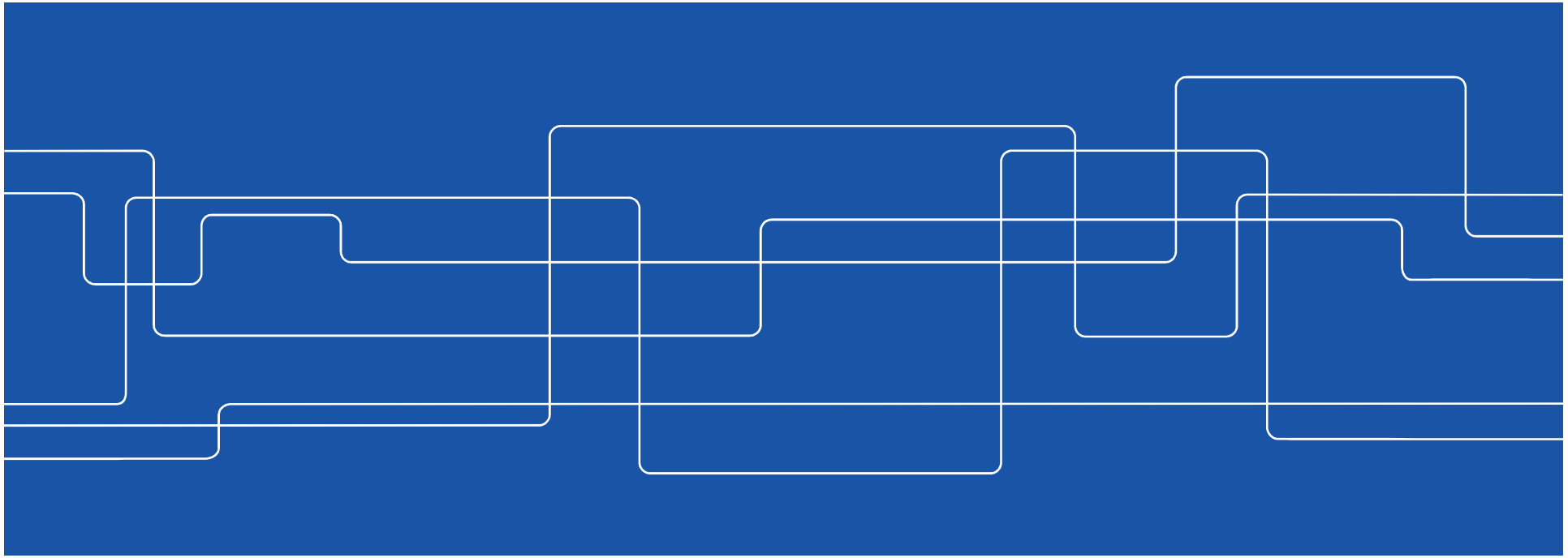
The **SAFT** project

Simulation of **A**ir traffic and atmosphere **F**or a quieter environmen**T**

Ulf Tengzelius KTH-MWL

CSA
Centre for
Sustainable
Aviation



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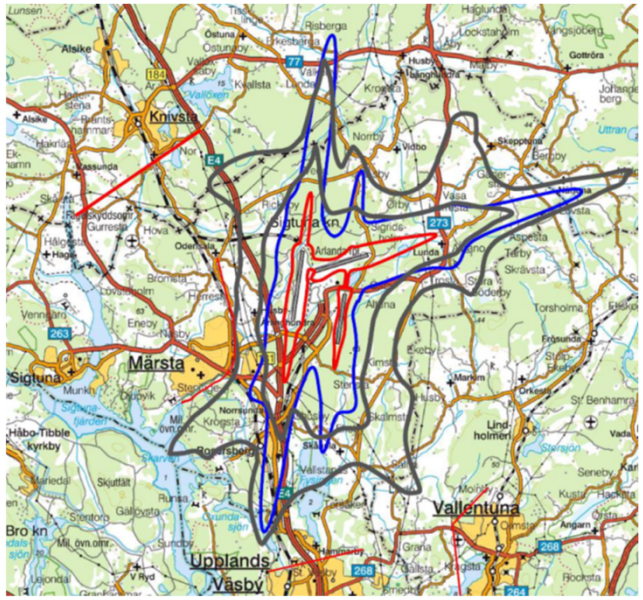
1. Background CSA Centre for Sustainable Aviation

- Increased noise problems around Arlanda airport - complaints from neighbours
- Renewed environmental permit - legal process - conciliation - support research - CSA formed
- CSA board:
  - Swedish transport administration
  - Swedavia
  - LFV Air Navigation Services of Sweden
  - The Swedish Transport Agency
  - KTH
- Pre-studies from late 2015 to spring 2016
- 3 projects and one pre-study starts now (Oct.2016)
  - SAFT
  - Brantare – steeper approach (>3°) noise impact
  - INFRA – ATM system/organisation studies
  - ULLA – measurements (pre-study)



FBN 55 dBA
FBN 65 dBA
permit

where:
FBN = $L_{Aeq(24hrs)}$ levels with noise events at night weighted with a factor 10 and during evenings a factor 3 (≈ DNL)

*"Noise Limits" – Guidelines from Swedish EPA: **55 dBA FBN** (outside) (outside: **70 dBA$_{max}$***, inside: 30 dB $L_{Aeq(24hrs)}$ or 45 dBA$_{max}$ at night)*

*) (Disputed) Amendments: **if 70 dBA$_{max}$ is exceeded,** it should not be more than:
A. 16 times between 06.00 and 22.00, and B. 3 times between 22.00 and 06.00
C. A do not apply for Stockholm (Bromma Airport)

2. Coupling between Noise and Sustainability

The 17 global sustainability goals agreed on by UN

http://www.un.org/sustainabledevelopment/sustainable-development-goals/#prettyPhoto

How do Noise matters couple to the no 3 sustainability goal ?

3 GOOD HEALTH AND WELL-BEING

Ensure healthy lives and promote well-being for all at all ages

- 2011 WHO study: ***"Burden of disease from environmental noise. Quantification of healthy life years lost in Europe"***
- In terms of "Disability-Adjusted Life-Years" (DALYs) in Europe *"Environmental noise"* is attributed *1.6M DALYs* per year partly through cardiovascular diseases
- Compared with, DALYs (Europe/year):

"Outdoor air pollution"	*1.5M DALYs*
"Traffic accidents"	*3.7M DALYs*

i.e. Noise should not be reduced to a matter of comfort only!

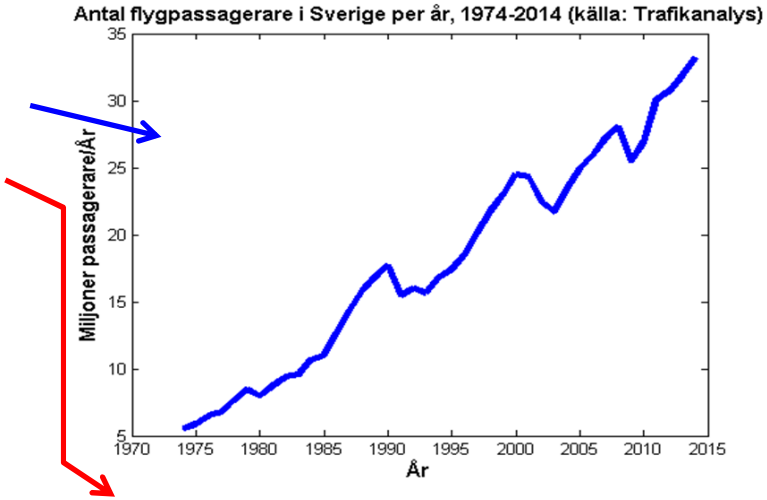
3. Air traffic noise – today and in the future

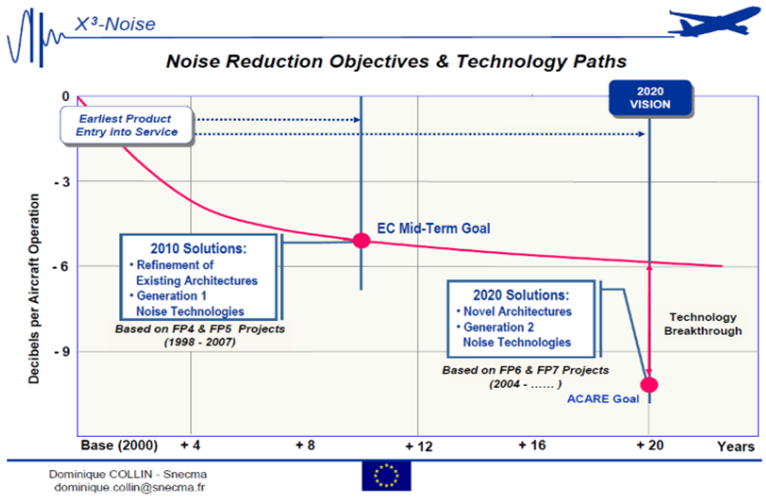
- International as well as Swedish air traffic expected to increase
- Expected aircraft noise reduction at source tend to flatten out
- Increased insight in noise effects and growing engagement among regulatory authorities and the public

⇒

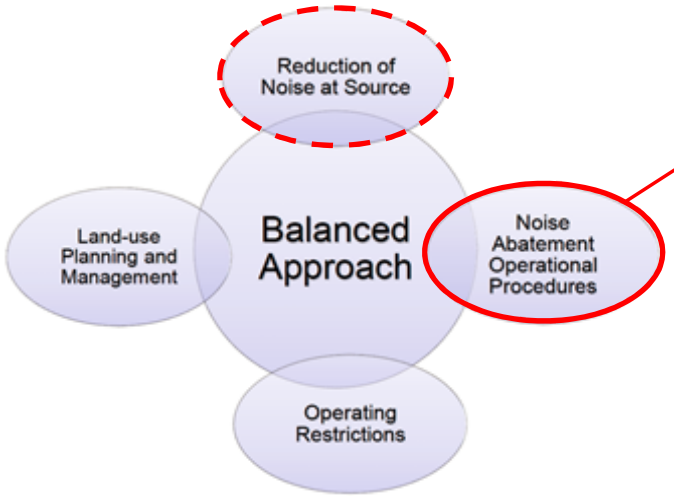
points out the Need for:

1. New measures to meet future noise requirements
2. Better understanding of impact on ground noise from aircraft operational procedures
3. Better understanding of weather/atmospheric impact
4. Better possibilities to simulate air traffic/noise propagation to find the most effective ways to accomplish noise reduction with today's and tomorrow's air traffic



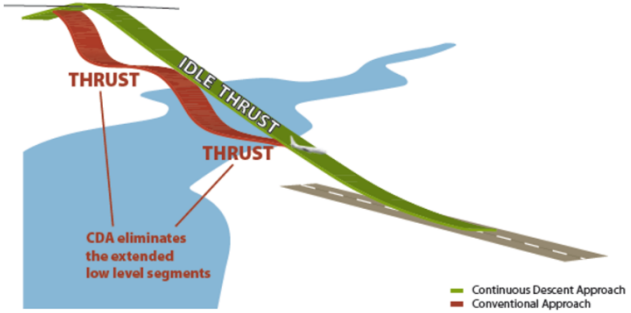


Possibilities to reduce noise- ICAO (2001)



- Reduction/redistribution of noise around the airport
- Enable full use of modern aircraft capabilities
- Various departure & approach procedures:
  - Displaced thresholds (landing/take off positions)
  - Reduced power/drag and CDA (Continuous Descent Approach)
  - Limited engine ground running
  - Noise preferential routes/runways
  - SID[1]/STAR[2] and RNAV[3] procedures optimisation and design

CDA OVERVIEW



SAFT: An aircraft environmental noise simulation tool which enables atmosphere dependencies to be included in studies of new procedures as well as new aircraft/engine designs.

[1] SID = Standard Instrument Departure
[2] STAR = Standard Terminal Arrival Route
[3] RNAV = "Area Navigation" a method of instrument flight rules (IFR) navigation

4. SAFT – objectives

- Establish a computational platform for aviation noise, accounting for the complete chain :
  - flight trajectory – flight mechanics/flight+engine condition – individual noise sources– atmospheric dependent sound propagation – noise contours/time signal – studies – conclusions – measures
- Enable future air navigation studies with regard to noise, effects of:
  - operational changes – trajectory/procedure optimisation
  - typical or current weather conditions, "noise forecasts"
  - optimisation of run-way use patterns with regard to noise/weather
  - new aircraft-/engine concepts
  - new runways, procedures for engine testing, ...

- Generate new knowledge and work for the dissemination of it:
  - build networks through collaboration between industry, academia and governmental authorities
  - find new ways to reduce the impact of aircraft noise
- Strengthen Swedish research in the long term:
  - framework for the implementation of methods developed at Swedish universities
  - catalyst in the process of establishing and develop new collaborations in the field of aircraft noise

5. The need for a simulation tool of the SAFT-kind ("… we already have INM, ECAC Doc.29 ?")

- INM and other programs, based on so called "Integrated Methods" like ECAC Doc.29, are used for noise mapping around Swedish airports
- The aim is primarily to study yearly patterns
- The methods are guiding in the legal processes (rather than measurements)

Integrated Methods works in general well for their purpose, but they do not, in contrary to so called simulation methods, allow for more realistic studies of:

- *Noise abatement procedures*
- *New technology for airframe- and engine design*
- *Weather effects, typical or actual, impacting on the noise on ground*

(forts 5. The need for a simulation tool of the SAFT-kind)

- An aircraft noise simulation program as SAFT should currently be seen as a complement to INM/ECAC Doc.29
- First, in the longer term – some decades? - It is reasonable that the Integrated Methods could be replaced by Simulation Methods

	Simulation tools	Integrated tools
Typical application	Single event operations	Combined fleet, yearly mean
Sound source	Separated from propagation Semi-empirical, physics-based Frequency and space resolved	Merged with propagation Measured Frequency and directivity info missing
Source data availability	**Limited open data available**	Good OASPL data found in the open ANP*-database
Sound propagation	Yes - separated from sound source	No - not separated from source
Studies of noise abatement flight procedures	Yes - Possible to simulate	No - or very limited possibilities
Time history for noise events	Yes - Possible to simulate (as well as listening tests based on these)	No – not possible to extract
Atmosphere impact	Yes - Possible to include	No - not included (ANP/NPD data established under certain "standard atm. conditions")
New technology studies	Yes – possible to simulate new aircraft or engine concepts	No – not possible to include
Computational time	Computationally more "heavy"	Computationally fast

*) ANP = The Aircraft Noise and Performance Database including the NPD –Noise Power Distance - data

6. Other Simulation tools

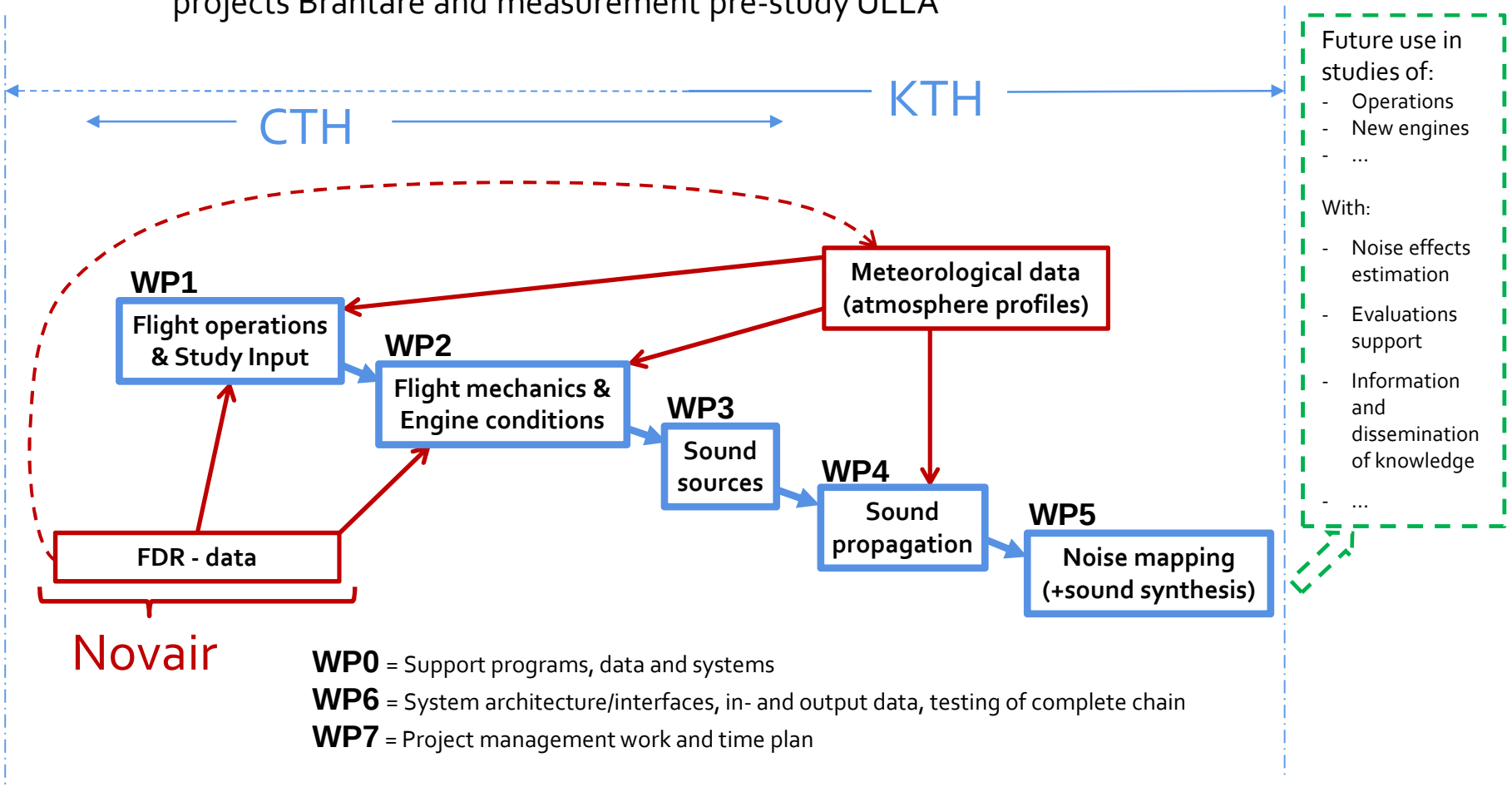
- ANOPP, NASA with its roots from 1975/80
  - Prior to its time – now actualised, because of faster computing and stronger need
  - Several noise source models still highly useful
  - **To a large part open and accessible!**

- FLIGHT – University of Manchester. Seems highly developed, emphasis is on flight mechanics, less on atmosphere / sound propagation
- SOPRANO – Anotec Spain. Aim for weather dependent noise propagation
- CARMEN(ONERA) and VCNS(NLR) – central point: noise event (re-?) generation for listening tests
- PANAMA (DLR - Germany) – High level, good access to validation data from measurements
- SONAIR (EMPA Swizerland) ,…

”New”, after ~ 2000, but: Closed alt. Commercial, no excess to source code!

7. The planned Simulation tool SAFT

A cooperation between:
KTH-MWL, Chalmers Turbomachinery/Aeroacoustics and Novair + sibling projects Brantare and measurement pre-study ULLA



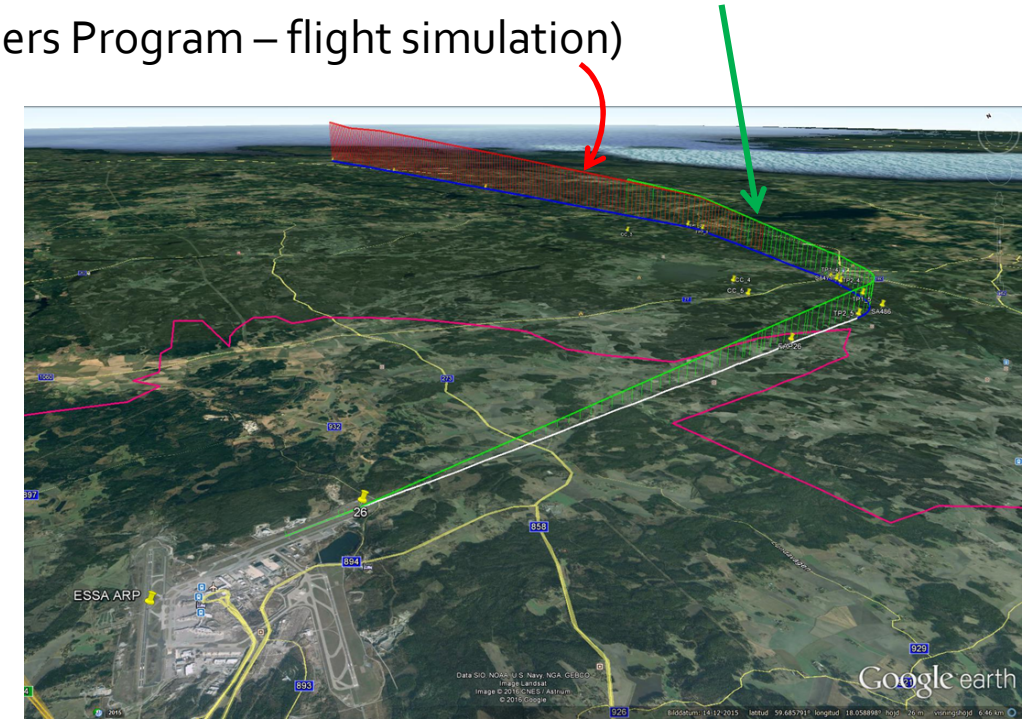
WP0 = Support programs, data and systems
WP6 = System architecture/interfaces, in- and output data, testing of complete chain
WP7 = Project management work and time plan

Flight operations & Study Input

(…cont. 7. The planned Simulation tool SAFT)

Different ways to generate flight paths for a given aircraft type:

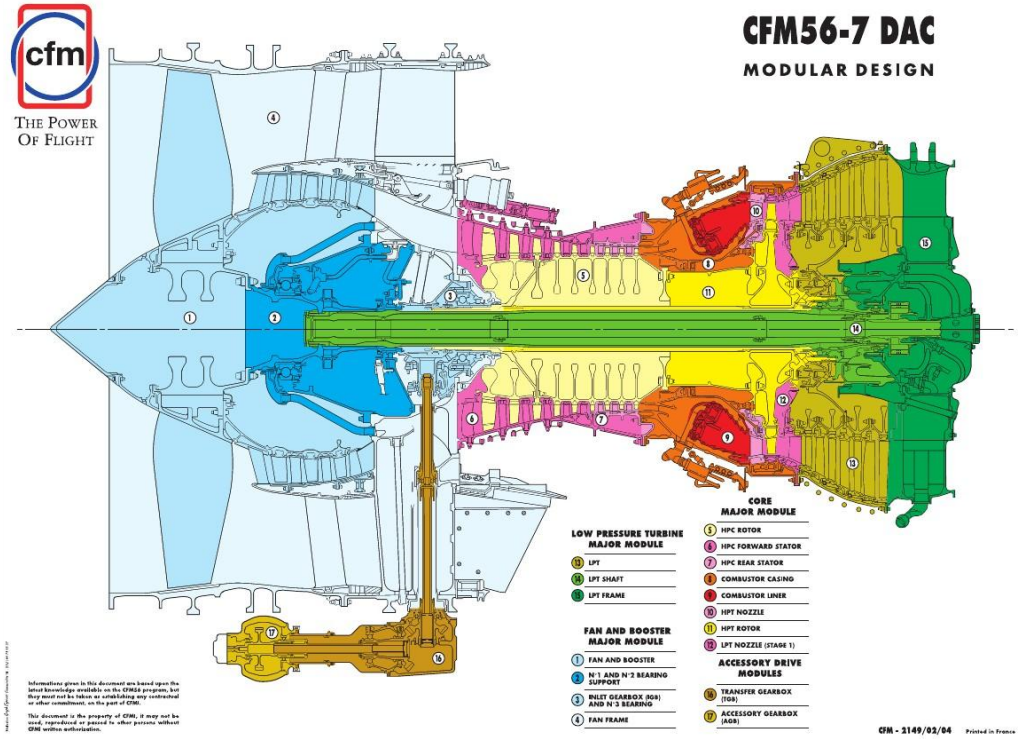
- "Standard Procedures" from the ANP-database (in the ECAC doc 29 implementation in SAFT)
- PEP (Airbus Performance Engineers Program – flight simulation)
- In house CTH tools
- BADA (?) Base of Aircraft Data – Eurocontrol ("all types of aircraft")
- FDR- Flight Data Recorder Real recorded data! *Important for validation of sound source models!*



Flight mechanics & Engine conditions

(…cont. 7. The planned Simulation tool SAFT)

- Establish thermodynamic model for actual aero engine (from open data) and the CTH-code GESTPAN*
- Link with flight mechanics model
- Run the aircraft and engine model in order to establish relations between engine-/flight conditions on one hand and flow-/thermodynamic variables on the other. The last ones constitutes input to noise source models.



*) GEneral Stationary and Transient Propulsion ANalysis

Sound sources 1(2)

(...cont. 7. The planned Simulation tool SAFT)

Typical semi-empiric source expression:

$$\left\langle p^2 \right\rangle^* = \frac{\Pi^*}{4\pi R^{*2}} \frac{\mathcal{D}(\theta,\phi)\ F(\mathrm{St})}{(1-\mathrm{M}_\infty \cos\theta)^4}$$

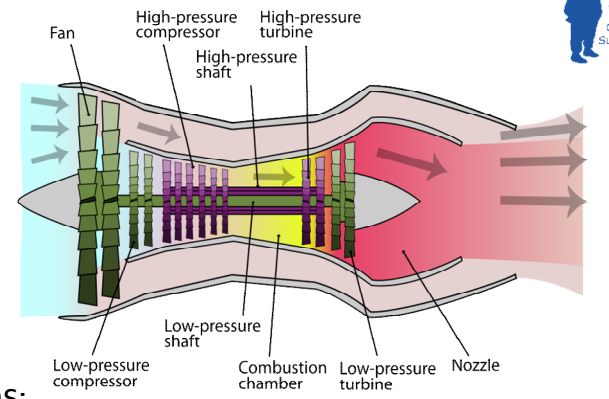
- Π^* nondimensional acoustic power
- $\mathcal{D}$ directivity function
- F spectral shape function
- M_∞ Mach number
- R^* nondimensional physical propagation distance R (normalized by wingspan)
- θ, ϕ polar and azimuthal directivity angles

$$\mathrm{St} = \frac{f L}{\mathrm{M}_\infty a_\infty}\left(1-\mathrm{M}_\infty \cos\theta\right)$$

- f frequency
- a_∞ ambient sound speed
- L characteristic length of sound source

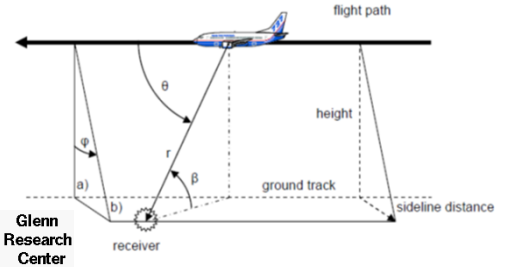
Engine noise sorces:

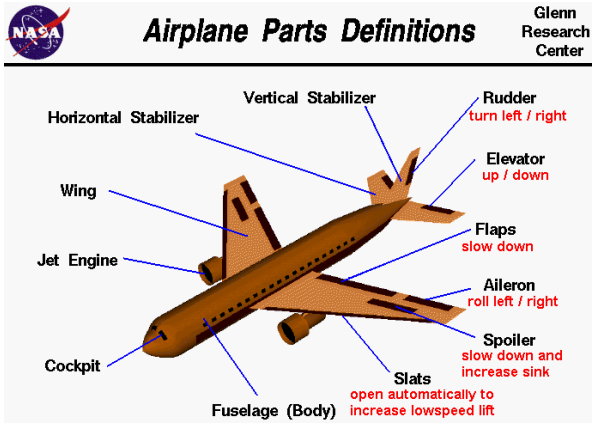
Fan
Compressor
Combustor
Turbine
Jet

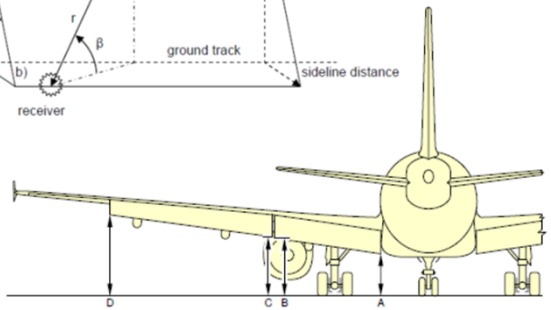


Airframe noise sources:

Flaps
Slats
Rudders
(Boundary Layers)
Landing Gear







Sound sources 2(2)

(...cont. 7. The planned Simulation tool SAFT)

Open data:

- Aircraft Noise and Performance (ANP) Database
- EASA Noise Database

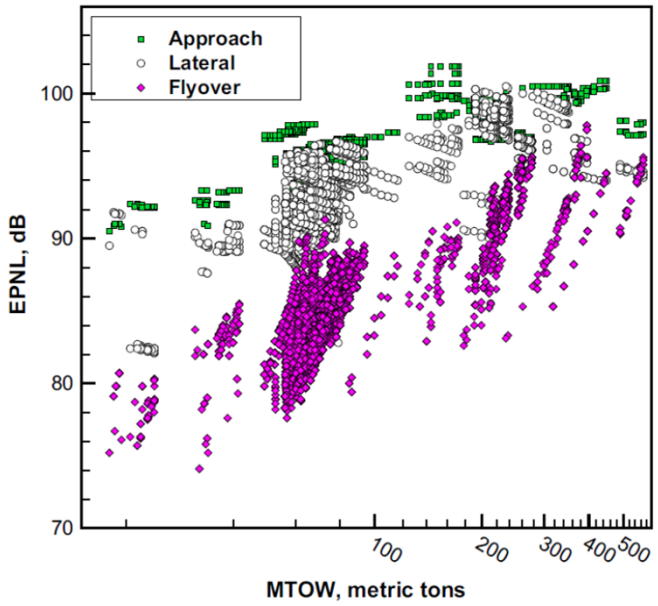


Fig. ref. A. Filippone / Progress in Aerospace Sciences 68 (2014) 27–63

Aircraft noise source breakdown example

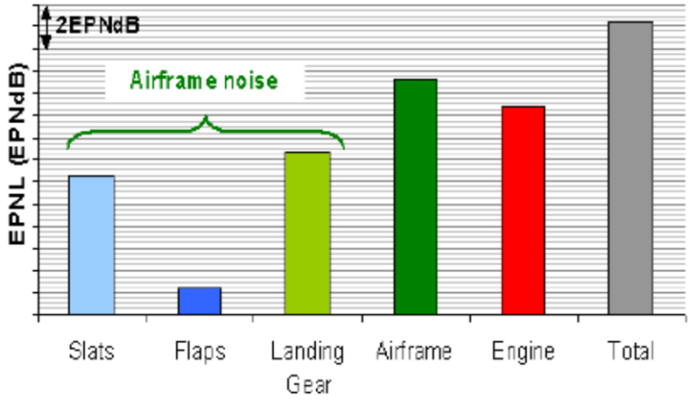


Fig. ref. AIAA/CEAS-2008 Dobrzynski DLR

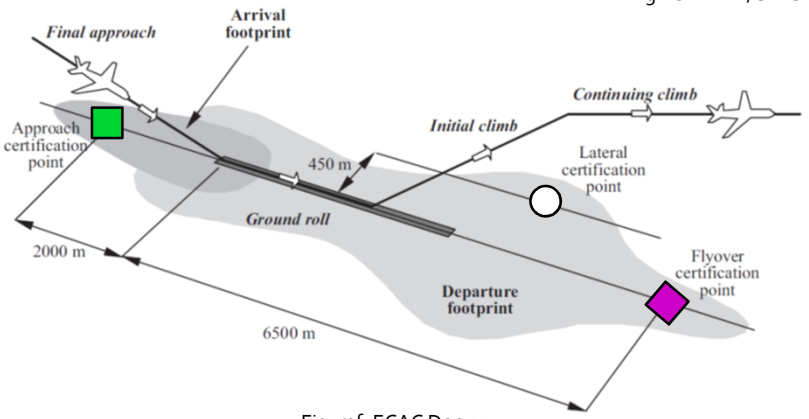


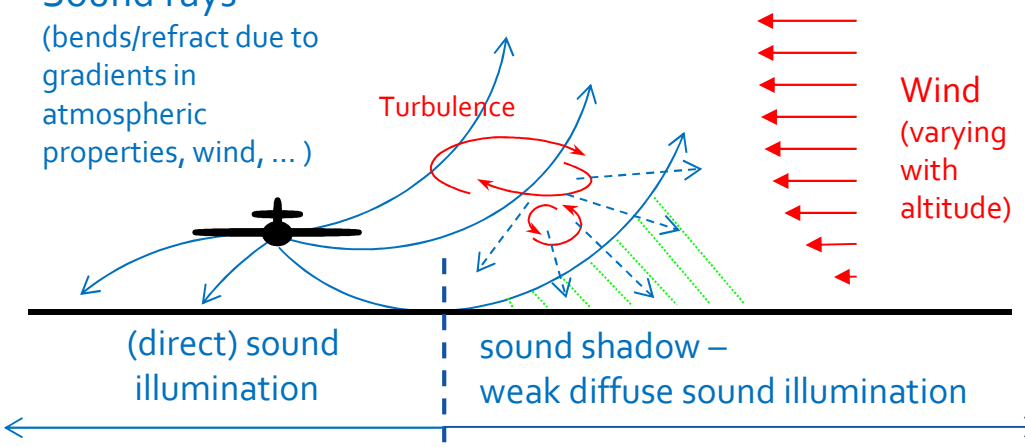
Fig. ref. ECAC Doc.29

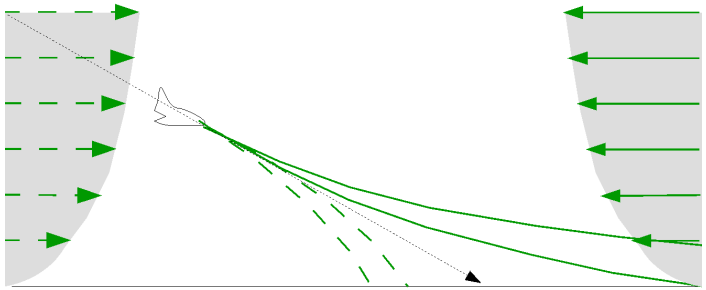
Sound propagation

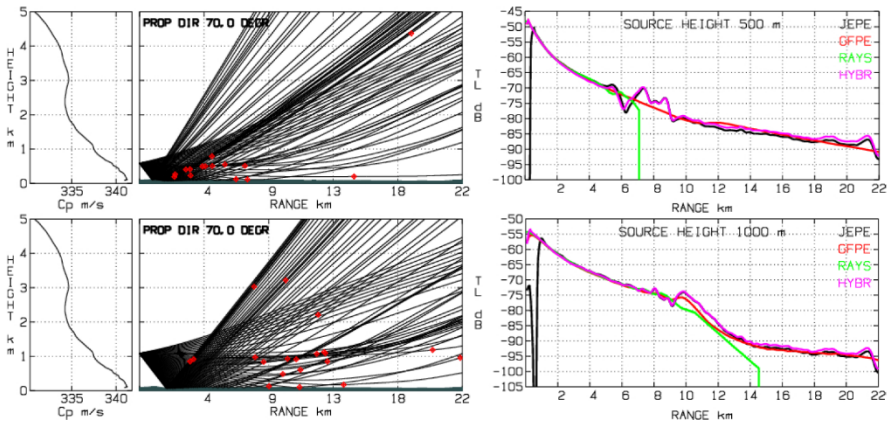
(…cont. 7. The planned Simulation tool SAFT)

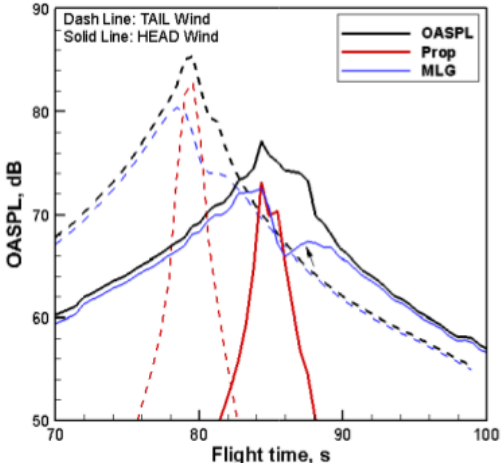
Sound rays

(bends/refract due to gradients in atmospheric properties, wind, …)









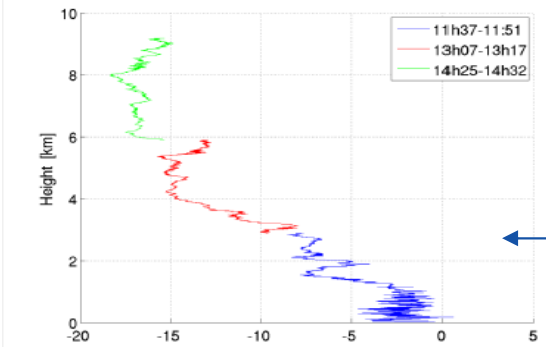
Meteorological data (atmosphere profiles)

(…cont. 7. The planned Simulation tool SAFT)

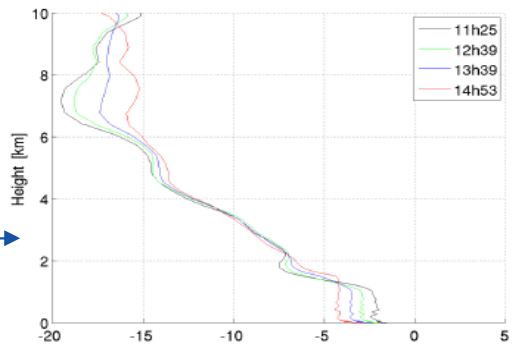
Example: Comparison measured and predicted atmospheric data

Measured ⟷ Forecast

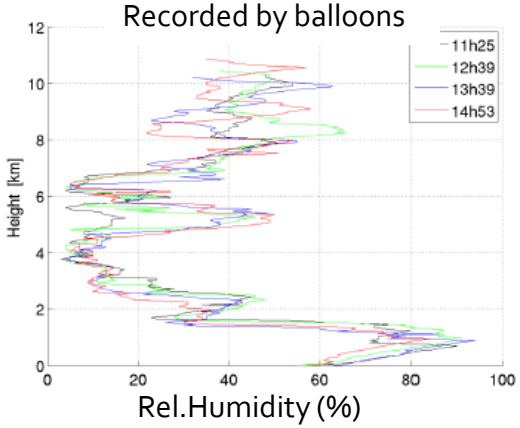
Recorded by Aircraft



Hirlam prognosis



Recorded by balloons



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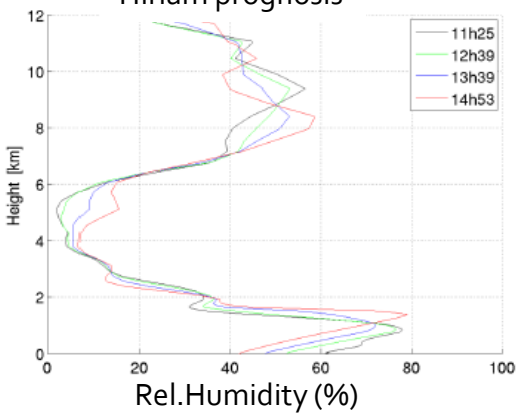
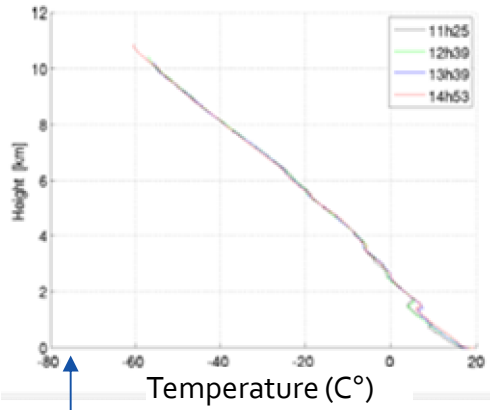


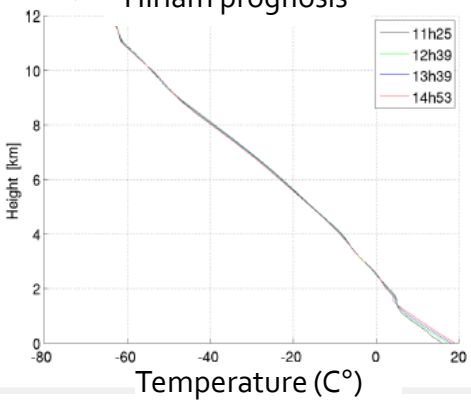
Recorded by balloons

Measured



Forecast

Hirlam prognosis

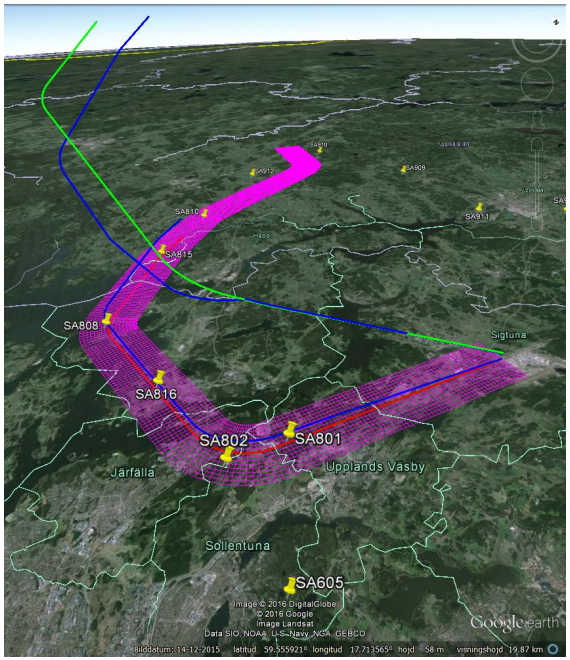


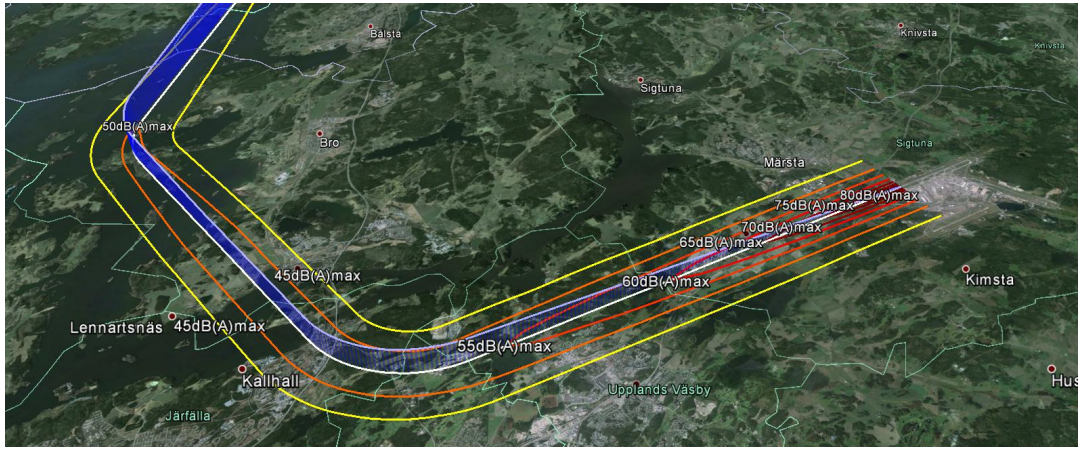
Noise mapping

(…cont. 7. The planned Simulation tool SAFT)

Example test of SAFT pre-study, functionality:

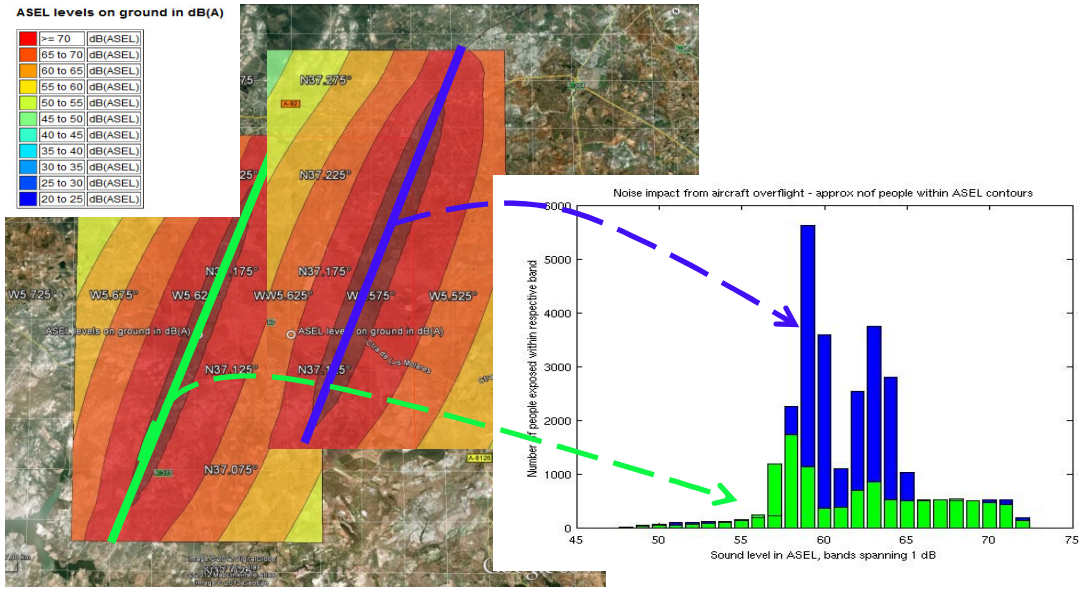
- Grid related to ground track
- Noise map for a A320-211 approach
- Noise source given by a ”retrofit”-method based on ANP-data, i.e. source not based on basic physics (EU-proj. IMAGINE, from FLULA a Swiss code)
- Underestimation of EPNL-levels …





… forts. Noise mapping

(…cont. 7. The planned Simulation tool SAFT)



Example change of noise impact by translation of route
(number of people exposed to certain noise level translation 5km west and 5km south)

8. Existing system for weather dependent sound propagation

Prognosis tool for artillery noise developed by Ulf Tengzelius and Ilkka Karasalo KTH-MWL.

(movie 135 MB left out)

The End– Thank You!