A NOISE MODELLING APPROACH FOR MULTICOPTER TYPE UNMANNED AIRCRAFT SYSTEMS

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Acoustic UAS Research at DLR (incomplete)

- **Technical Acoustics Department**
- **M**easurement of UAS noise
- **M**odelling of UAS noise, high fidelity (CAA) and **semi-empirical methods**
- **P**rediction of UAS noise

- **Projects**
- Horizon UAM – Investigate perspectives for air taxi systems (Urban Air Mobility)
  - Lead: Institute of Flight Guidance (BS, Aeronautics)
  - No explicit acoustic measurements, development of a celluar based app to measure and assess annoyance

- KoBoL : Koordinierte autonome Boden-Luft Systeme für eine neue Rettungsmobilität
  (Coordinated surface-air-systems for a new rescue mobility)
  - Lead: Institute of Transportation Systems (B, BS, Transport)
  - Annoyance of UAS systems, explicity measurements for use in laboratory studies on nocturnal drone operations on sleep quality

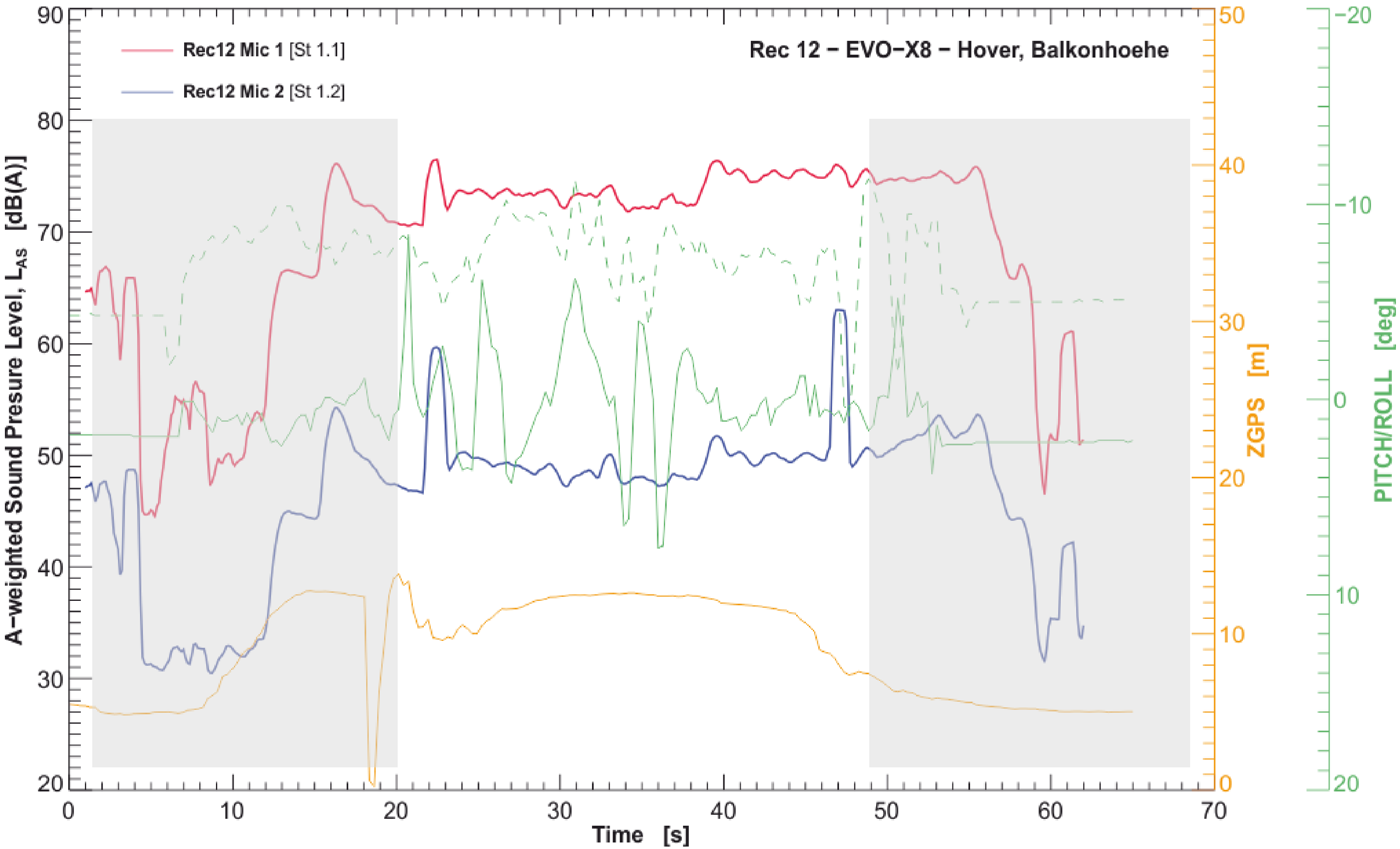
KoBol

- **Manoeuvers**
- Delivery of goods from original altitude and return to original altitude
- Overflight/passage for delivery or inspection
- Delivery from one point of delivery to the next, not reaching original height again

UA-model	Evo-X8 heavy	Octocopter
Rotors	8	
No. of blade per rotor	2	
Blade diameter	24“	24 x 4.4
Length [m]	0.170	
Width [m]	0.170	
MTOM [kg]	20	
Flight software	PX4.1 13.1	

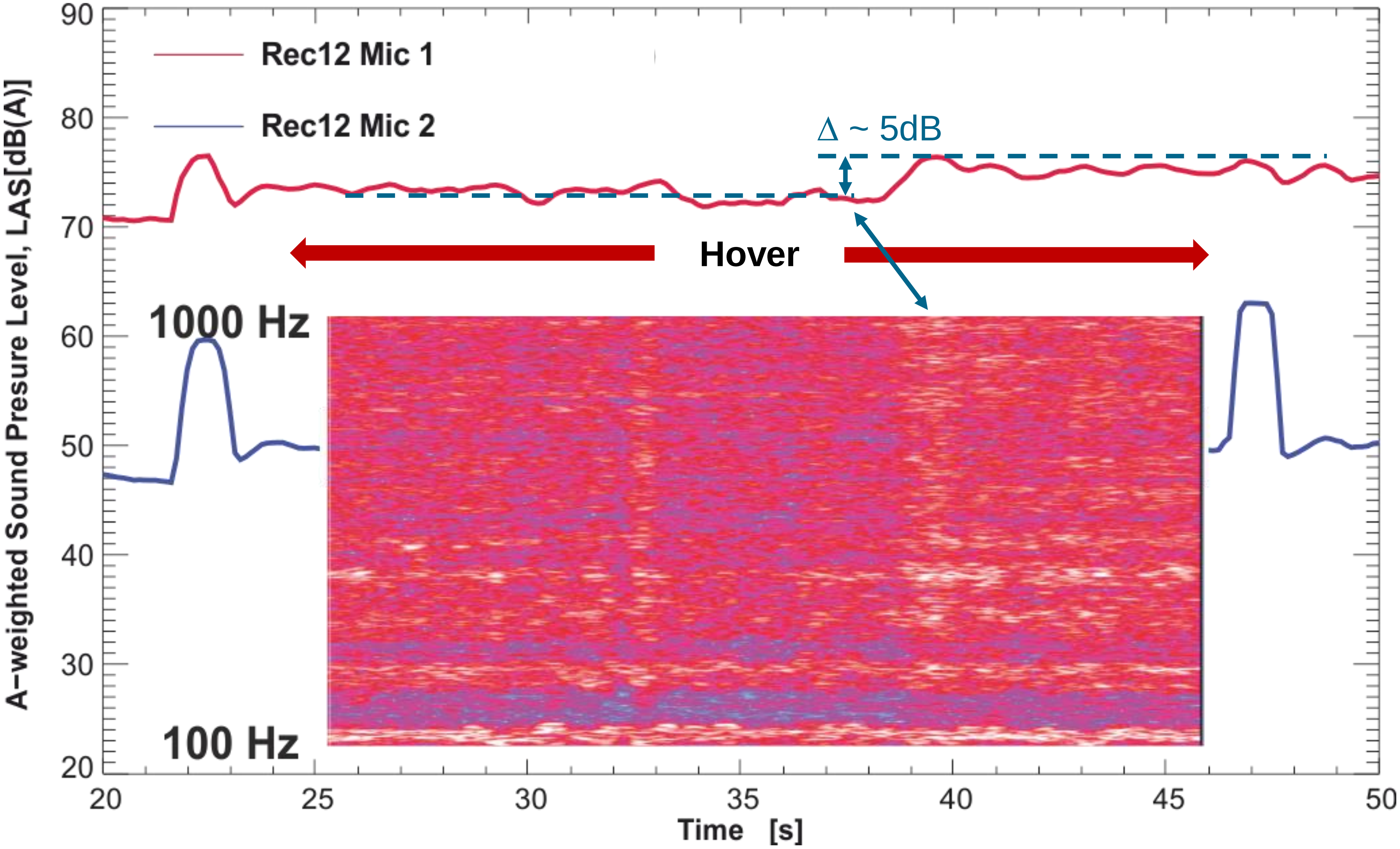
- **Drone / UAS**

UAS Flight Characteristics



Everything moves at any time even though the UAS hovers.

UAS Noise Characteristics



Low frequency noise

- 100 Hz to 1 kHz
- Strong tonal noise components visible

- Despite constant operating conditions (hover) a significant level increase is observed
- Wind speed, mean velocities and gusts, drive the noise levels

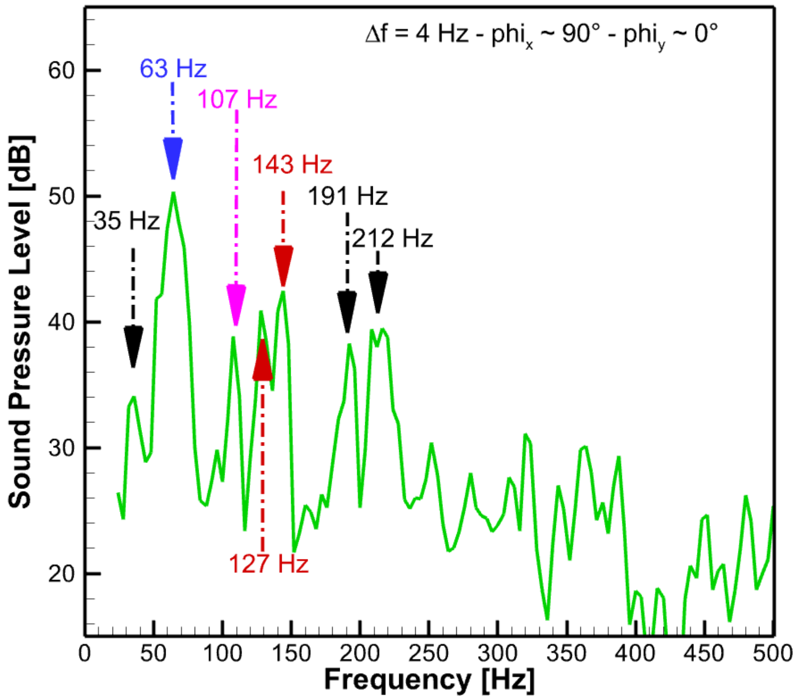
Noise Modelling

- **Target**
  - Provision of representative tonal and broadband sound pressure level spectra and directivities
  - Coupling of the noise model with a propagation tool to acount for propagation effects

  - **Representative**
    - Modeling of quadcopter and octocopter type UAS (not the least driven by availability)
    - Separate modeling of tonal and broadband noise components
    - Account for operating parameters like
      - rpm
      - thrust
      - flight speed and
      - meteo effects
- Selected vehicles: evo-X8 heavy octocopter and Holybro quadcopter

Octocopter: Tonal Noise

Octocopter, V_{UAS} = 10 m/s



Head wind

Rotor#	rpm [min-1]	rotation [Hz]
0	1598	27
1	1912	32
2	1931	32
3	2181	36
4	1909	32
5	2092	35
6	1820	30
7	1899	32

Tail wind

Rotor#	rpm [min-1]	rotation [Hz]
0	1666	28
1	1964	33
2	1914	32
3	2146	36
4	1852	31
5	2059	34
6	1860	31
7	1992	33

	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7
Narrow peak frequency [Hz]	35	63	107	127	143	191	212
[1/min]		BPF		2BPF		3BPF	
			2BPF of 27 Hz		2BPF of 36 Hz		4BPF of 27 Hz

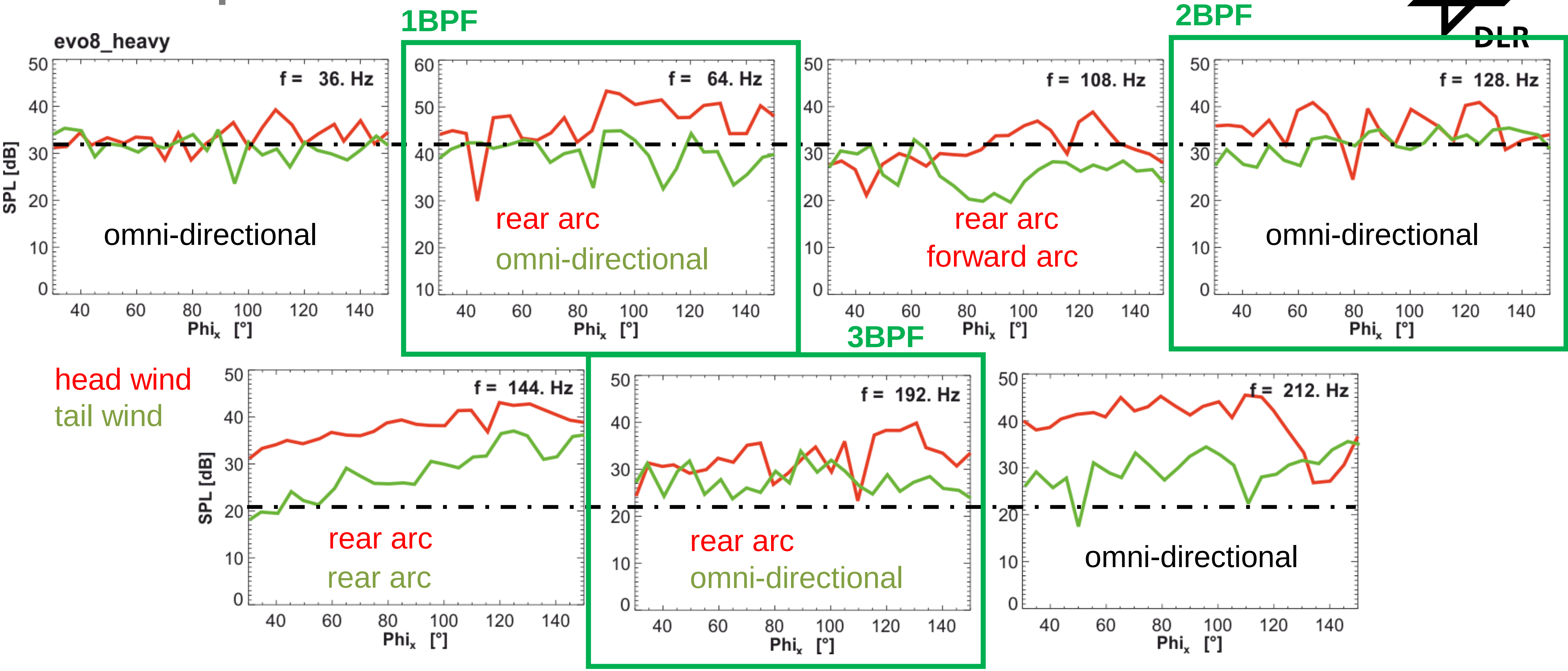
- **BPF pattern will be used for prediction: SPL(2BPF) =SPL(BPF) -8dB and SPL(3BPF)= SPL(BPF) -10dB**

$$M_H = \frac{1}{c}\sqrt{\left(\frac{\pi D N_P}{60}\right)^2 + v^2}$$

- Tonal noise is predicted on basis Dobrzynski's work: "Ermittlung von Emissionskennwerten für Schallimmissionsrechnungen an Landeplätzen", DLR report IB 129-94/17
- Parameter: helical blade tip Mach number and blade loading
- Rotor/engine: blade number, blade diameter and number of rotors, power, rpm

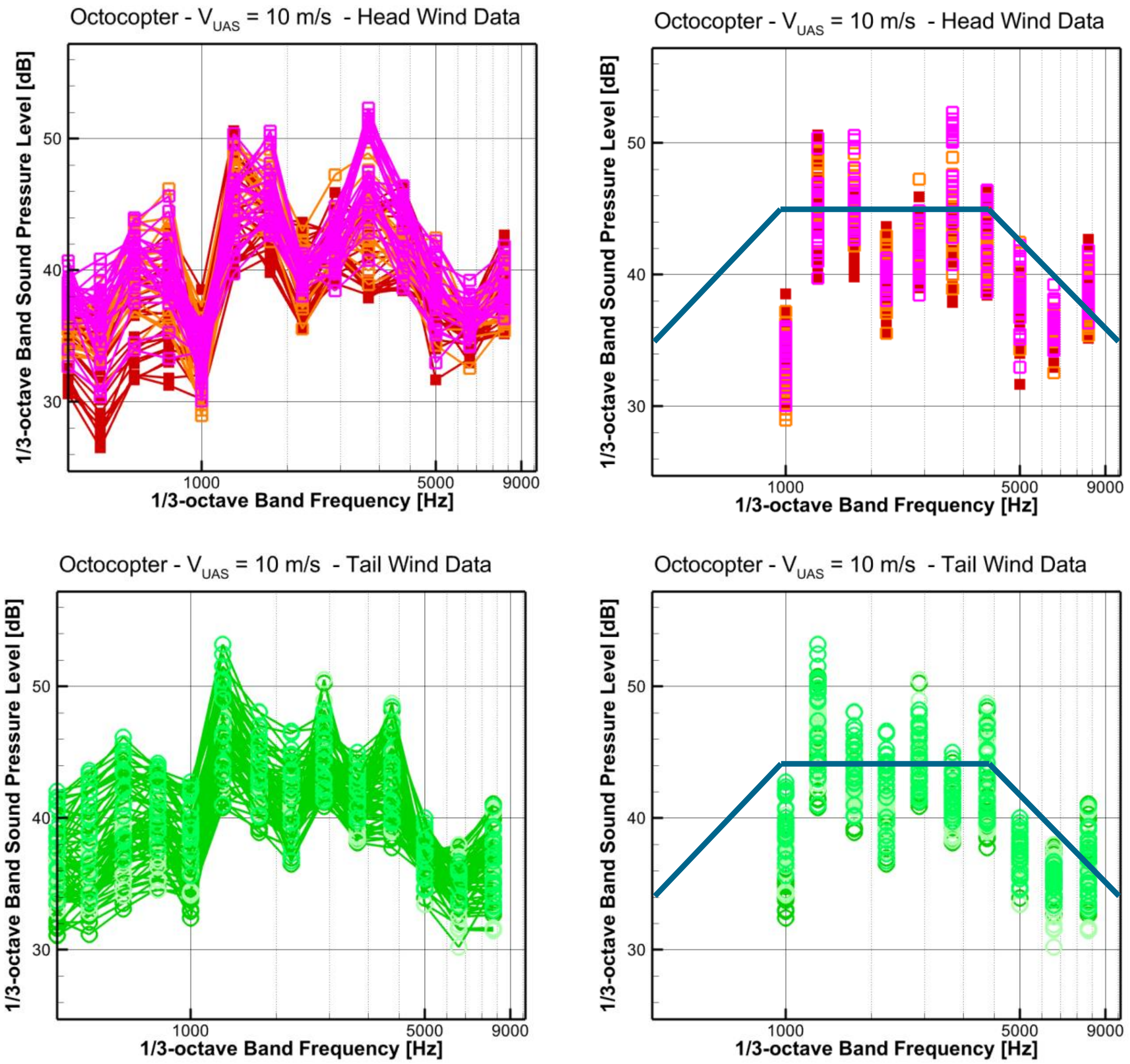
$$c_{P,B} = \frac{c_P}{n_B} = \frac{1000 * P}{\rho\left(\frac{N_P}{60}\right)^3 D^5 n_B}$$

Octocopter: Directivities



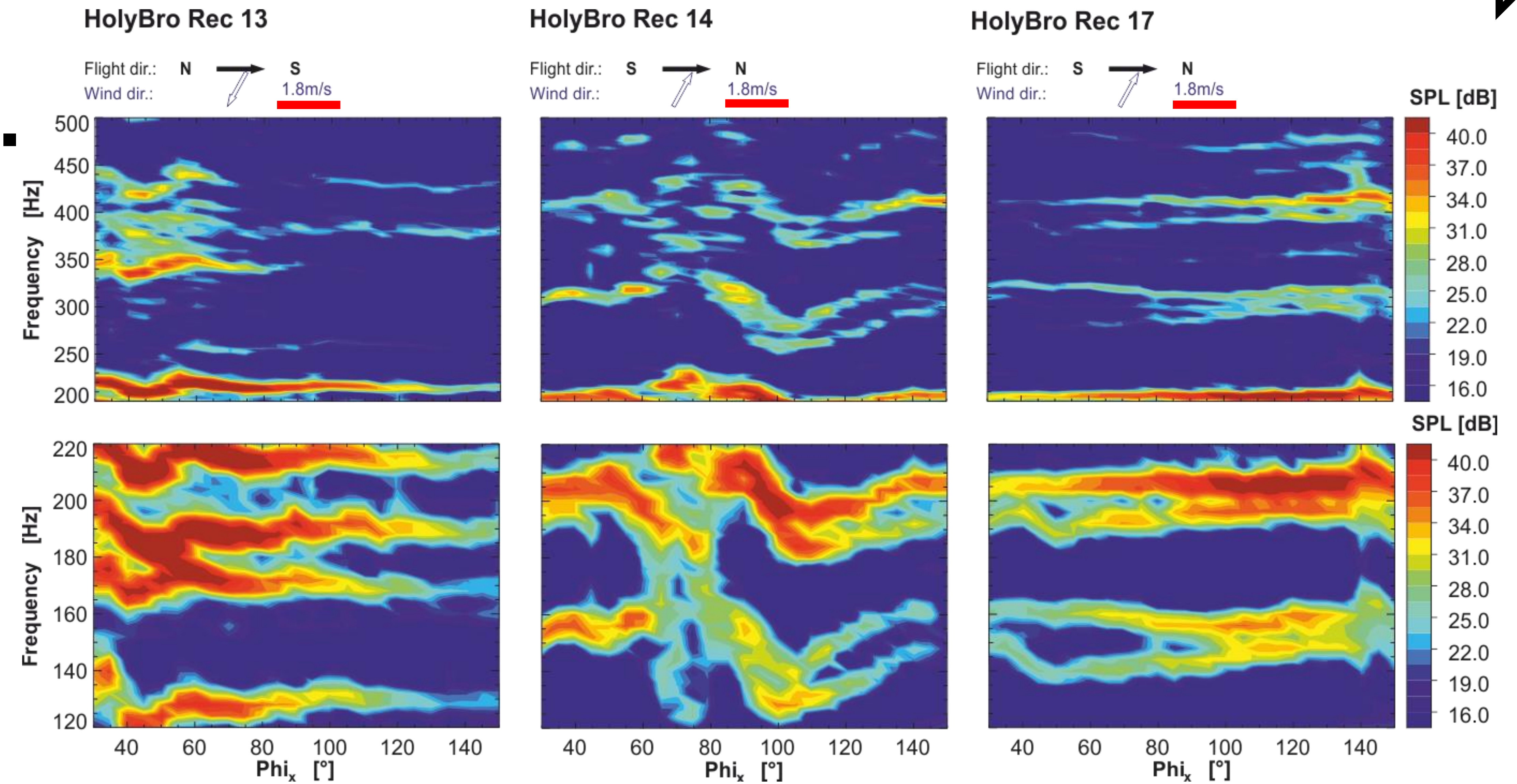
- Moderate rear arc directivity for head wind condition
- Omni-directional directivity for tail wind

Octocopter: Broadband Noise



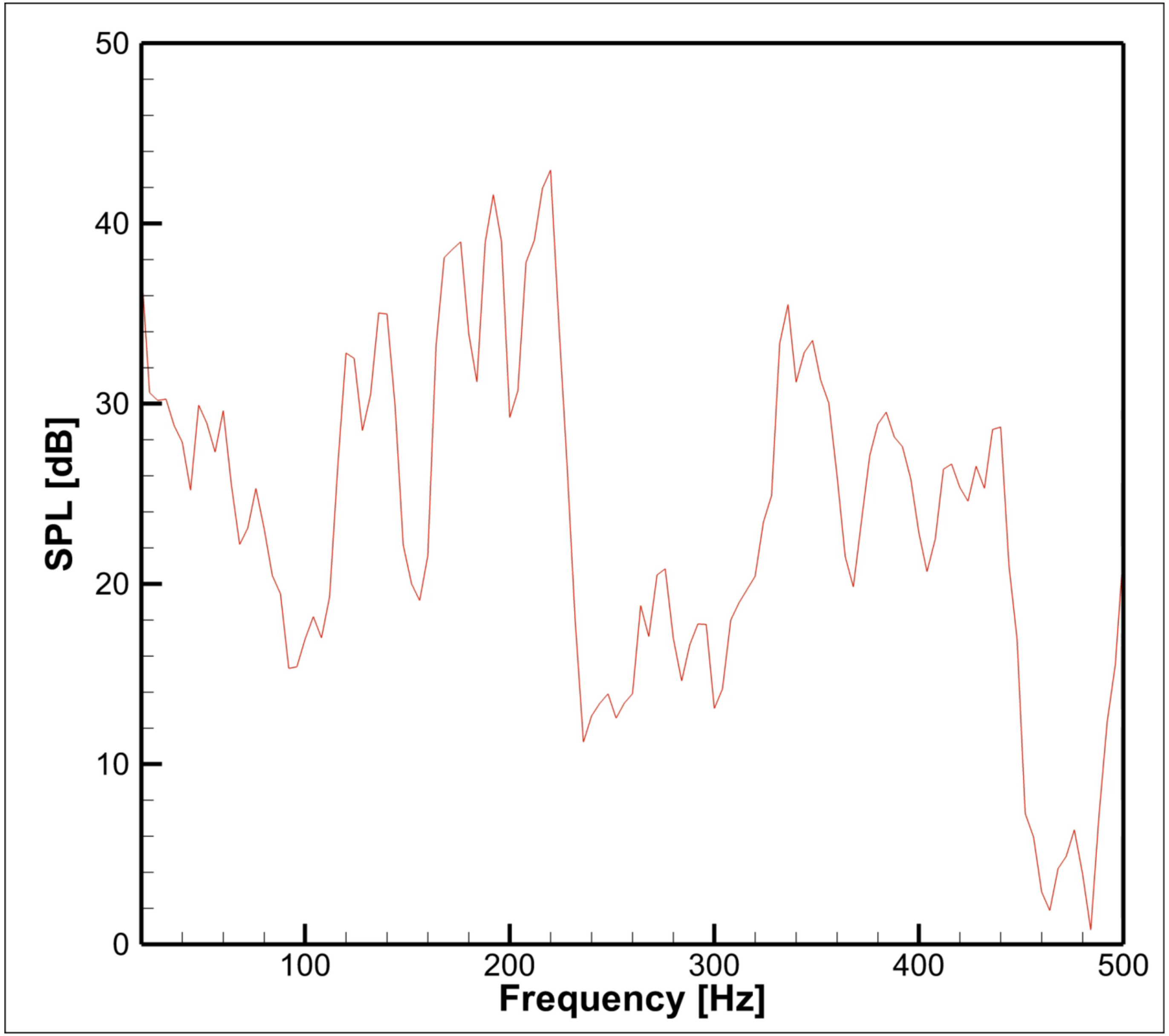
- Broadband noise model
  - 400 Hz to 1250 Hz
    linear increase from 35 dB to 45 dB
    $SPL(f) = 0.018*f_m + 30.28$ dB
  - 1250 Hz to 4000 Hz
    constant 45 dB
  - 4000 Hz to 10 kHz
    linear decrease from 45 to 35 dB
    $SPL(f) = -0.00167*f_m$ 38.32 dB
  - No consideration of wind direction

Quadcopter: Tones and Directivities



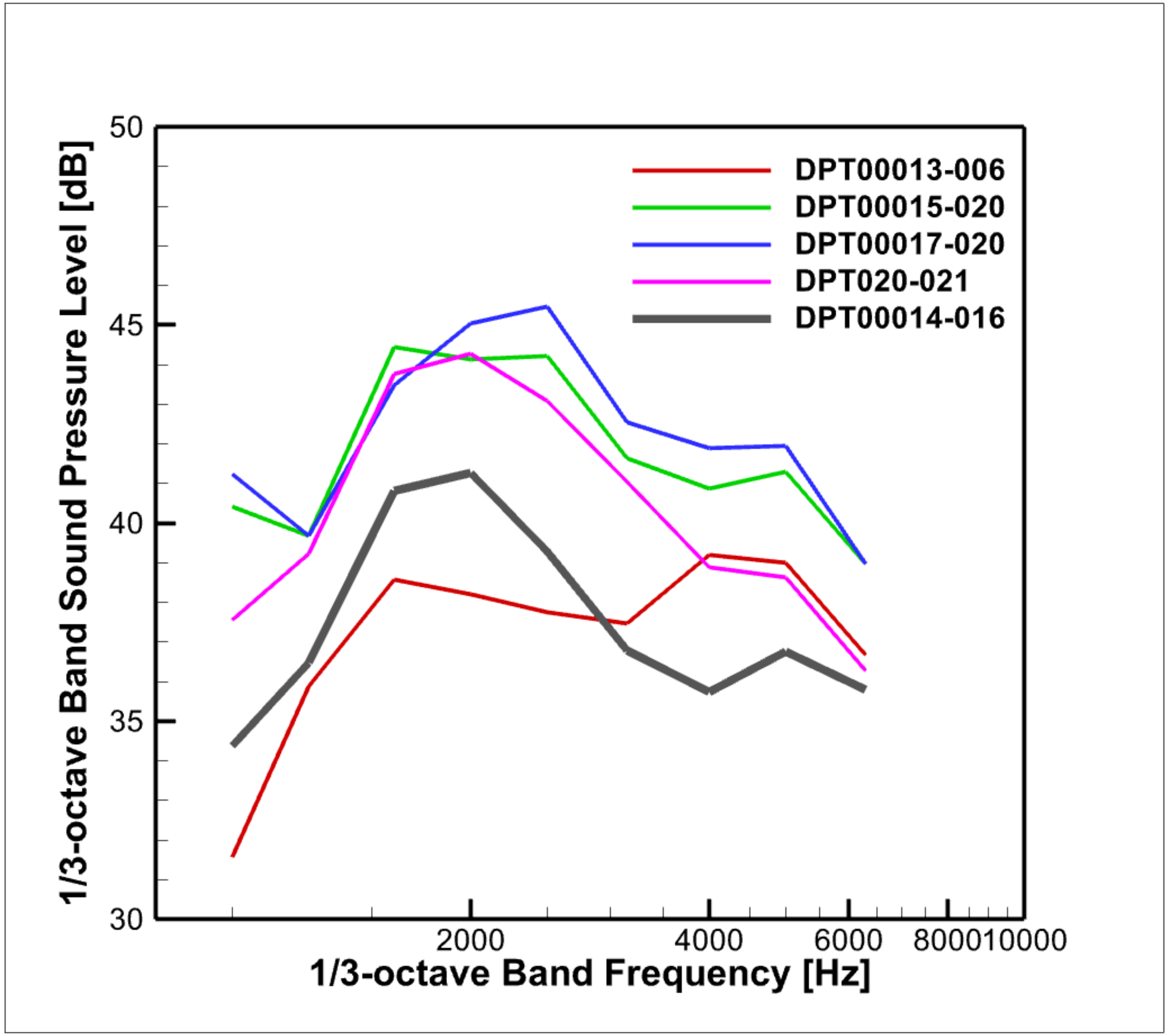
Quadcopter: Tonal Noise

- Very complex tone combinations
- Tone levels depend on wind influence
- No option for modelling due to missing rpm-data as link between UAS operation and acoustic signal
- Effect of rotor rotation pattern



Quadcopter: Broadband Noise

- Spectral shapes for different flyovers look similar
- Significant level differences, up to now not fully understood
- Polynomial approximation of broadbad noise



Conclusions / Outlook

- UAS noise consists of complex tonal patterns and a broadband component
  - Tones: modelling on basis of measured tones and recorded rpm data
  - Broadband: modelled on basis of constant band SPL, approx. 800 Hz to 8 kHz
- Operational data recording: basically two type of operating systems exist, both SBC based. Availability of data dependent on individual configuration.
- Link of acoustic and operational data is difficult due to inconsistent op-data

- Final prediction scheme must be able to handle tone interferences and wind (instationary outer effects‘) influence
- Concept: Markus Lummer, „Installation: numerical investigation“, CEAS Aeronautical Journal (2019) 10:159–178, https://doi.org/10.1007/s13272-019-00382-5

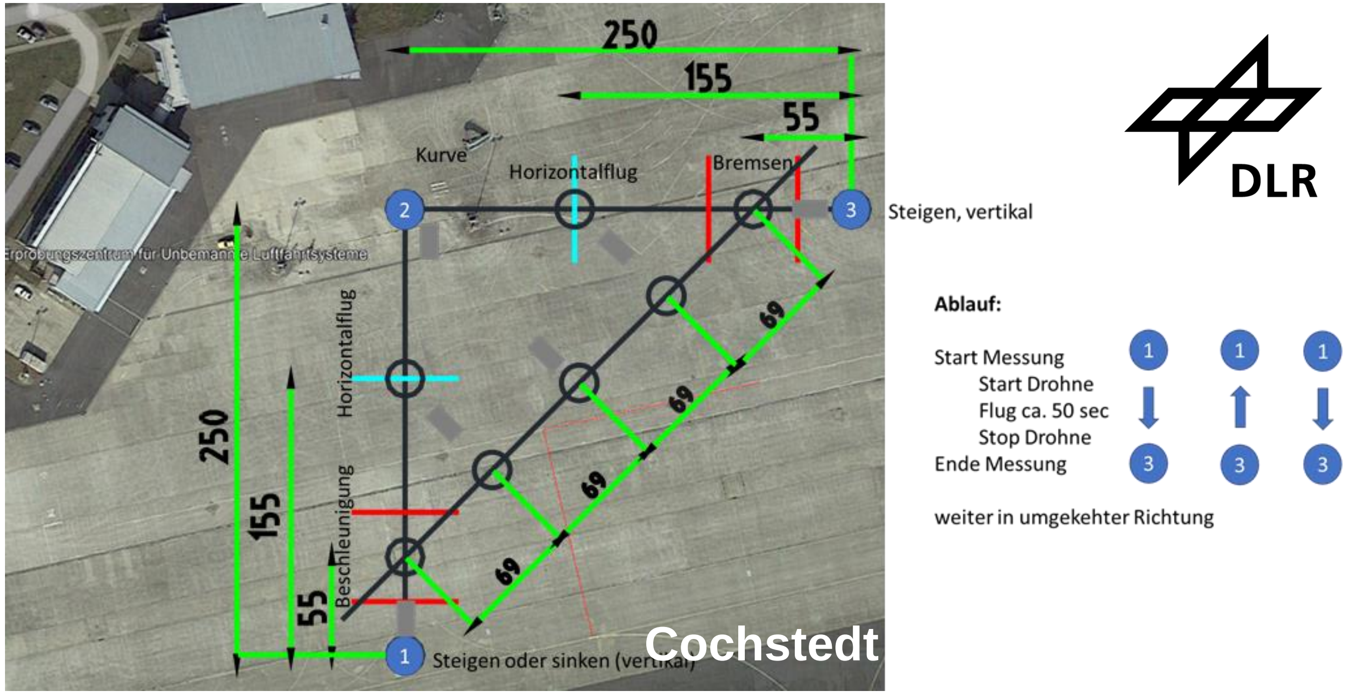
Outlook

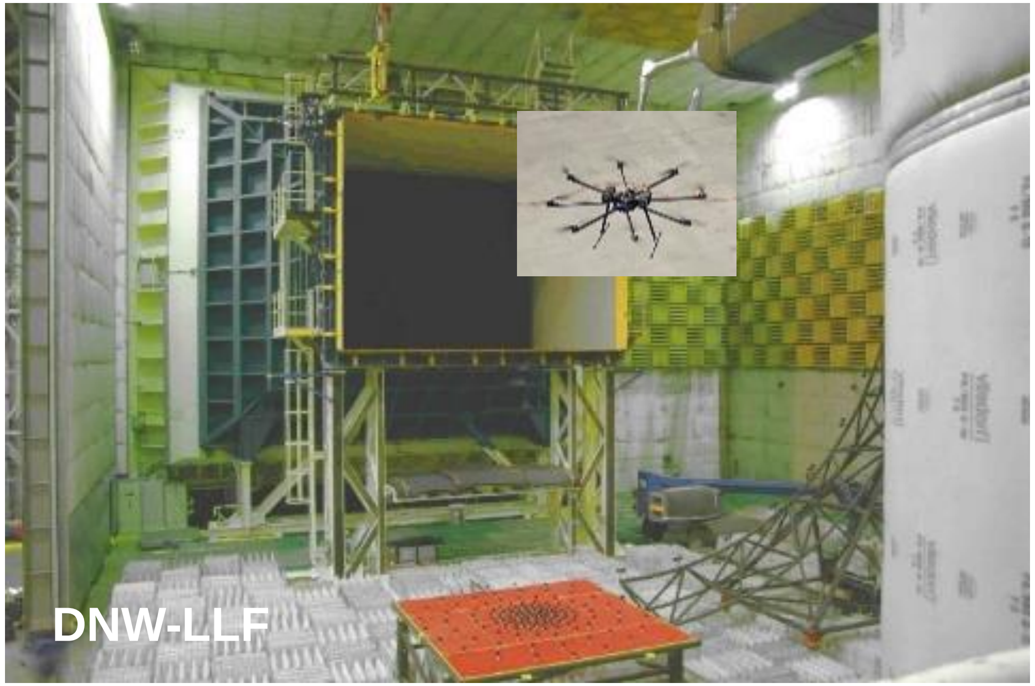
- **Controlled conditions**

- Measure noise for typical operation
  - Climb / descent
  - Accelerate / decelerate
  - Cruise / hover

and record all operation parameters

- „Caged drone“ in wind tunnel, install a security net to avoid damage but allow for UAS op. in free flight condition
- Measure under constant
  - mean flow conditions
  - turbulence conditions (wt shearlayers)





Thank you for your attention