EASA
European Union Aviation Safety Agency

Research project:

Upgrade of the noise rotorcraft model NORAH

Webinar: final dissemination event

13/03/24, 15:00-17:00 CET

An Agency of the European Union

This project is funded by the European Union's Horizon 2020 Programme

Disclaimer

This project is funded by the European Union under the Horizon 2020 Programme.

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Union Aviation Safety Agency (EASA). Neither the European Union nor EASA can be held responsible for them.

This deliverable has been carried out for EASA by an external organisation and expresses the opinion of the organisation undertaking this deliverable. It is provided for information purposes. Consequently, it should not be relied upon as a statement, as any form of warranty, representation, undertaking, contractual, or other commitment binding in law upon the EASA.

Welcome to this webinar!

This webinar is the final dissemination event of this research project

This project has received funding from the European Union’s Horizon 2020 research and innovation Programme

European Commission

The EC delegated the contractual and technical management of this research action to EASA

EASA contracted NLR as Consortium lead for the implementation of the research action following a public tender procedure

EASA-managed projects are addressing research needs of aviation authorities and are an important pillar of the EASA R&I portfolio

The agenda

TIME	**TITLE, SPEAKER**
15:00 H – 15:05 H	**Welcome to the webinar** Willy Sigl, EASA
15:05 H – 15:15 H	**Research scope and objectives** Ivan de Lepinay, EASA
15:15 H – 15:35 H	**Overview of the project implementation** Marthijn Tuinstra, NLR
15:35 H – 15:55 H	**Rotorcraft noise data acquisition** Nico van Oosten, ANOTEC
15:55 H – 16:15 H	**Overview of the NORAH2 model method and validation** Herold Olsen, SINTEF
16:15 H – 16:25 H	**Benefits of the project, training, access to the model** Ivan de Lepinay, EASA
16:25 H – 16:55 H	**Questions and answers** Participants, EASA Project Team, and Contractor Project Team
16:55 H – 17:00 H	**Concluding remarks** Willy Sigl, EASA

Note: this webinar will be recorded and made available at the EASA website after the event.

Question and Answers

→ For sending questions and input, please use the slido app, which is also accessible through WebEx:

- www.slido.com
- event code: 9872020
- passcode: rk502h

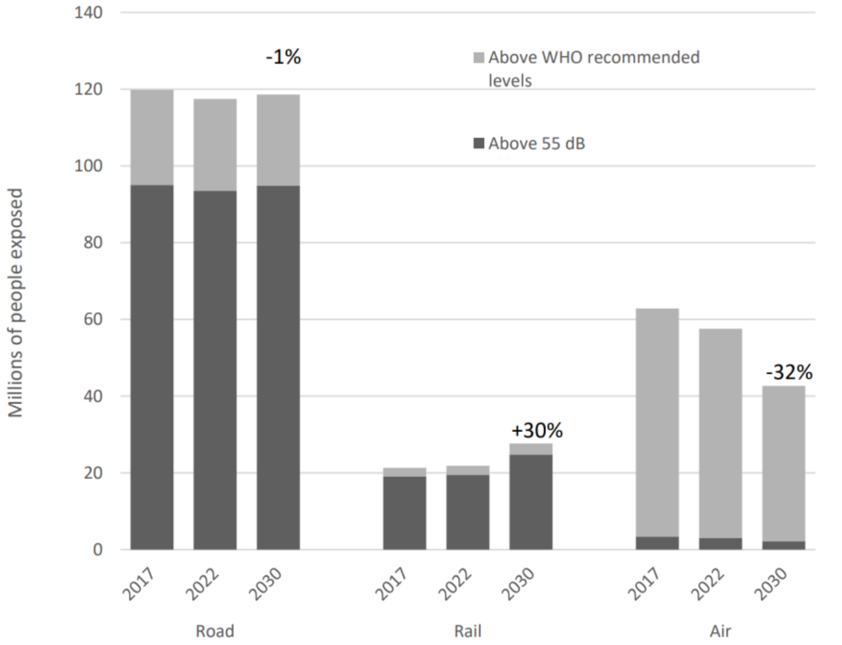
European Union Aviation Safety Agency

Research Scope and Objectives

Environmental noise is a key priority for Europe

- According to EEA, at least one in five people in the EU are exposed to long-term noise levels considered harmful to their health.
- Third report on END implementation calls for more actions to meet the target of 30% reduction in people chronically disturbed by transport noise by 2030 compared to 2017

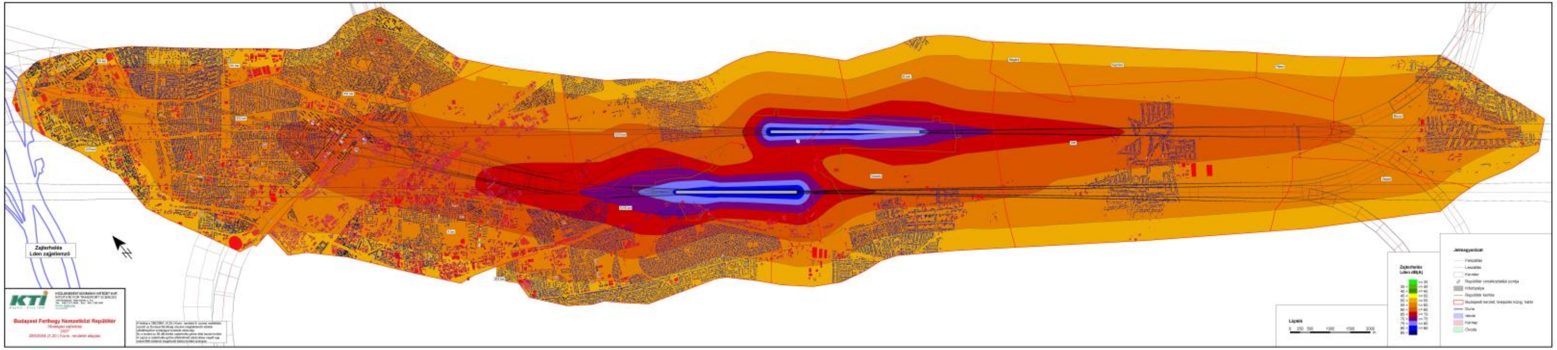
Estimated total number of people exposed to noise in the EU, with increase/decrease projections between 2017 and 2030



EU Member States maintain strategic noise maps

Directive 2002/49/EC (END) requires EU countries to prepare and publish noise maps and noise management action plans every 5 years for:

- agglomerations with more than 100,000 inhabitants
- major roads (more than 3 million vehicles a year)
- major railways (more than 30,000 trains a year)
- major airports (more than 50,000 take-offs or landings a year, including small aircrafts and helicopters)



Data to assess rotorcraft noise is scarce

- Annex II to the END (Directive 2015/996) provides limited guidance and data to model helicopter noise
  - Section 2.7.21: For the calculation of helicopter noise, the same calculation method used for fixed-wing aircraft may be used, provided helicopters are treated as propeller aircraft and engine-installation effects, associated with jet aircraft are not applied.
  - Appendix I Tables I-18 to I-27: contains data for 5 helicopter classes based on MTOM
- Some noise models (e.g. AEDT) cover helicopters but…
  - Available helicopter types may not match the European fleet
  - Noise modelling is based on noise-distance data with limited directivity consideration
  - Noise data is independent of the helicopter climb/descent angle or speed

Europe has a large fleet of helicopters

- About 7600 registered civil helicopters
- 360 different helicopter types/variants
- 91 ICAO aircraft type designators
- 2.6 million flight-hours
- 6.75 million take-offs / landings

Engine configuration	Number of registered helicopters (2020)	Average annual flight-hours per helicopter
Piston	2809	≈ 275
Single turbine	2349	≈ 349
Twin turbine	2409	≈ 418
Unknown	17	≈ 46
All	**7584**	**≈ 343**

The 1st NORAH phase was launched in 2015

Under EC DG MOVE contract the first NORAH project led to:

→ The development of a first hemisphere-based noise modelling methodology applicable to rotorcraft

→ The acquisition of 148 noise hemispheres for 8 helicopter types representative of about 70% of the European fleet

→ The development of a software prototype NORAH1 already tested and used by about 20 organisations






The objective of the 2nd NORAH phase was to…

- Further improve the rotorcraft noise modelling methodology
  - More acoustic propagation effects
  - More flight conditions
- Enhance the fleet coverage with
  - Additional important helicopter types
  - Drones and/or eVTOL aircraft
- Update the NORAH software prototype accordingly

Overview of the project implementation

Overview of the NORAH2 project implementation

- Starting point
  - NORAH 1.0,
  - outcome of contract MOVE-C2-2014-269 issued by the EC
- Outline
  - (NORAH1) User requirements from survey
  - Improvements of the rotorcraft modelling method
  - Extension of the NORAH hemisphere database
  - Improved software prototype
  - Conclusions and recommendations

Survey

- Feedback gathered from NORAH 1.0 users via survey:
  - 26 responses
  - Feedback from France, Switzerland, Sweden, Germany, Denmark, Italy, UK, Malta, Ireland, Slovenia, Norway, Netherlands, Austria, Romania, and Ukraine, USA, Canada, Japan
  - Majority active as Policy makers & Land use planners
  - 65% are currently using a helicopter noise model
  - 71% would like to use NORAH in the future

Survey, requested features

- Additional Metrics
  - LAeq., Number of events above x (NAx)
- Sound propagation
  - Topography considered important (excluding buildings)
- Database
  - Heavy helicopters needed are requested to be added
  - Freedom to set flight parameters (interpolation)
  - Specific operations (hover, taxiing, etc.)
- Software
  - Usage: Mostly integrate in other software (2 out of 3)
  - Hemisphere database & method is considered most important component (prototype itself is less important)
  - Use radar tracks

Helicopter noise modelling methodology

- New modelling Features
  - Hemisphere flight condition interpolation to allow greater freedom to set flight parameters in the noise modelling.
  - Inclusion of screening effects from buildings and topography.
  - Inclusion of specific operations such as hover, taxiing and turns

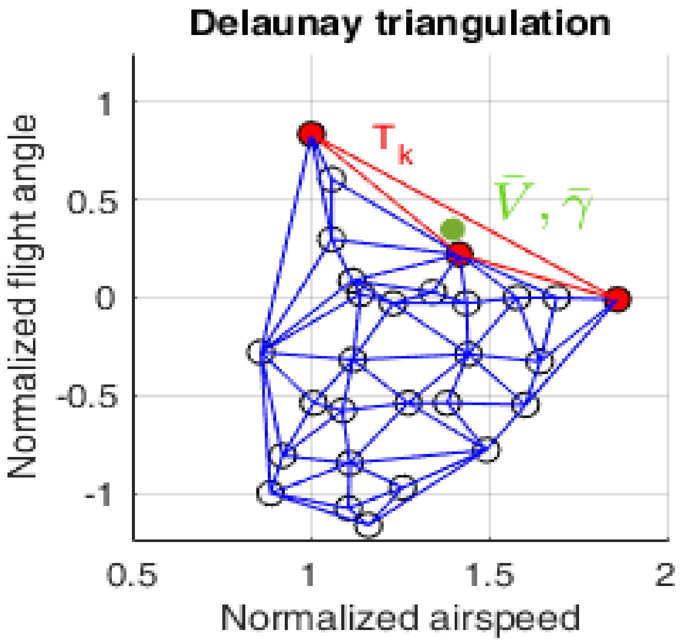
- NORAH 2 Rotorcraft noise modelling method available for download at NOISE - SC01.D1.5c report (europa.eu) .

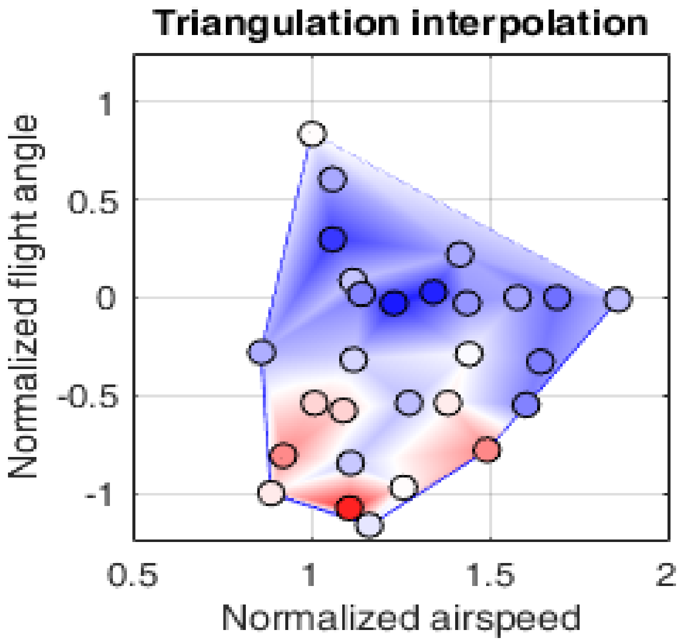
Flight condition interpolation

- NORAH 1:
  - no interpolation
  - Only modelling of tracks that are in the hemisphere database
- Advantage: Modelling is accurate, track matches hemisphere conditions
- Disadvantage:
  - deviation between actual flown tracks and modelled tracks
  - Position error
  - Hemisphere condition mismatch

Flight condition interpolation

→ Delaunay triangulation to allow interpolation between ‘closest’ vertices





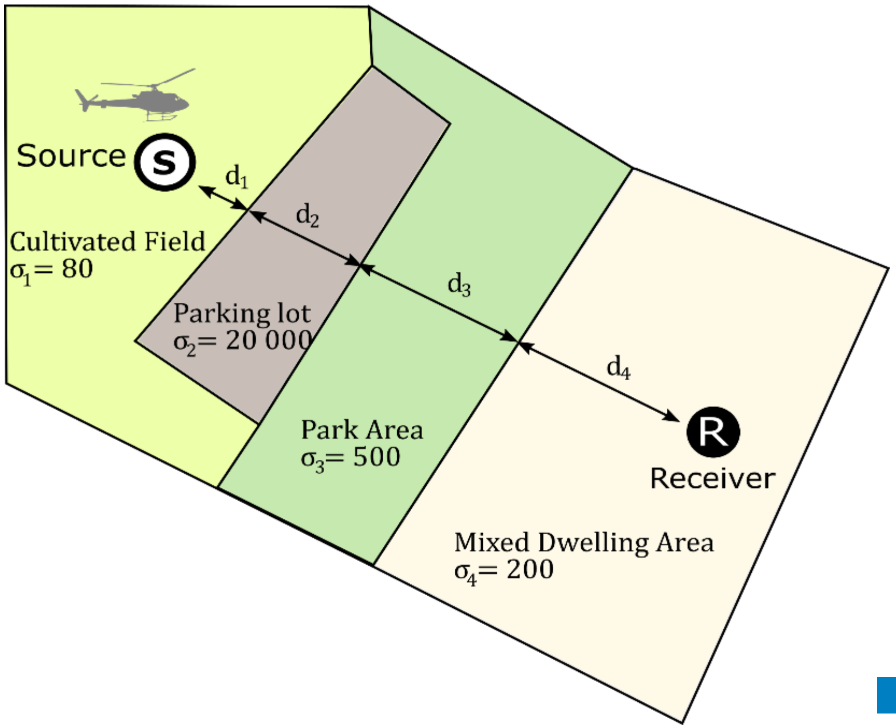
Noise propagation over uneven terrain

- NORAH 1:
  - Flat soft ground
  - Single surface impedance
- Not possible to account for geographic variations
- Not possible to include varying ground surface types

- NORAH2 introduces noise propagation over uneven terrain, fully in line with CNOSSOS-EU: Common noise assessment methods in Europe

Varying surface types

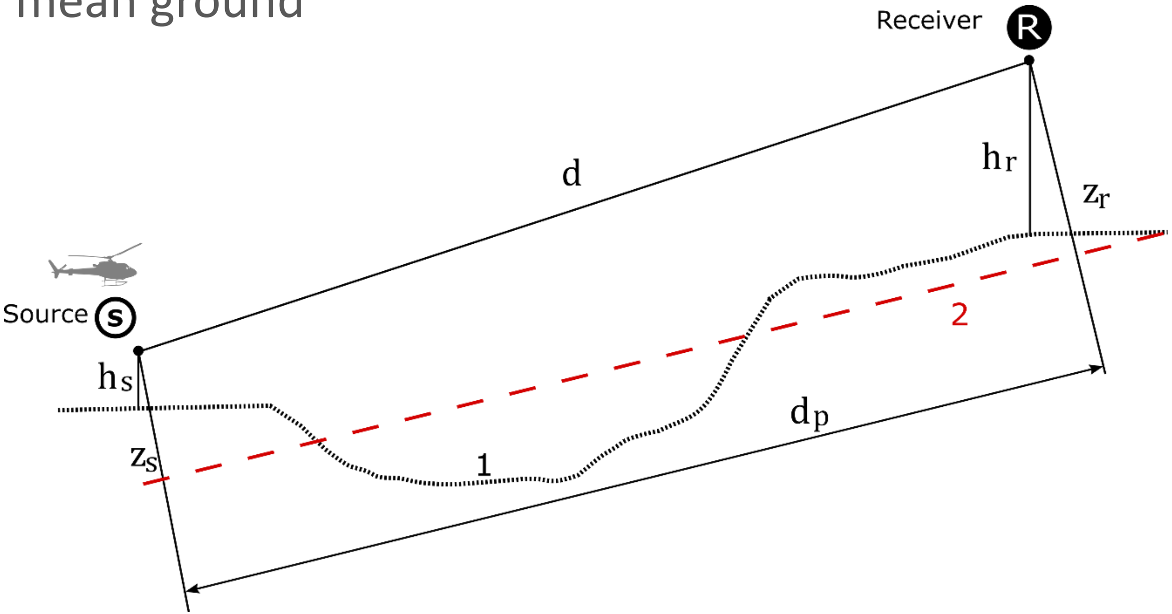
- Allow for varying surface types, e.g.
  - Snow
  - Moss
  - Forest floor
  - Lawns
  - Gravel
  - Asfalt



EASA

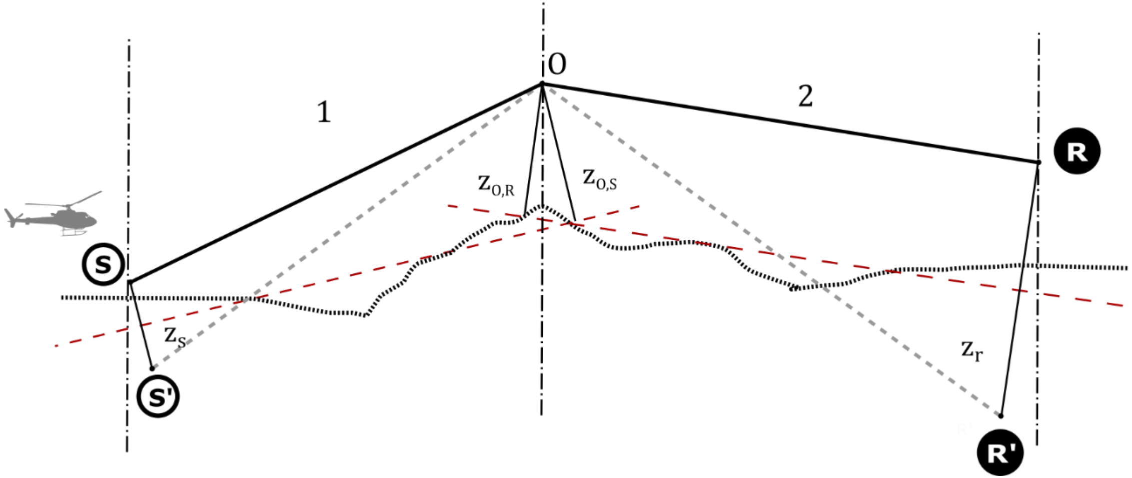
Accounting for geographic variations

- Allow for varying topography
  - Definition of a mean ground



Noise diffraction for blocked line of sight

→ Allow for screening effects



Specific operation: Hover, idle and taxi

- In NORAH 1 no guidance was offered on how to include the hover, idle and taxi flight phase
- NORAH 2
  - offers modelling guidance,
  - measurement guidance for the hemisphere database
  - Specific hemisphere format
  - Approximation methods for varying level of data availabilty

The NORAH1 hemisphere database

- NORAH 1 database
  - Robinson R22
  - Robinson R44
  - Robinson R66
  - Schweizer S300
  - Eurocopter EC120
  - Eurocopter EC135
  - Eurocopter AS350
  - Bell 412

coverage of >70% of the European helicopter fleet, through class representation

Extension of the NORAH hemisphere database

- NORAH 2 database extension
  - Guimbal Cabri G2
  - Agusta A109
  - Sikorsky S-92

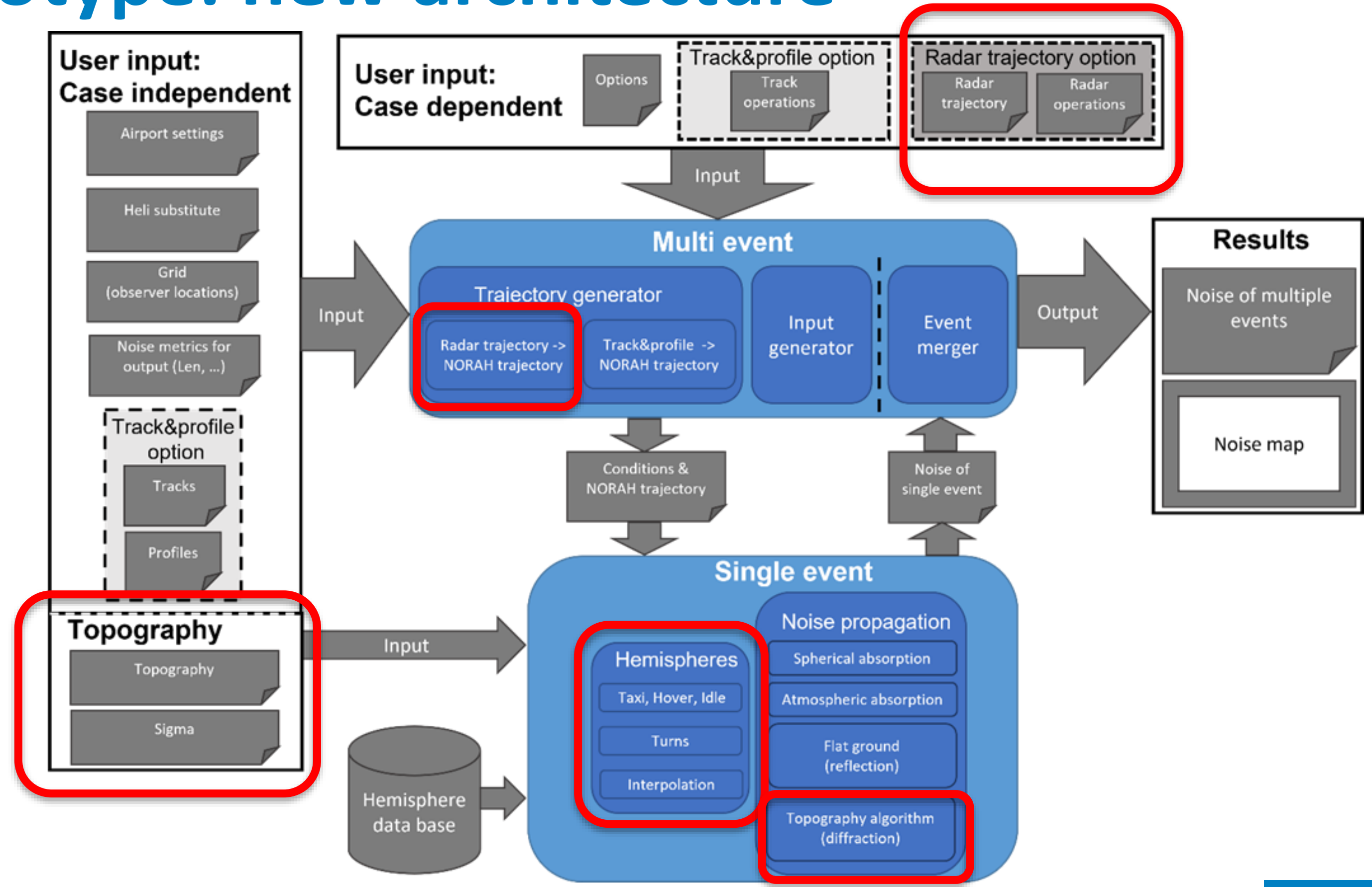
coverage of >80% of the European helicopter fleet, through class representation

Software prototype

- NORAH 1 architecture
  - Multiple event module (Python)
  - Single event module (Fortran)
  - Simple ASCII based input output format

Software prototype: new architecture

- → Architecture adapted to accommodate new modelling features
- → Hemisphere database extended



Conclusions

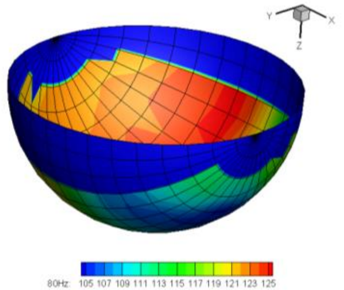
- A rotorcraft noise modelling method was defined
  - A hemisphere interpolation method was devised, that greatly increases the user's flexibility,
  - Noise propagation modelling over uneven terrain,
  - Modelling guidance for special operations (hover, taxi, turns)
- Extension of the hemisphere database (S92, A109, GC G2)
- Implemented in a software prototype NORAH2

Recommendations

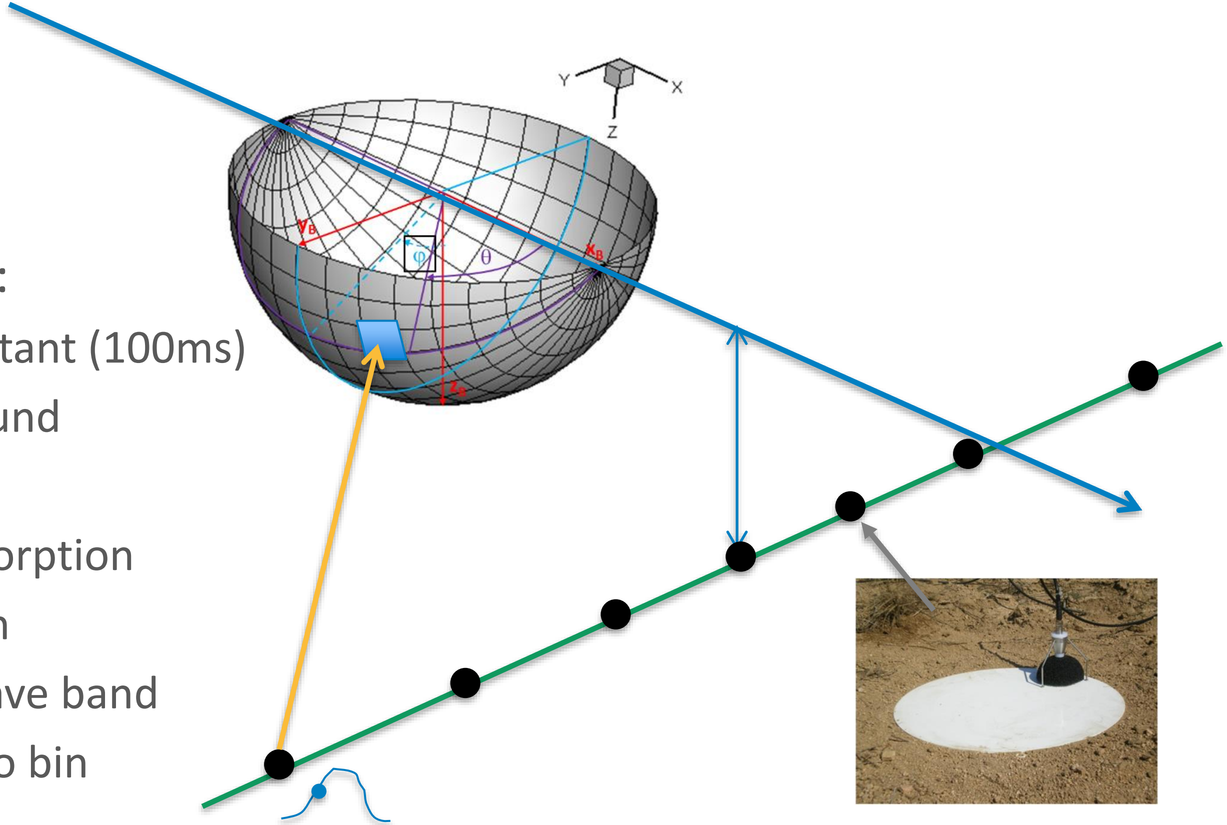
- → Broaden validation of the method (class representation, NORAH predictions vs measured noise in an operational environment, etc.)
- → Further extension of the database, also considering novel aircraft transport concepts (EVTOLs, drones)
- → Adapt software prototype for propagation modelling in an urban environment
- → Research into noise metrics tailored for helicopter noise, e.g. accounting for low frequency ‘thumping’ noise

Rotorcraft noise data acquisition

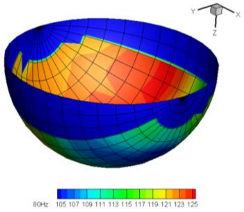
How to create hemispheres from measurements?



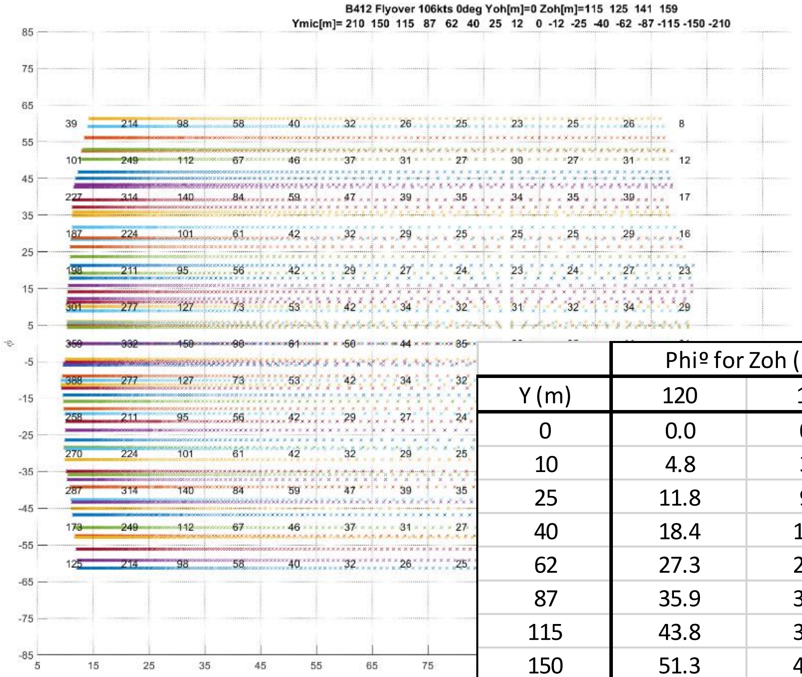
- Back-propagation:
  - For each time instant (100ms)
  - Travel time of sound
  - Distance
  - Atmospheric absorption
  - Ground reflection
  - For each 1/3 octave band
  - Result assigned to bin



Microphone array

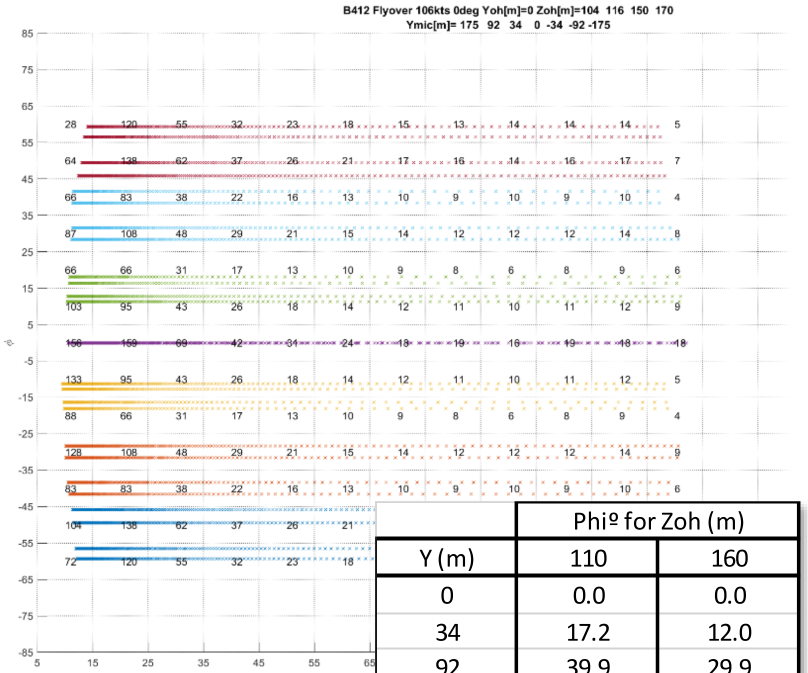


Full array



	Phiº for Zoh (m)	
Y (m)	120	150
0	0.0	0.0
10	4.8	3.8
25	11.8	9.5
40	18.4	14.9
62	27.3	22.5
87	35.9	30.1
115	43.8	37.5
150	51.3	45.0
210	60.3	54.5

Sparse array

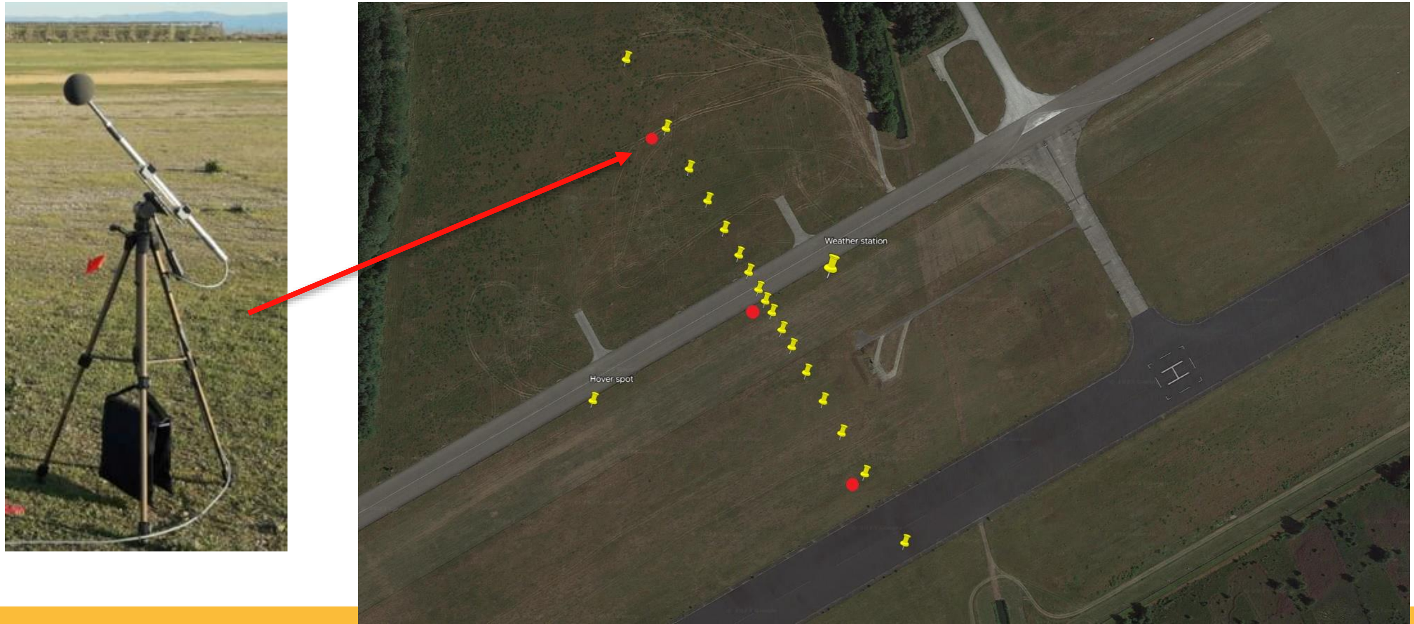


	Phiº for Zoh (m)	
Y (m)	110	160
0	0.0	0.0
34	17.2	12.0
92	39.9	29.9
175	57.8	47.6

EASA

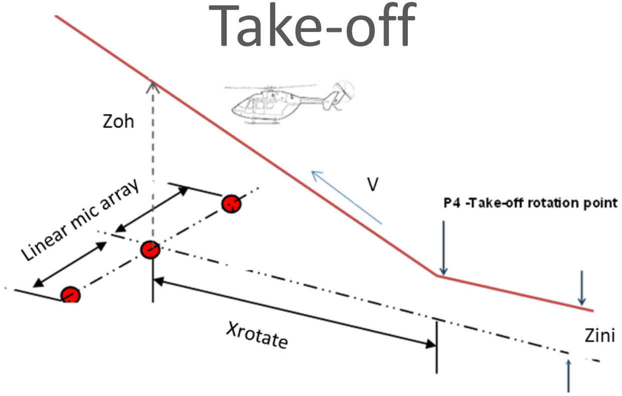
Additional microphones for Data quality check

- → Certification flight conditions included in test matrix
- → 3 microphones at 1.2m poles at certification locations
  - → If needed, shifted laterally due to different overhead height (maintain phi)

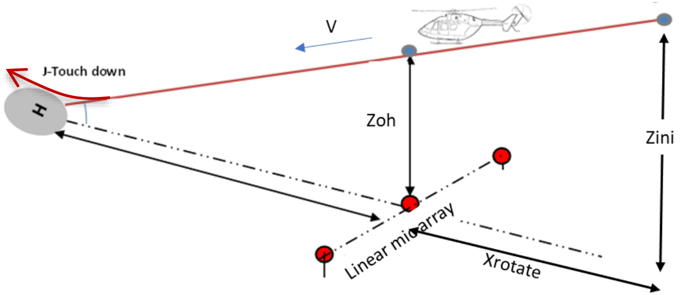


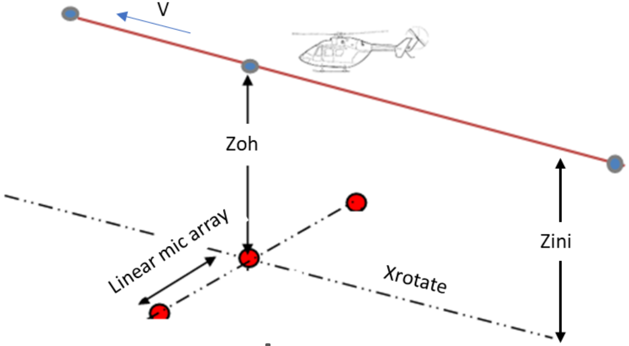
Flight Procedures

Take-off

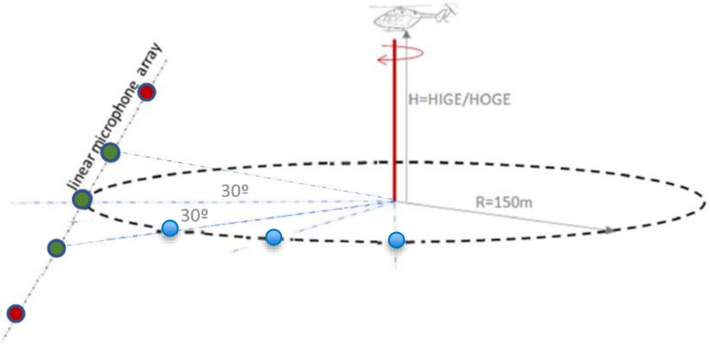


Approach





Flyover

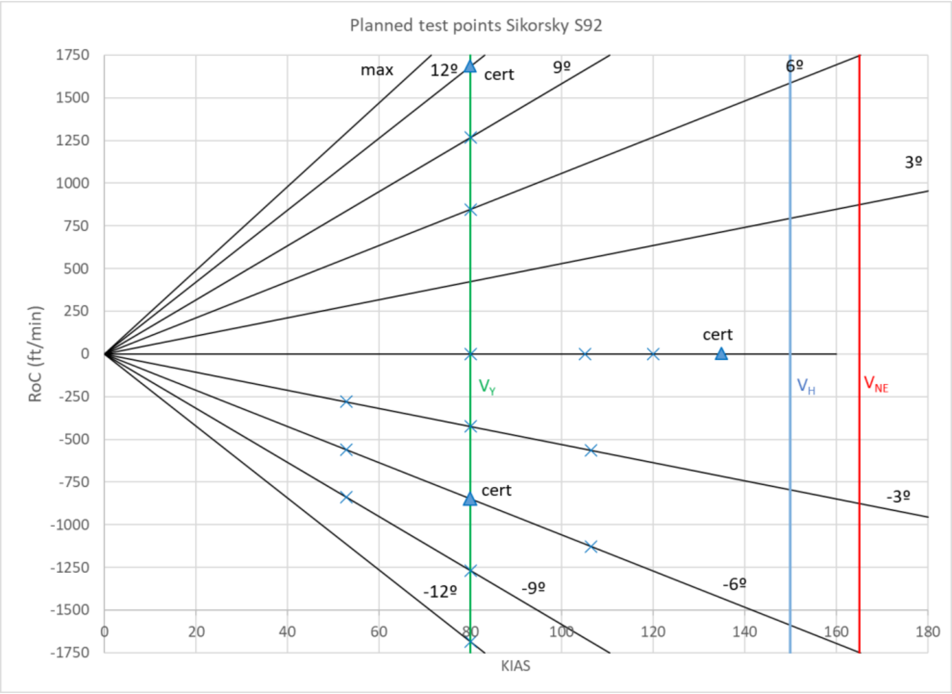


Hover

Test conditions

Weight [kg]	Speed [kts]	Descent angle [º]	Rotor speed [%]	Engine power [kW]	Target Height [m]#	No. of valid runs	Remarks
MLW +5/-10%	Vy	6	**	***	110/120	2	certification condition
					150/160	2	certififcation condition with higher height
	0.66*Vy		**	***	110/120	2	
					150/160	2	
	1.33*Vy		**	***	110/120	2	
					150/160	2	
	Vy	3	**	***	110/120	2	
					150/160	2	
	0.66*Vy		**	***	110/120	2	
					150/160	2	
	1.33*Vy		**	***	110/120	2	
					150/160	2	
	Vy	9	**	***	110/120	2	
					150/160	2	
	0.66*Vy		**	***	110/120	2	
					150/160	2	
	Vy	12	**	***	110/120	2	
					150/160	2	
Minimum number of valid runs						**36**	

** V_y corresponding to MTOW*
*** according to Airplane Flight Manual*
**** adapted to descent angle*
 # depending on microphone array deployed

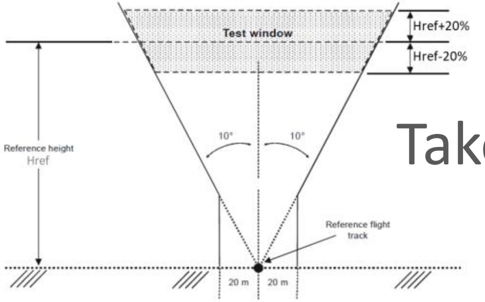


Limitations

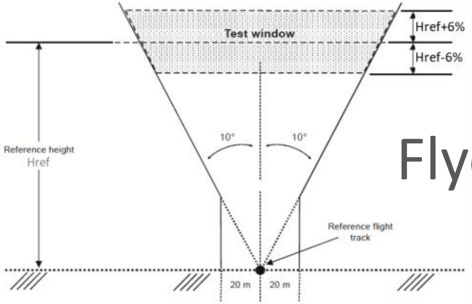
- In general ICAO Annex 16 Chapter 8 is followed
- Flight conditions
  - Main rotor speed variations within ±1% from target value
  - Airspeed variations within ±5 kts (2.5 m/s) from target value
- Weather conditions
  - As per Chapter 8
- Hover
  - As per CAEP WG1 guidelines (CAEP12_WG1_3_IP03)

Geometrical limitations

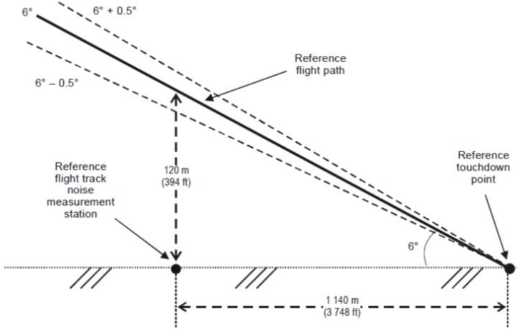
→ Requires adaptation due to changes in overhead height



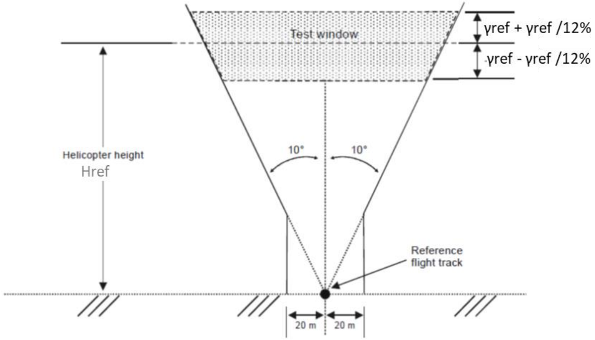
Take-off



Flyover



Approach



Selected helicopters + test sites

Guimbal Cabri G2

- Test site: Mollerussa (Spain)
- Test period: April 2022
- Mainly used to verify assumptions so as to optimise next test campaigns

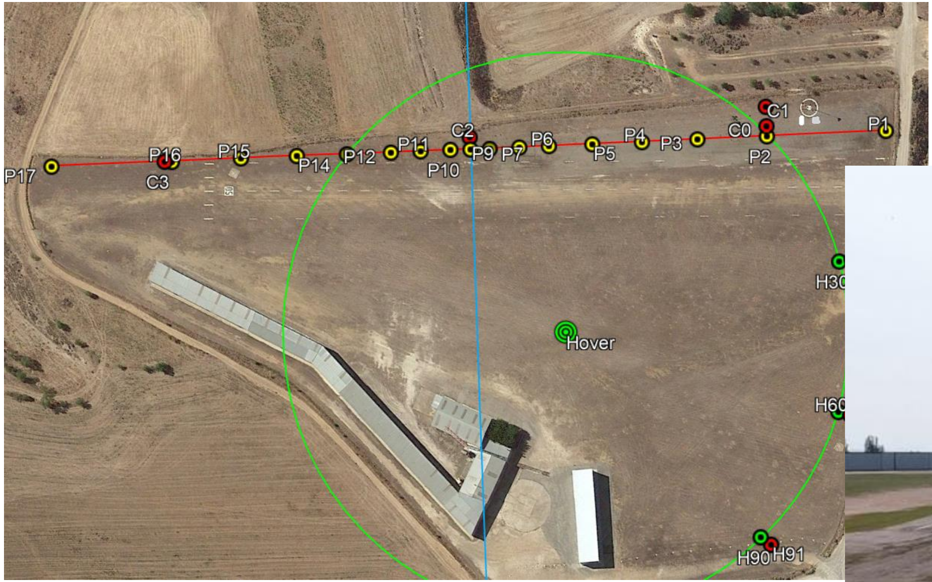
Leonardo Helicopters A109

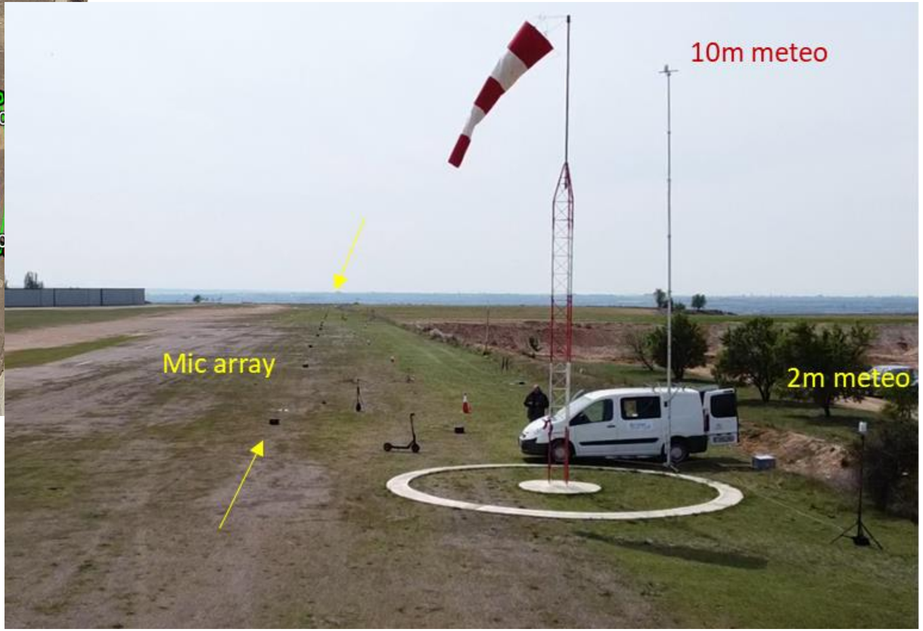
- Test site: De Peel (Netherlands)
- Test period: September 2023

Sikorsky S-92

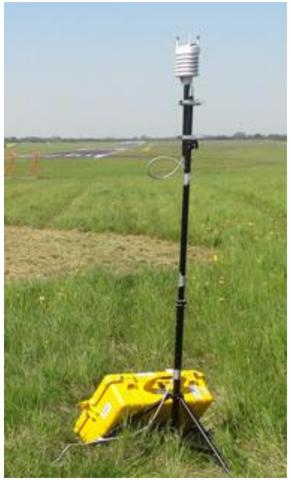
- Test site: Stavanger (Norway)
- Test period: September 2022

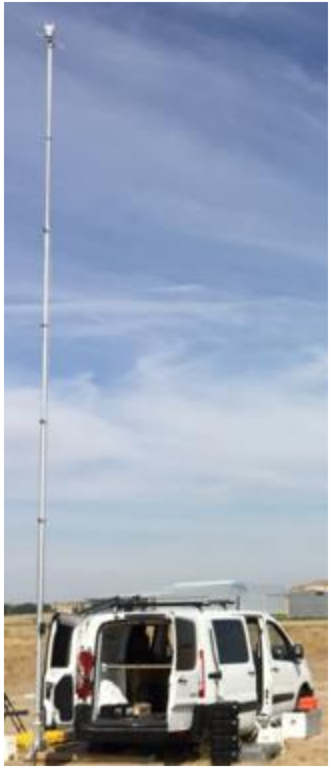
Test setup on ground



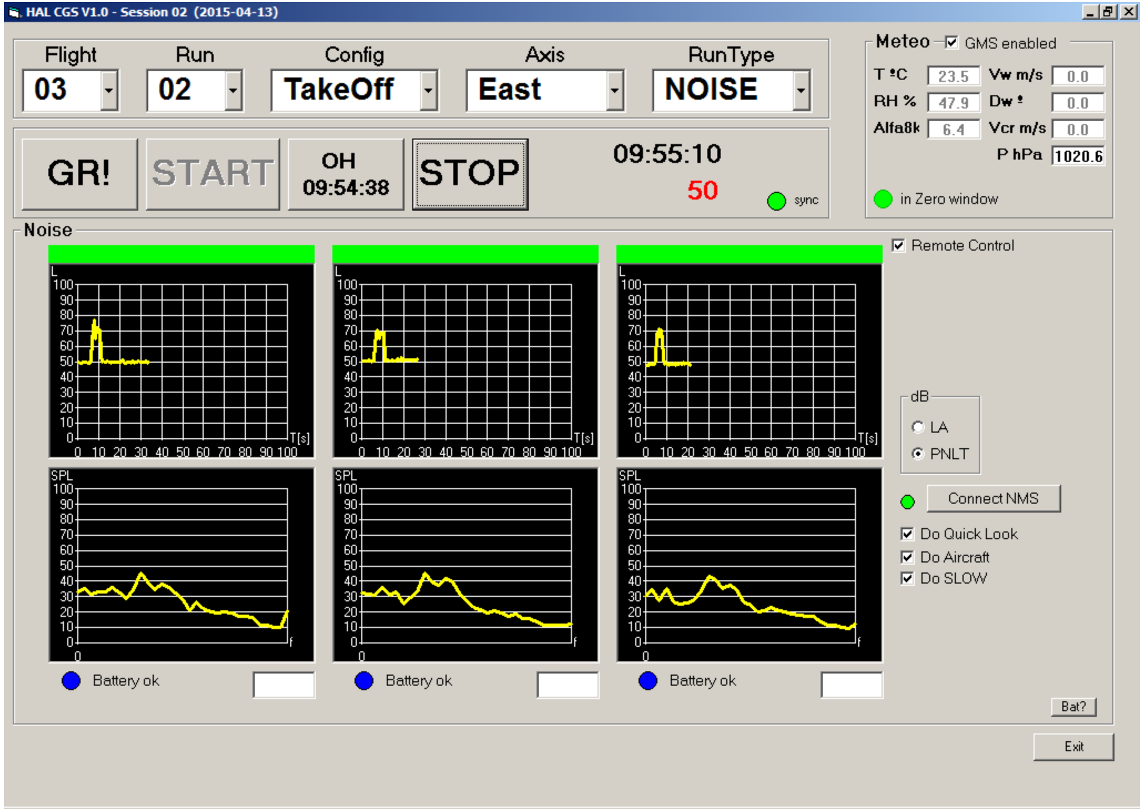


Ground-based measurement equipment



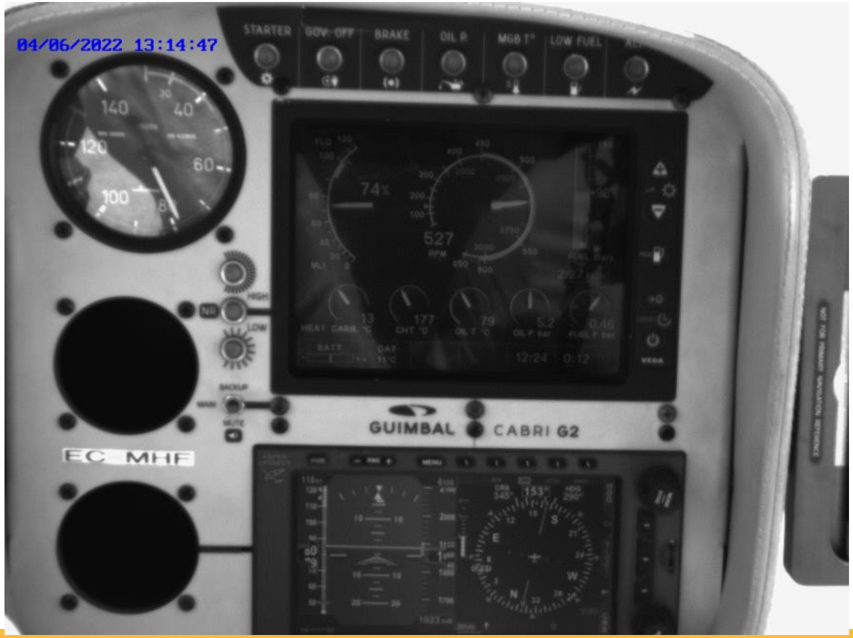


Ground-based Real-time test monitoring

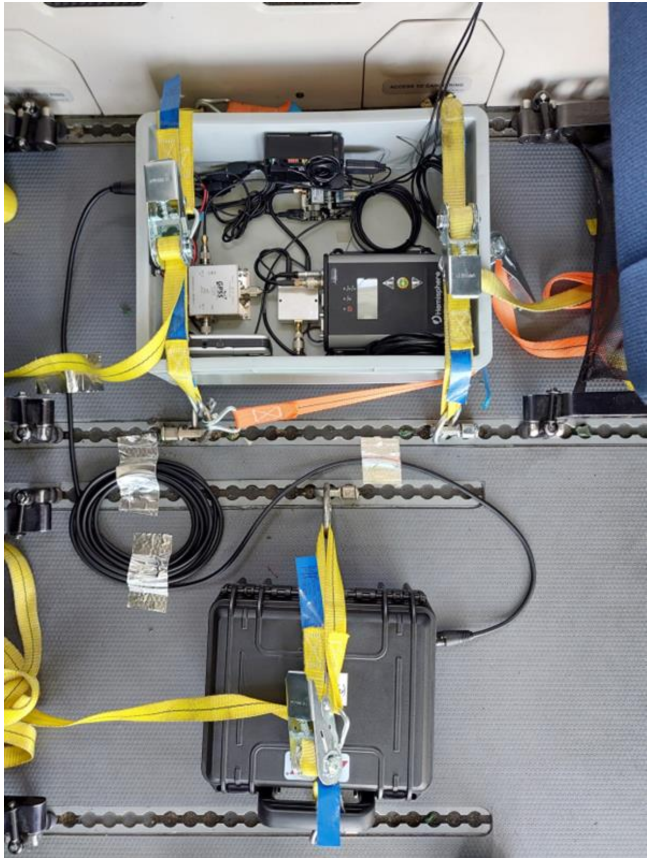


On-board measurement equipment

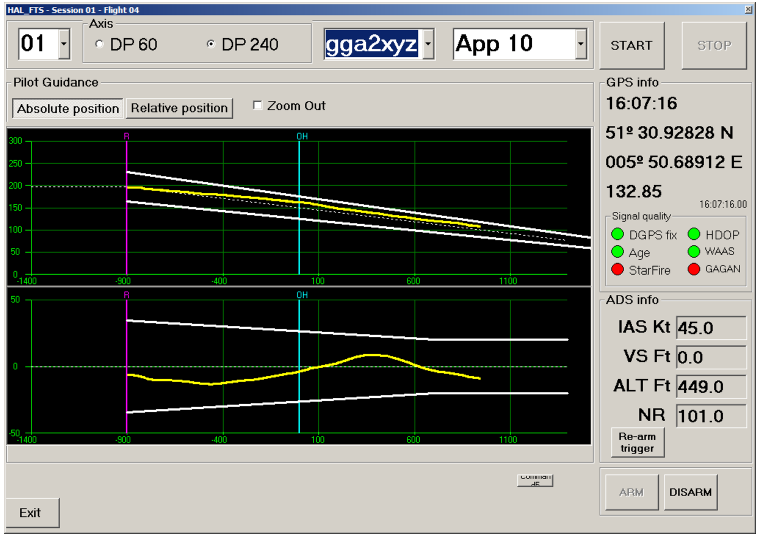
- → No connection to standard onboard instruments/FDR
- → Camara-based system developed to acquire data in real-time
- → Connected to Pilot Guidance System

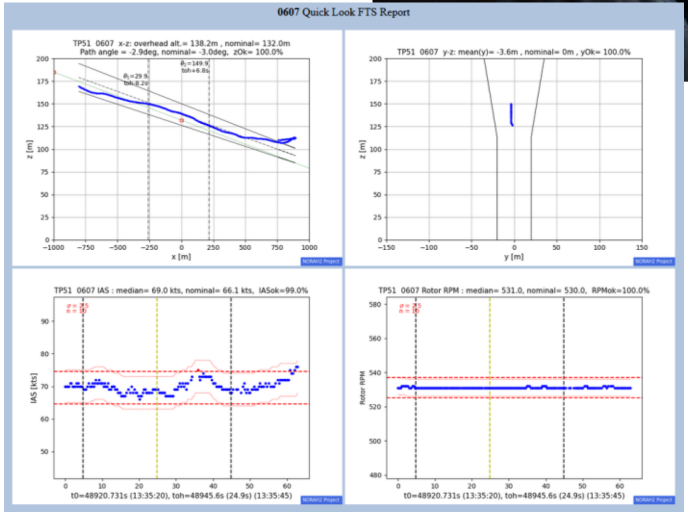


Flight Track System



Pilot Guidance and Quick-Look





EASA

Data quality checks

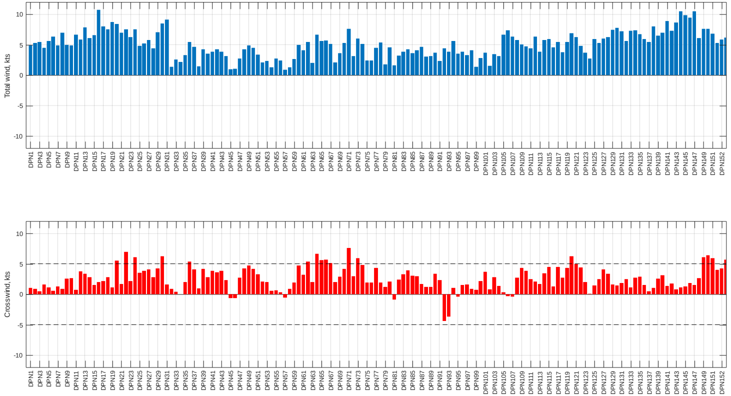
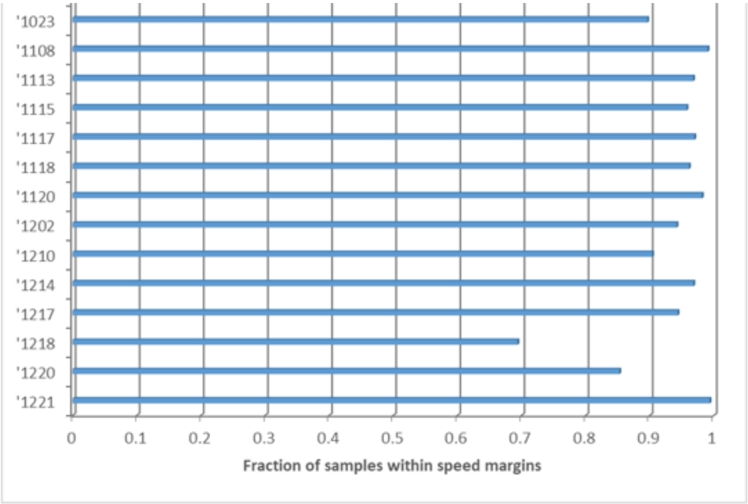
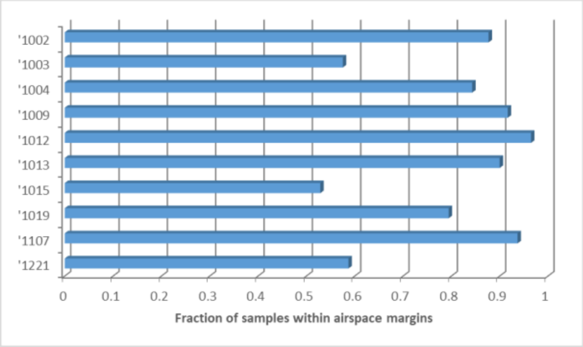
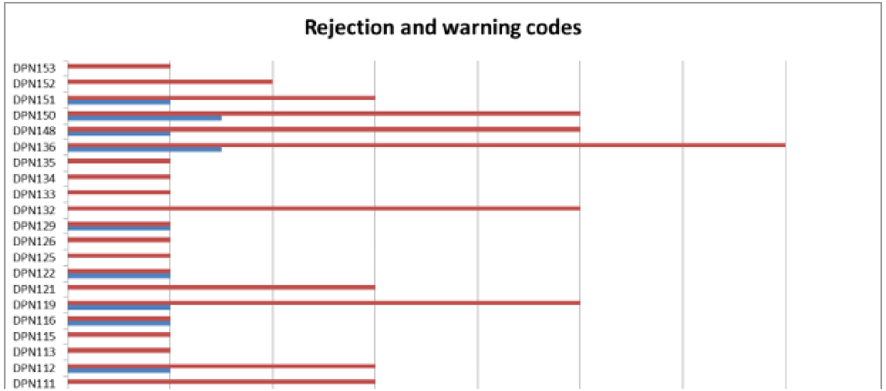


Figure 1: Total wind and cross wind in kts for all data points, limits indicated by dotted lines







EASA

Data analysis

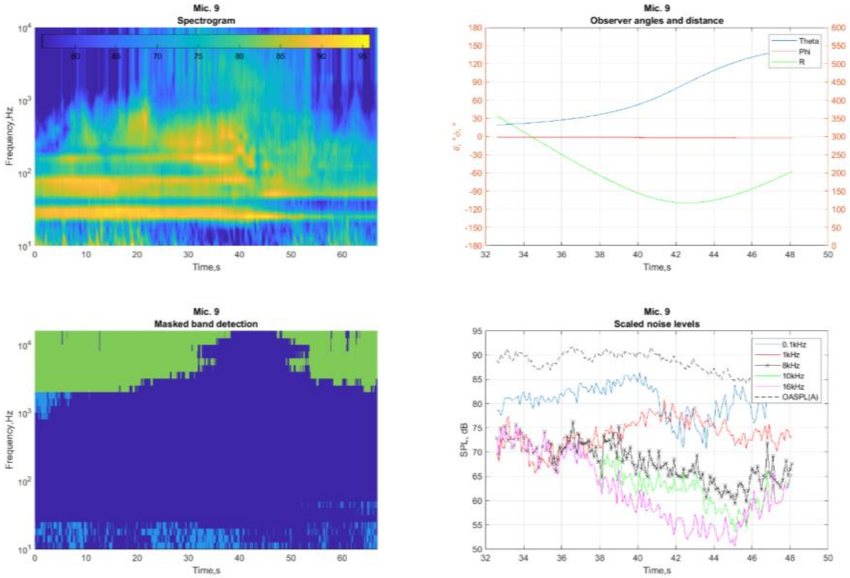
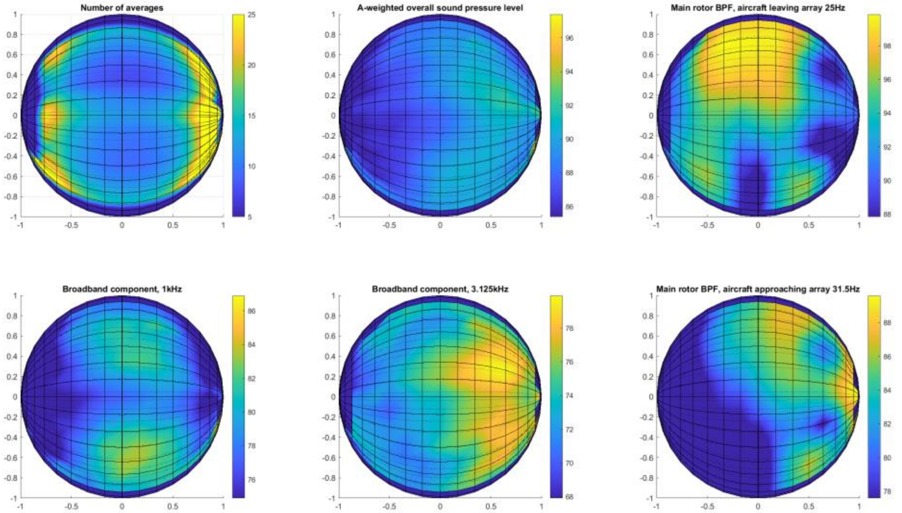


Figure 1: Spectrogram 1/3 octave band spectra every 0.1s [top left]; polar angle (theta), azimuth angle (phi) and distance from helicopter to microphone (R) [top right]; masked band detection, (dark blue = 3dB>background noise, light blue = masked and uncorrected, green = masked and reconstructed, yellow = not masked, equal energy correction) [bottom left]; scaled noise levels for several 1/3 octave band frequencies & A-weighted OASPL [bottom right]



Final hemisphere dataset for NORAH2

→ Sikorsky S92

	Speed (kts)	Angle º
Takeoff	85.3	10.9
	80.5	5.3
	79.5	7.7

	Speed (kts)	Angle º
Approach	78.8	-6.5
	53.0	-6.8
	104.6	-6.5
	80.7	-3.8
	53.5	-5.1
	106.1	-3.2
	79.3	-8.9
	54.4	-10.0
	80.2	-12.5

	Speed (kts)	Angle º
Flyover	133.9	0.0
	80.3	0.0
	105.0	0.0
	120.1	0.0

	Condition	Height (m)
Hover	HIGE	1.5
	HOGE	30
	Flight Idle	0
	Ground Idle	0

Overview of the NORAH2 model method and validation

This project is funded by the European Union's Horizon 2020 Programme

Methodology Overview

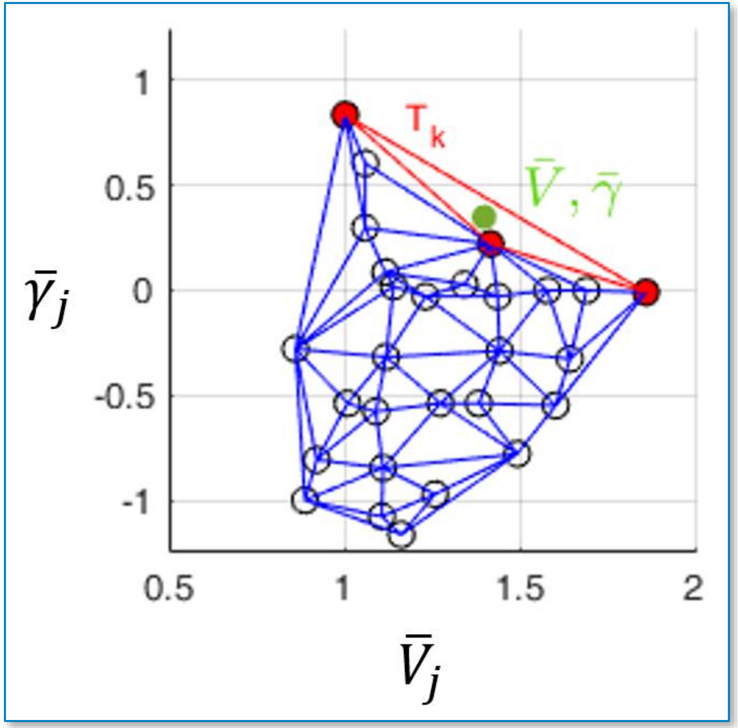
- → Hemisphere Interpolation
- → Ground Effect
- → Screening Effect

Hemisphere Interpolation

- Normalized angle: $\bar{\gamma}_j = F_{fc} \dfrac{\gamma_j}{\gamma_{max} - \gamma_{min}}$
- Normalized velocity: $\bar{V}_j = \dfrac{V_j}{V_{max} - V_{min}}$
- Angle-to-velocity ratio: F_{fc}=2
- Triangulation: Delaunay triangulation
- Interpolation:

$$\hat{L}_i(f_c, \varphi, \theta, V, \gamma) = 10 \log_{10}\left(\sum_{j \in T_k} \frac{10^{\frac{\tilde{L}_{i,j}(f_c,\varphi,\theta)}{10}}}{\delta_j} \Big/ \sum_{j \in T_k} \frac{1}{\delta_j} \right)$$

- where: $\delta_j = \sqrt{(\bar{\gamma} - \bar{\gamma}_j)^2 + (\bar{V} - \bar{V}_j)^2}$



Flat ground model (NORAH 1)

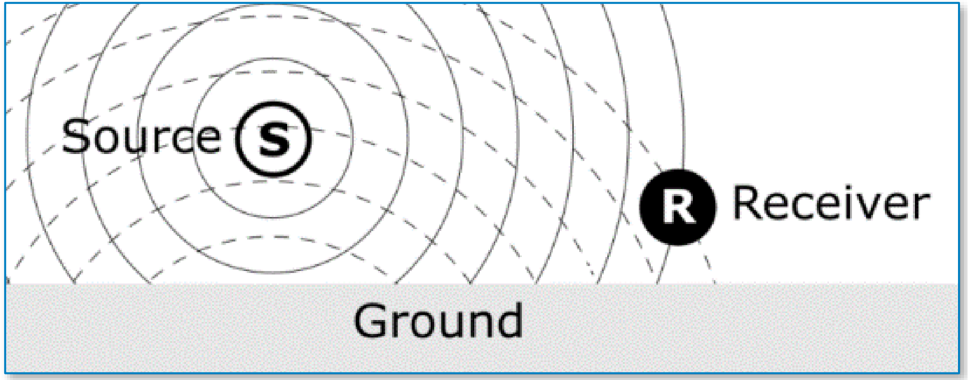
→ Ground Reflection

Chien & Soroka:

$$\Delta L_g = 10\, log\left\{1 + \frac{r_1^2}{r_2^2}|Q|^2 + 2\frac{r_1}{r_2}|Q|I\right\}$$

$$Q = R_p + \left(1 - R_p\right)F(d)$$

$$I = \frac{sin\left(\frac{0.727 f_C \Delta R}{c}\right)}{\frac{0.727 f_C \Delta R}{c}} cos\left(\frac{6.325 f_c \Delta R}{c} + \psi\right)$$



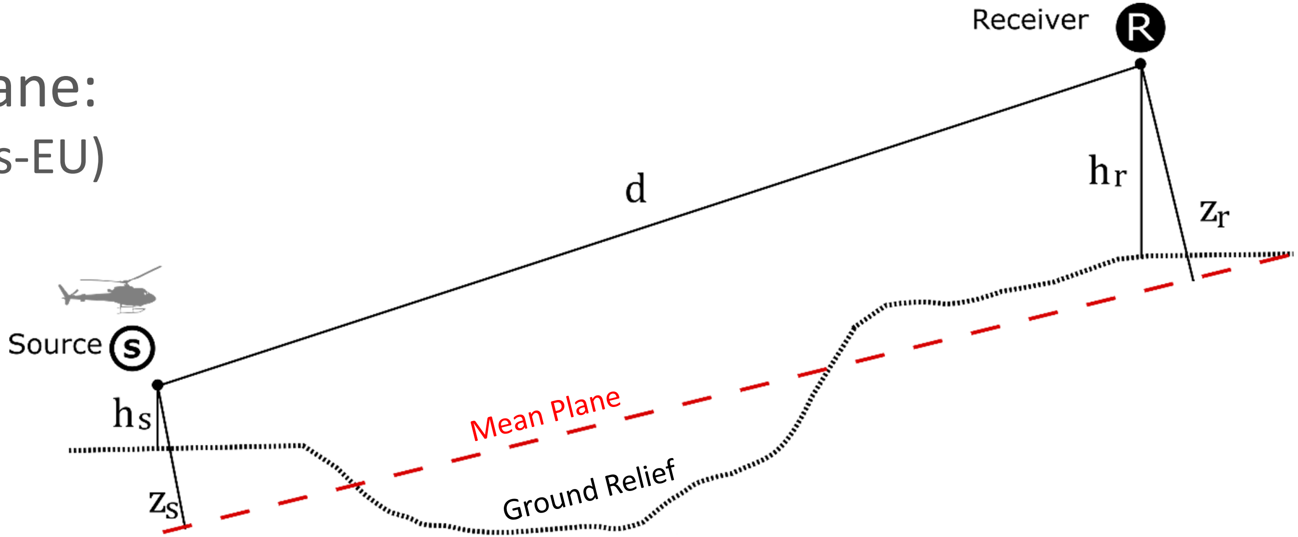
→ Ground Impedance

Delany & Bazely:

$$Z_s = \left\{1 + 0.0511\left(\frac{f}{\sigma}\right)^{-0.754}\right\} + i\left\{0.0768\left(\frac{f}{\sigma}\right)^{-0.732}\right\}$$

Varying Ground (NORAH 2)

- Mean Ground Plane:
  (same as for Cnossos-EU)



- Mean Ground Surface:

$$\bar{\sigma} = 10^{\left[\frac{1}{\sum d_i} \sum_{i=1}^{n} (d_i * \log(\sigma_i))\right]}$$

EASA

Ground Type Classes (Cnossos-EU)

with corresponding sigma values (σ)

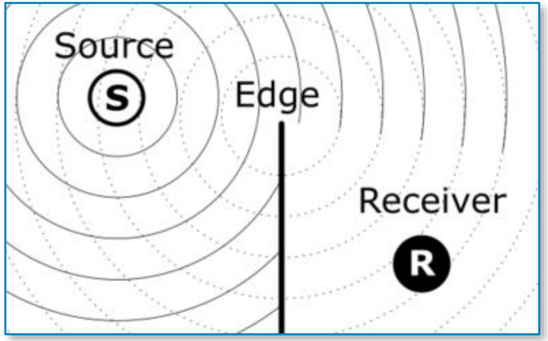
Description	Class	$(kPa \cdot s/m^2)$
Very soft (snow or moss-like)	A	12.5
Soft forest floor (short, dense heather-like or thick moss)	B	31.5
Uncompacted, loose ground (turf, grass, loose soil)	C	80
Normal uncompacted ground (forest floors, pasture field)	D	200
Compacted field and gravel (compacted lawns, park area)	E	500
Compacted dense ground (gravel road, car park)	F	2000
Hard surfaces (most normal asphalt, concrete)	G	20 000
Very hard and dense surfaces (dense asphalt, concrete, water)	H	200 000

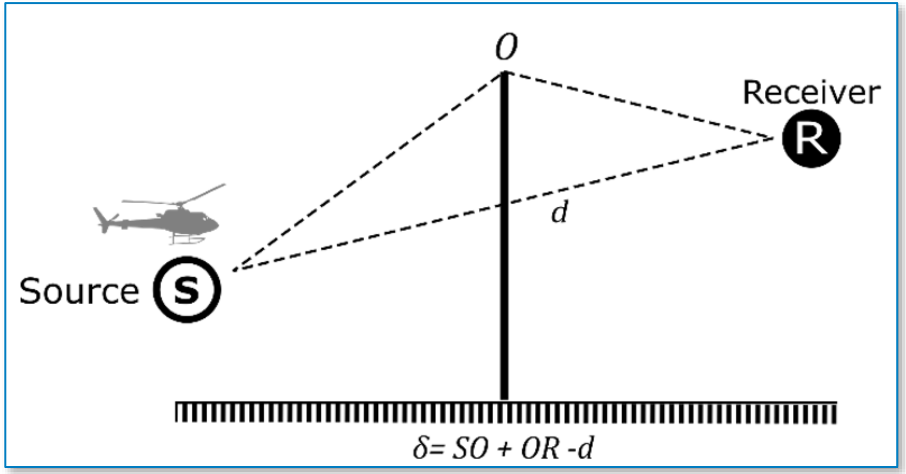
Screening effect

→ Edge Diffraction theory (based on Maekawa) (same as in Cnossos-EU)

$$\Delta L_{pd} = \begin{cases} 10\, C_h \cdot \log_{10}\left(3 + \frac{40}{\lambda} C''\,\delta\right) & if\ \frac{40}{\lambda} C''\,\delta \geq -2 \\ 0 & otherwise \end{cases}$$

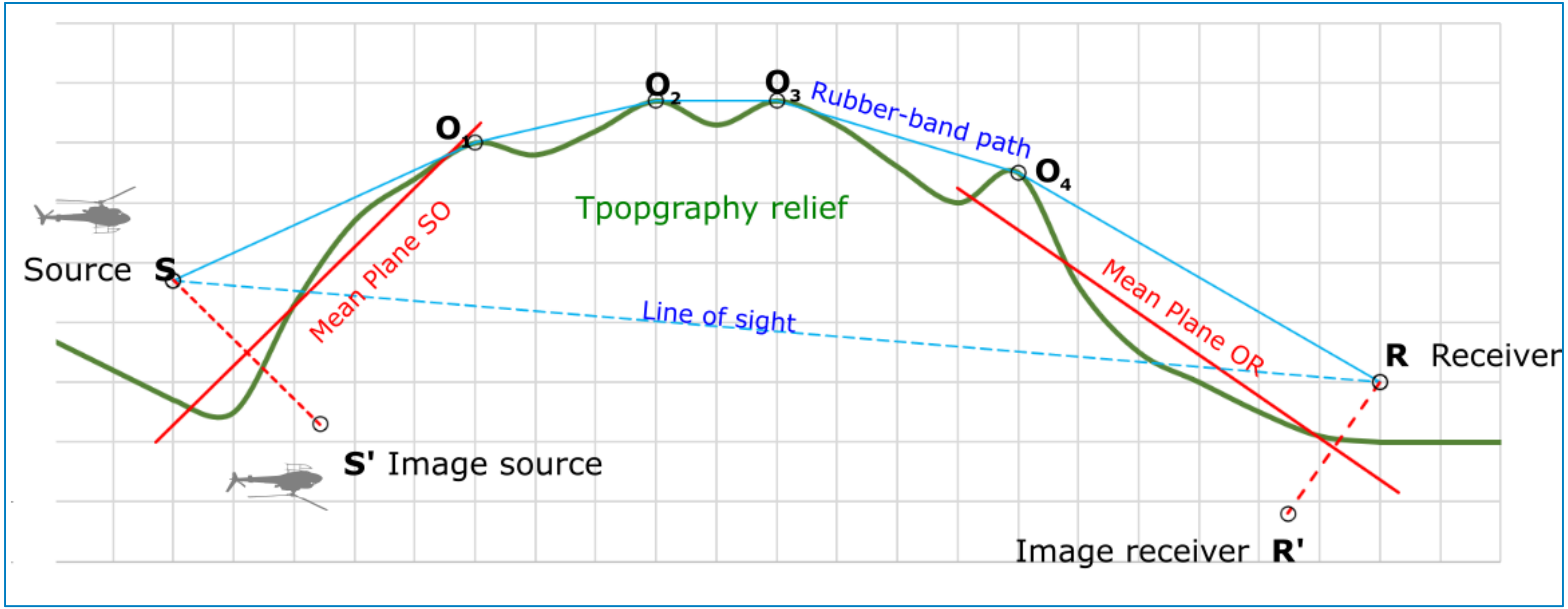
δ is the path difference





Multiple Screening by topography

- Ground effects are added on source- and receiver side
- Equivalent to screening effects in Cnossos-EU



Validation Overview

- **Source**

  Comparison with certification levels
  - By measurements
  - By simulation
- **Method**
  - Peer review
  - Comparison with more advanced method
- **Prototype Implementation**
  - Peer review

EASA

Source Validation

→ Measurement setup; repeated certification levels

Helicopter	Operation	Unit	Measured	Certification	Difference
Guimbal Cabri G2	Flyover	SEL	75.8	75.7	0.1
Agusta A109	Take-off	EPNdB	92.4	92.4	0.0
Agusta A109	Flyover	EPNdB	89.8	88.8	1.0
Agusta A109	Approach	EPNdB	91.7	90.1	1.6
Sikorsky S-92	Take-off	EPNdB	95.3	94.6	0.7
Sikorsky S-92	Flyover	EPNdB	98.7	97.2	1.5
Sikorsky S-92	Approach	EPNdB	96.9	97.5	-0.6

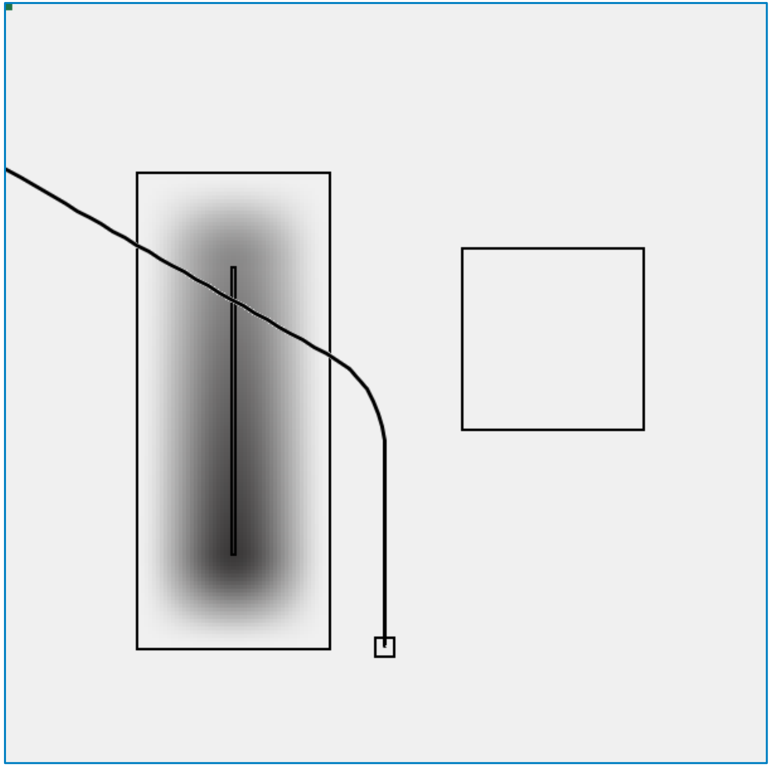
Calculation Validation

→ NORAH 2.0 calculations predict the certification levels

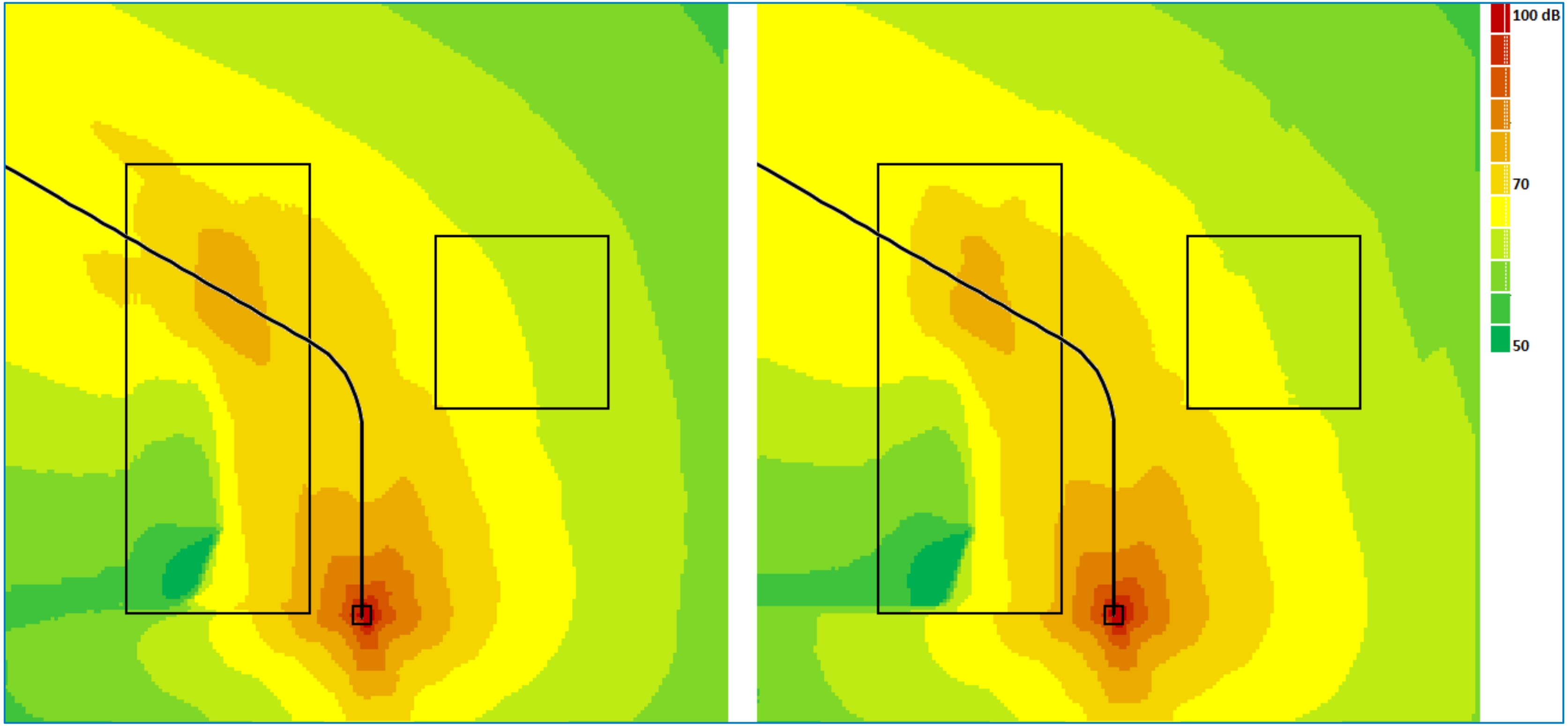
Helicopter	Operation	Unit	Predicted	Certification	Difference
Sikorsky S-92	Take-off	EPNdB	96.0	94.6	1.6
Sikorsky S-92	Flyover	EPNdB	99.0	97.2	1.8
Sikorsky S-92	Approach	EPNdB	97.4	97.5	-0.1

Validation of propagation effects

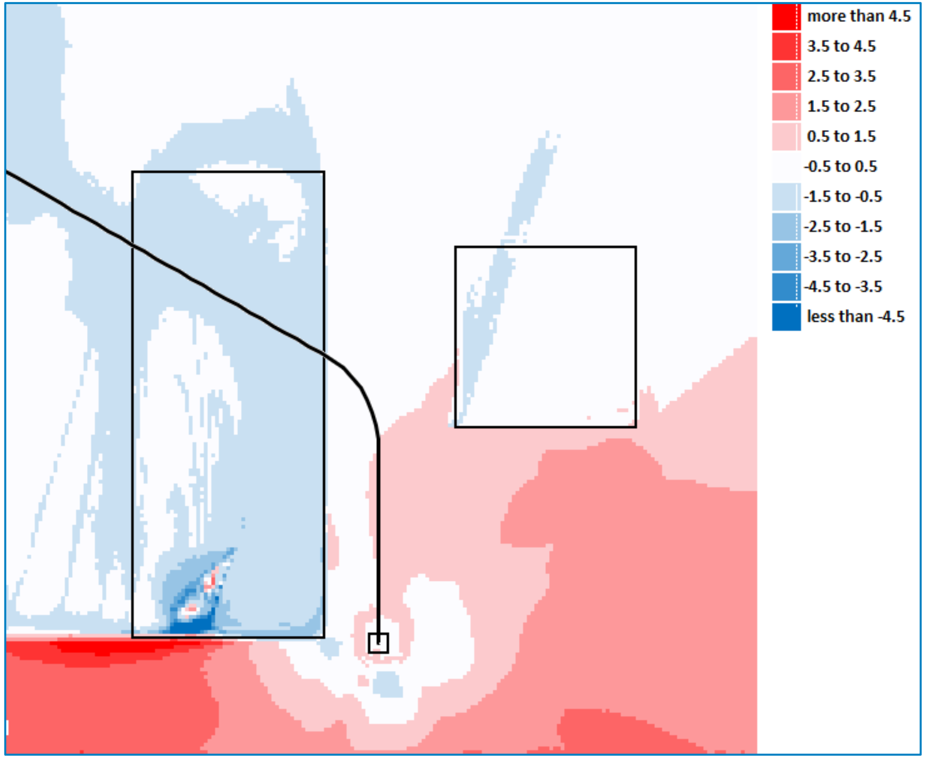
- Comparison with Nord 2000
  - Replaced program module in Norah Prototype
- Test setup
  - A 2x2 km area
  - Generally soft ground
  - Some hard ground (the square)
  - A mountain ridge (the rectangle)
  - A helipad (square marker)
  - A Take-Off with R22 helicopter (the flight track)



NORAH 2.0 (left) vs. Nord 2000 (right) SEL [dB]



Difference: Nord 2000 minus NORAH 2.0



- Observations:
  - General agreement, within ± 1 dB
  - Larger deviations in areas with very high screening effects ± 10 dB
  - 2-3 dB deviation for long-distance ground-to-ground propagation
- Evaluation:
  - Good agreement for situations of importance to noise mapping
  - Some deviations in less important situations with strong screening or long-distance ground-to-ground propagation

Validation Conclusion

- → Agreement with official certification levels
- → Agreement with Nord 2000, for the important situations

- → Peer reviewing of method (within the consortium)
- → Peer implementation of core methodology

- → Updates related to background literature

Benefits of the project, training, access to the model

The NORAH project will enable…

- → Noise model developers to enhance the capability of their tools to cover rotorcraft noise
- → Member States to quantify helicopter noise as part of the END reporting and adjust their noise action plans accordingly
- → Local planners to estimate the noise generated by drones and eVTOLs ahead of their entry into service
- → Further research in the field of aircraft noise modelling and mitigation

Project results will be shared on the EASA website

This includes:

- → The rotorcraft noise modelling methodology
- → The data acquisition process
- → The NORAH2 software prototype
- → Noise hemispheres
- → Tutorials (videos) on how to use the software prototype

EASA

What will happen next?

March/April 2024	Final project deliverables will be published on the EASA website
April 2024	EASA will present the project outcome to ECAC AIRMOD (in charge of maintaining / developing aircraft noise modelling guidance in Europe)
Q3 2024	EASA will present the project outcome to ICAO CAEP MDG (in charge of maintaining aircraft noise modelling guidance at ICAO level)
Q3 2024 to Q1 2025	EASA will partner with candidate Member States to generate strategic noise maps at major European heliports
Q4 2024	EASA will publish additional noise hemispheres for drones and/or eVTOLs
2025+	EASA will engage with EC to integrate the NORAH rotorcraft noise modelling methodology into Directive 2002/49/EC

Questions and answers

Question and Answers

→ For sending questions and input, please use the slido app, which is also accessible through WebEx:

- www.slido.com
- event code: 9872020
- passcode: rk502h

EASA

Concluding Remarks

This project is funded by the European Union's Horizon 2020 Programme

Upcoming EASA research & innovation events

March 12th
Integrity improvement of rotorcraft main gear boxes (**MGB**)
Final dissemination event (webinar)

March 13th
Assessment of environmental impacts – rotorcraft (**NOISE**)
Final dissemination event (webinar, training for users)

March 19th
Market-based Measures – AERO-MS (**MbM**)
Final dissemination event (webinar); Training event on 20 March

April 23rd
New standards for drones and U-Space (**SHEPHERD**)
Final dissemination event (webinar)

April 23-24
Mental Health of Pilots and ATCOs (**MESAFE**)
Final dissemination event during EASA Mental Health Conference

April 25th
Helicopter underwater escape #2 (**HUE2**)
Final dissemination event (webinar)

Research agenda – future research topics

Environment
- New SAF production pathways

Security impacting safety
- AI aspects, conflict zones

Artificial intelligence
- Human factors

Data for Safety
- Research on sfuture uses cases

Health / medical
- Obstructive sleep apnea, high air space operations

Automation
- Impact on responsibilities of flight crews and air traffic controllers

ATM / ANS
- Performance of ground equipment, airspace classifications

Air operations
- Flight time limitations for emCO

Drones
- BVLOS operations

PNT

Icing

European Union Aviation Safety Agency

Thank you for joining this webinar!

Environmental Research - Rotorcraft Noise | EASA (europa.eu)