Numerical Research of UAV Aeroacoustic at CMT – Clean Mobility & Thermofluids

Roberto Navarro, Luis Miguel García-Cuevas, Jorge García-Tíscar*, Federico N. Ramírez**

CMT – Clean Mobility & Thermofluids, Universitat Politècnica de València, Spain

* jorgarti@mot.upv.es

** fera1@mot.upv.es

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Clean Mobility & Thermofluids

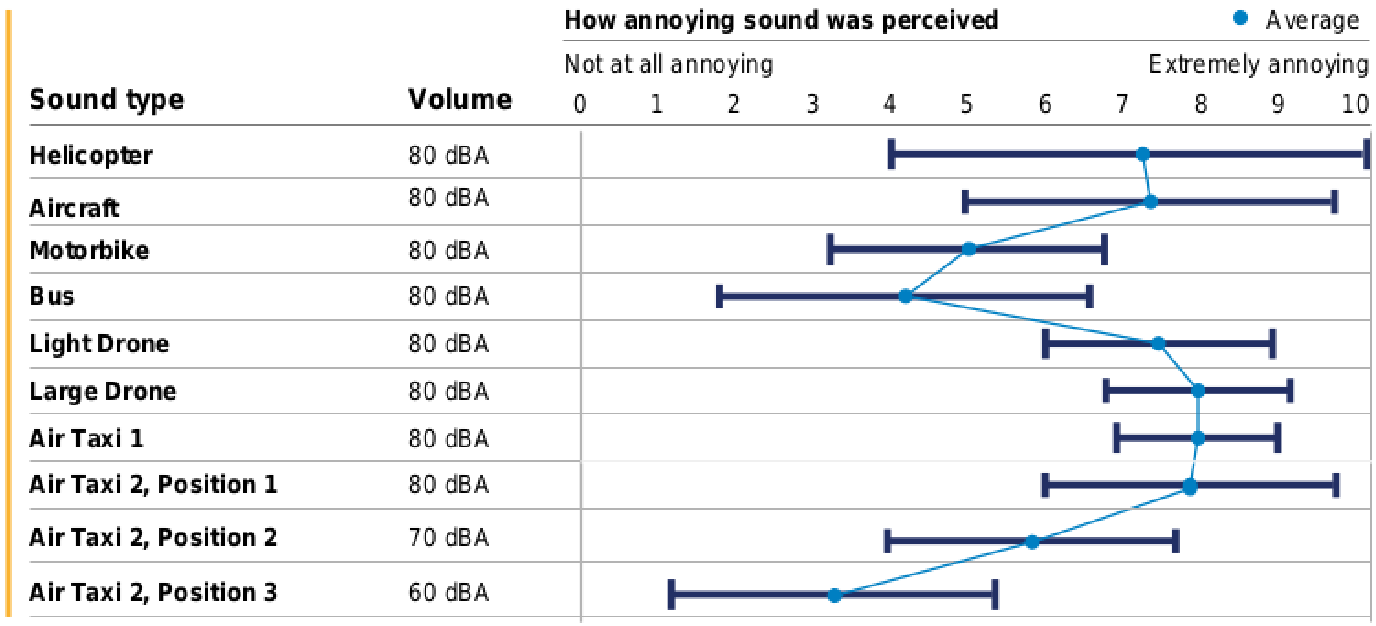
MINISTERIO DE CIENCIA E INNOVACIÓN

AGENCIA ESTATAL DE INVESTIGACIÓN

Part of project *MODERA*, grant TED2021-131087A-I00, project ENOLA, grant PID2022-142018OA-I00, and project HYDRONE, grant PID2020-119468RA-100, all funded by MCIN/AEI/10.13039/501100011033 and by European Union NextGenerationEU/PRTR

Introduction

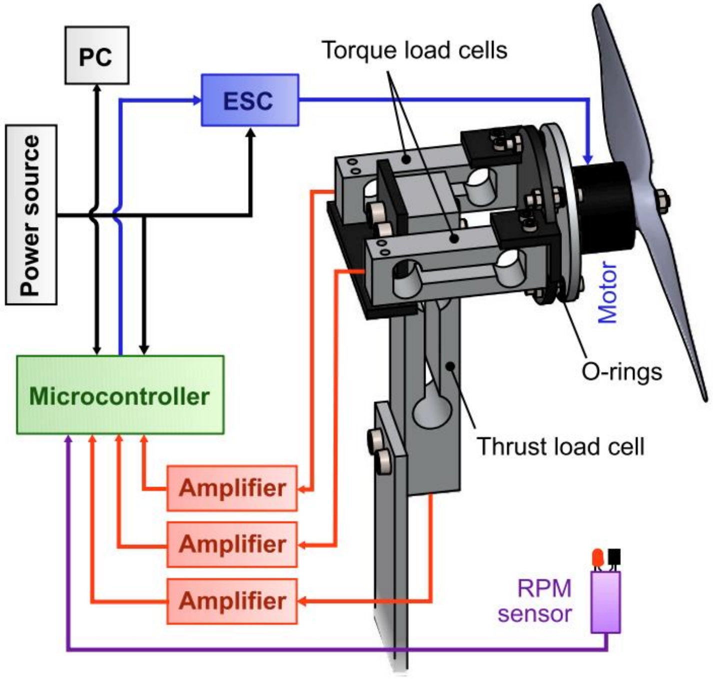
- **Noise is one of the top 3 concerns regarding UAV urban deployment**
- **Noise quality, not only level, is important**
  - **Critical to predict noise spectra, not only overall sound level**
- **Propellers are the main sources of noise in eUAVs**

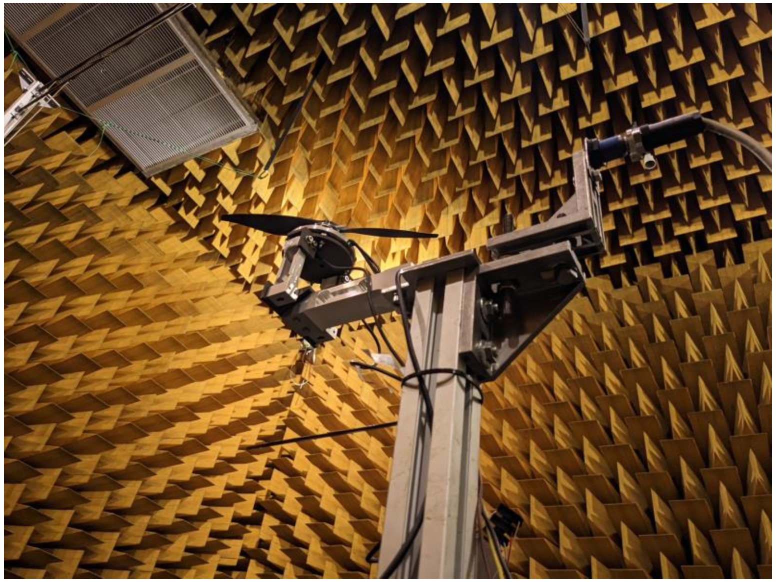


Study on the Societal Acceptance of Urban Air Mobility in Europe. EASA report. 2021

Experimental facilities

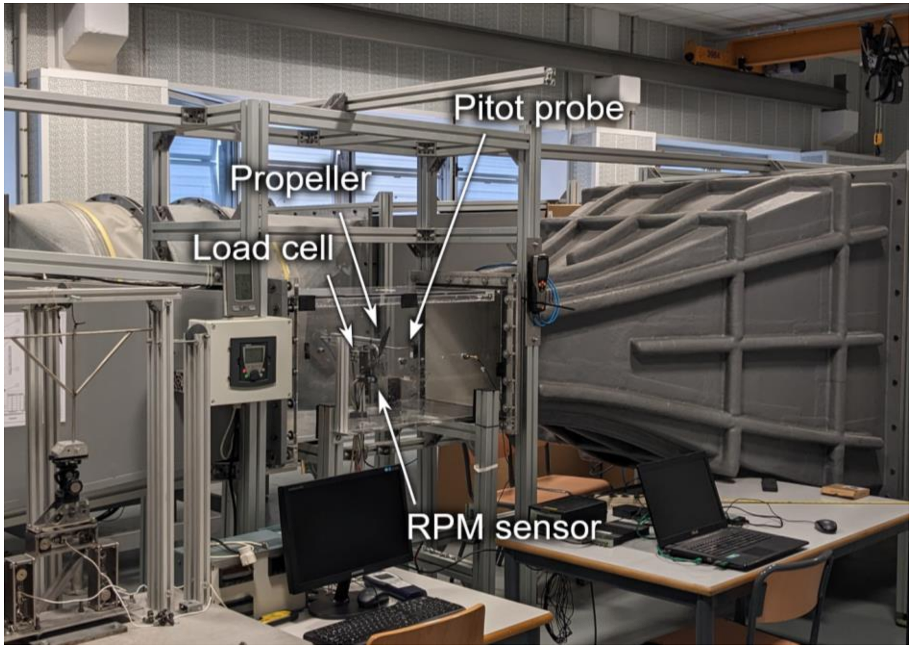
- In-house test bench design
- 7.5 x 6.5 x 6 m. anechoic chamber
- Several microphones and acquisition systems





Experimental facilities

- **Closed wind tunnel with a 44 x 44 x 100 cm test section (up to 80 m/s)**
- **Open wind tunnel with a 2.8 x 2.8 x 22 m test section (up to 32 m/s)**



Numerical models

Aerodynamic models

- Blade Element Momentum Theory (BEMT)
- Steady RANS – Moving Reference Frame (MRF)
- URANS
- DES (IDDES)

Acoustic models

- Simple Farassat

$$p(x,t) = -\frac{F_N(r_f\omega^2/c)}{4\pi c x N_b} \cdot \sum_{n=0}^{N_b-1} \left(\frac{\cos\theta \sin\theta \cos(\omega t_{e,n} - \phi_n - \phi)}{(1 + (r_f\omega/c)\sin\theta \sin(\omega t_{e,n} - \phi_n - \phi))^3} \right)$$

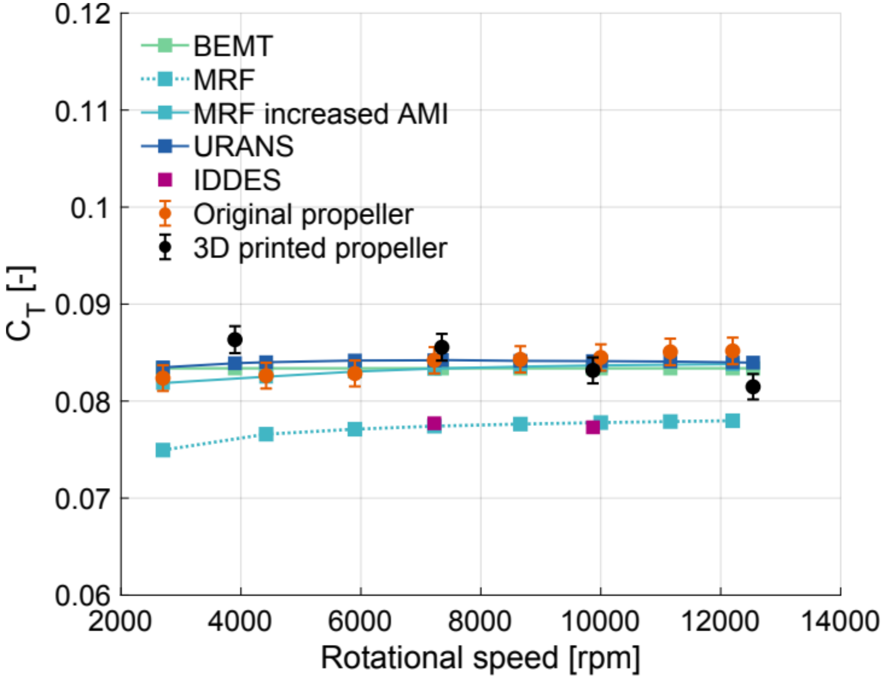
- Ffowcs Williams & Hawkings (Farassat 1A formulation)

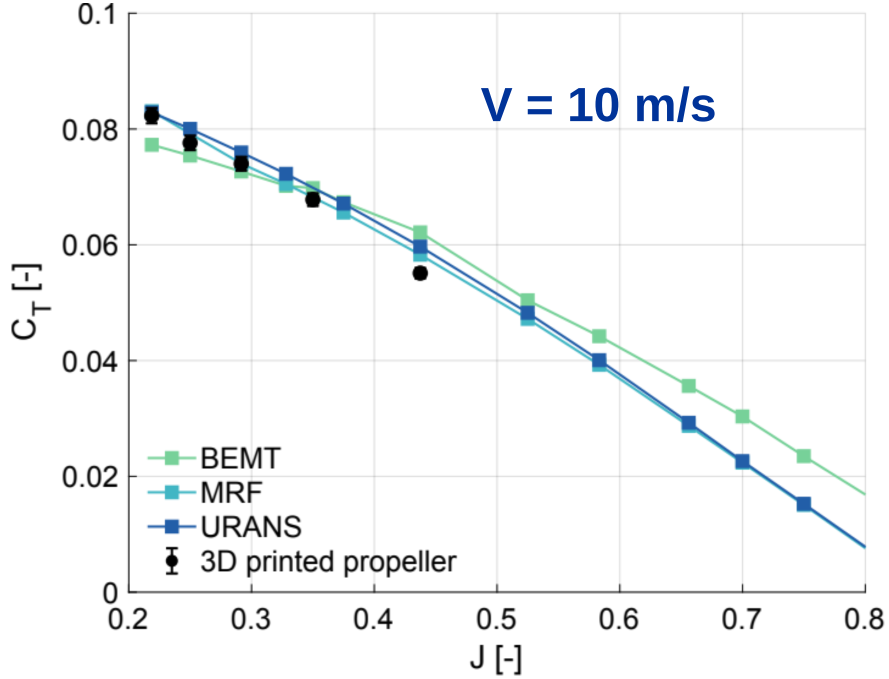
$$4\pi p'_T(\vec{x},t) = \int_{f=0} \left[\frac{\rho_0(\dot{v_n} + v_{\dot{n}})}{r(1-M_r)^2} \right]_{ret} dS + \int_{f=0} \left[\frac{\rho_0 \dot{v}_n r \dot{M}_r + c_0(M_r - M^2))}{r^2(1-M_r)^3} \right]_{ret} dS$$

$$4\pi p'_L(\vec{x},t) = \frac{1}{c_0} \int_{f=0} \left[\frac{\dot{L}_r}{r(1-M_r)^2} \right]_{ret} dS + \int_{f=0} \left[\frac{L_r - L_M}{r^2(1-M_r)^2} \right]_{ret} dS + \frac{1}{c_0} \int_{f=0} \left[\frac{L_r(r\dot{M}_r + c_0(M_r - M^2))}{r^2(1-M_r)^3} \right]_{ret} dS$$

Models' comparison

- Good fit of thrust force
- Big influence of the AMI size in MRF results
- Underprediction of thrust with the IDDES model
- Effect of 3D print propellers

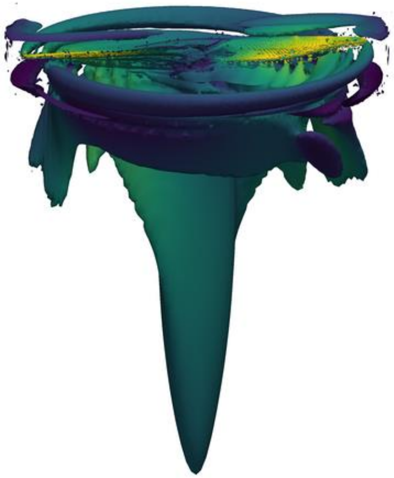




Models' comparison

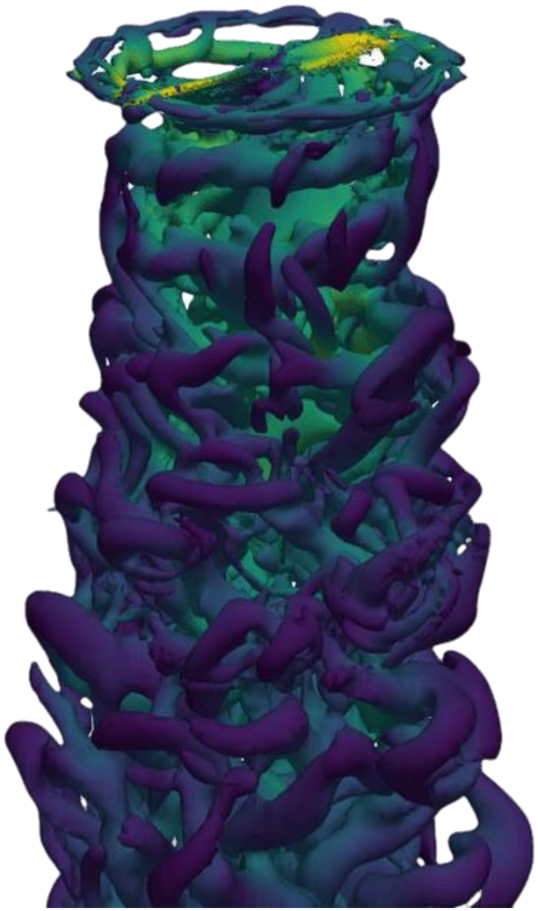
- Wake differences

MRF



URANS

IDDES



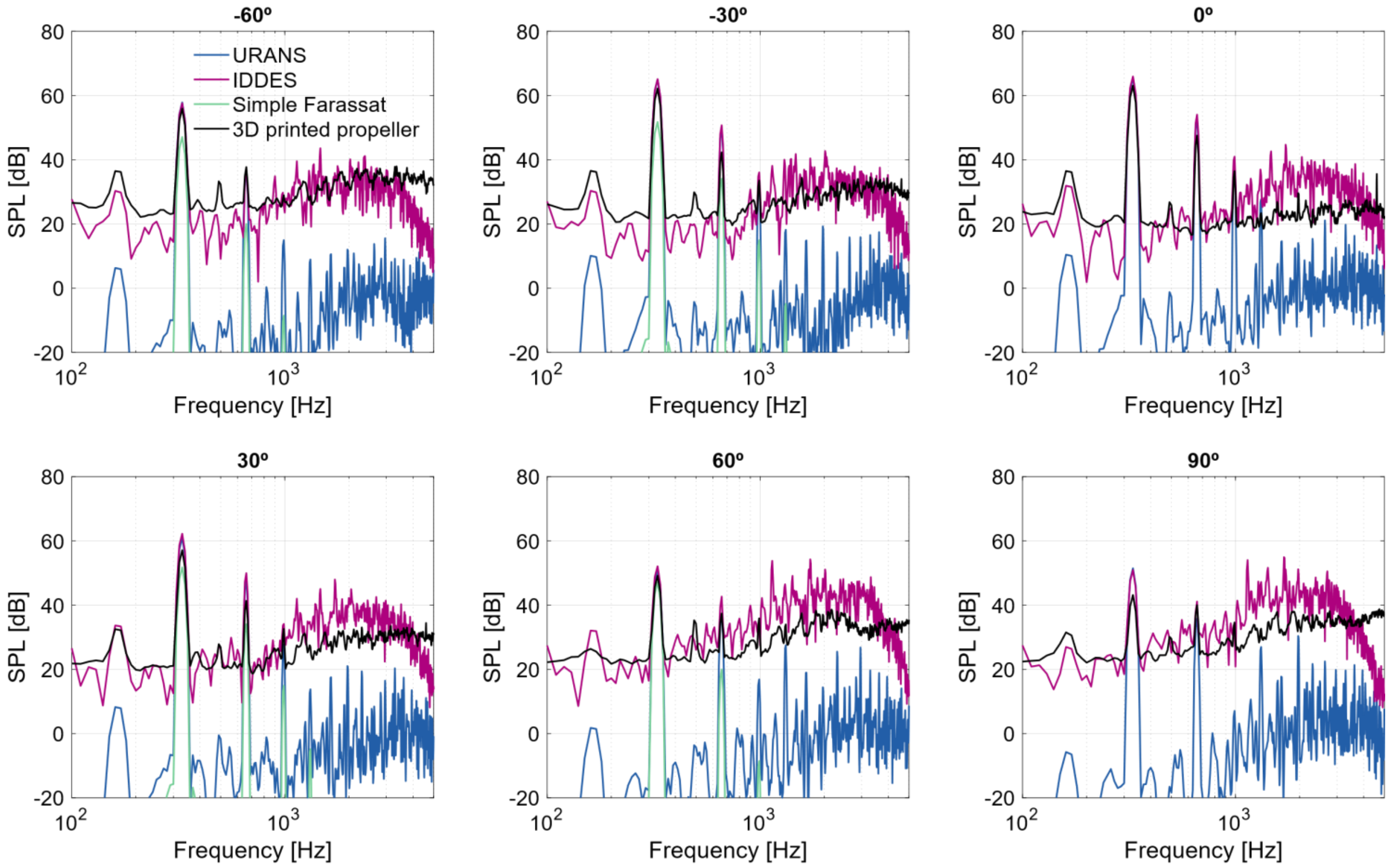
Q-criterion = 10000

7225 RPM

Meaningful differences!

Models' comparison

- **Acoustic prediction (spectra)**

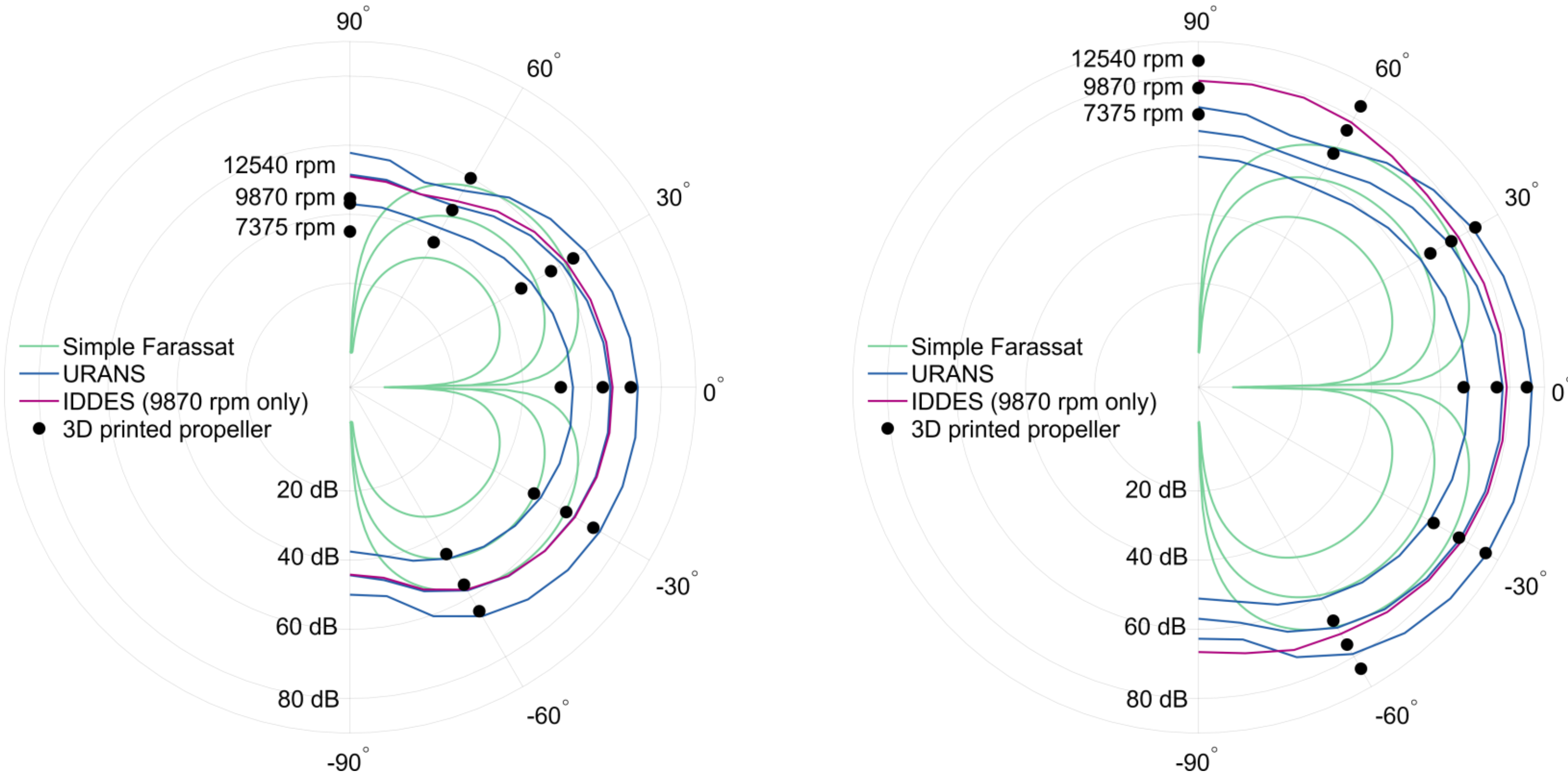


Models' comparison

- **Acoustic prediction (directivity)**

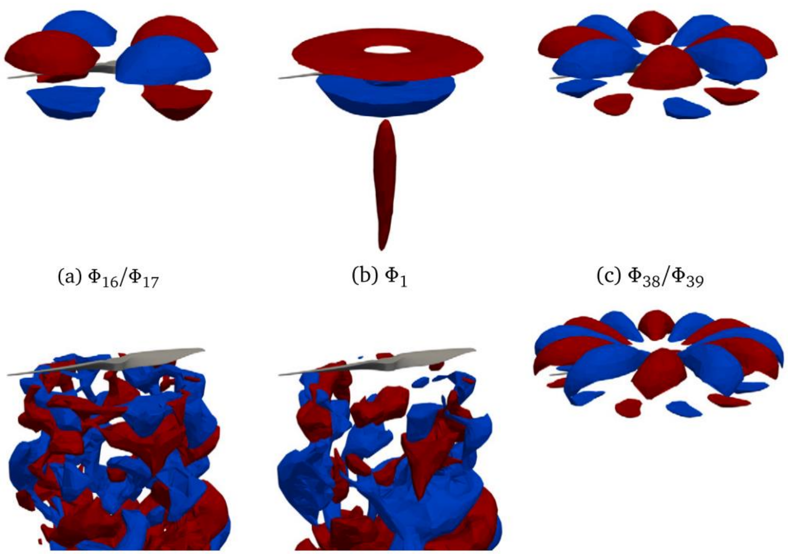
SPL at BPF

OASPL



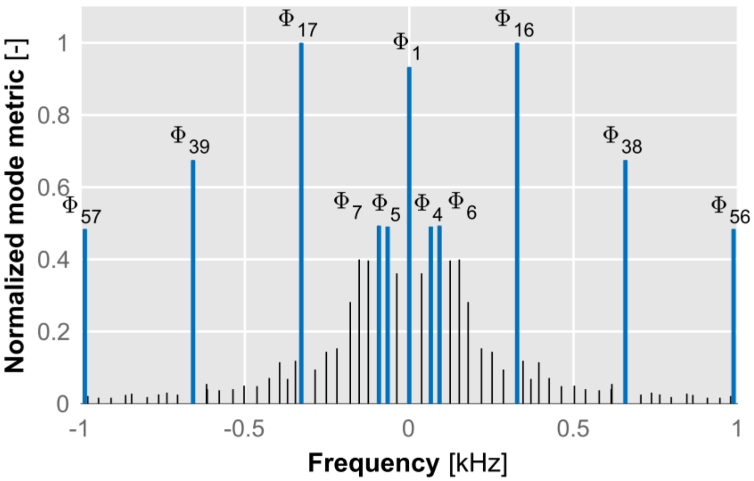
Modal decomposition

- **Dynamic Mode Decomposition (DMD)**
- **Acoustic modes of azimuthal order m (m = h * b, with h=1,2,3,4...)**



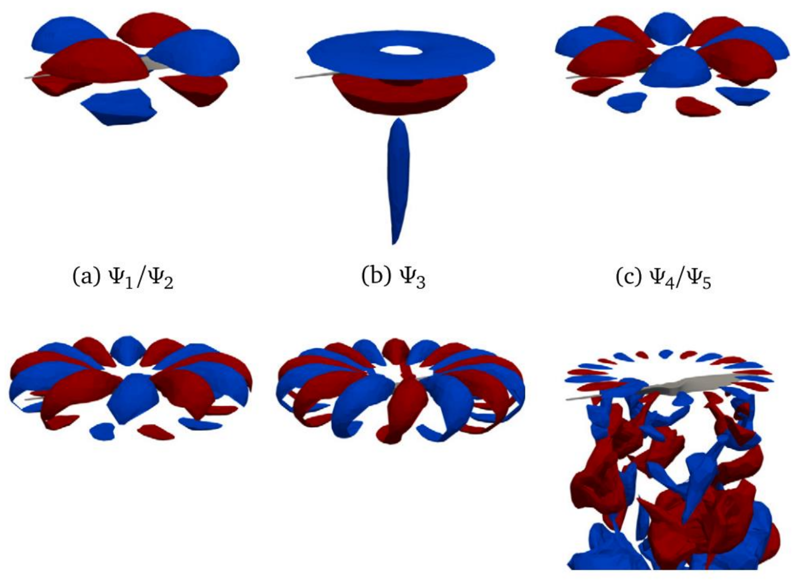
(a) Φ_{16}/Φ_{17} (b) Φ_1 (c) Φ_{38}/Φ_{39}

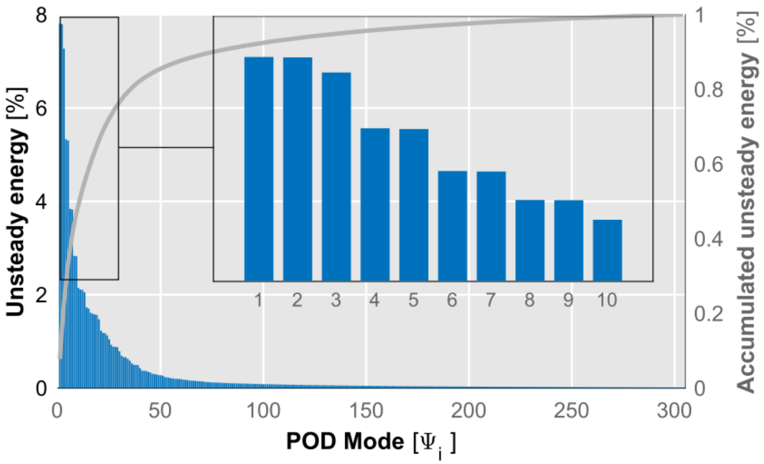
(d) Φ_6/Φ_7 (e) Φ_4/Φ_5 (f) Φ_{56}/Φ_{57}

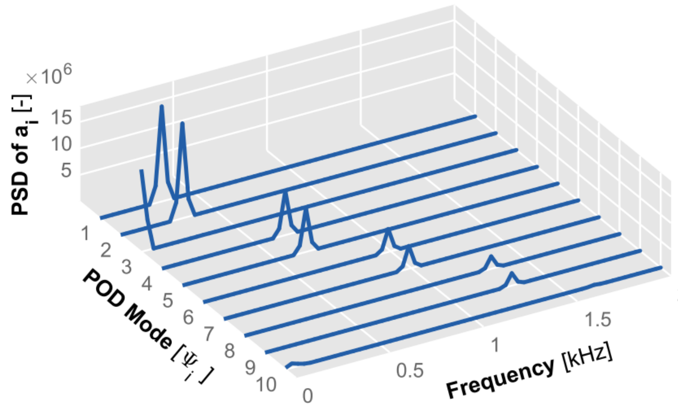


Modal decomposition

- Proper Orthogonal Decomposition (POD)
- Modes really similar to DMD

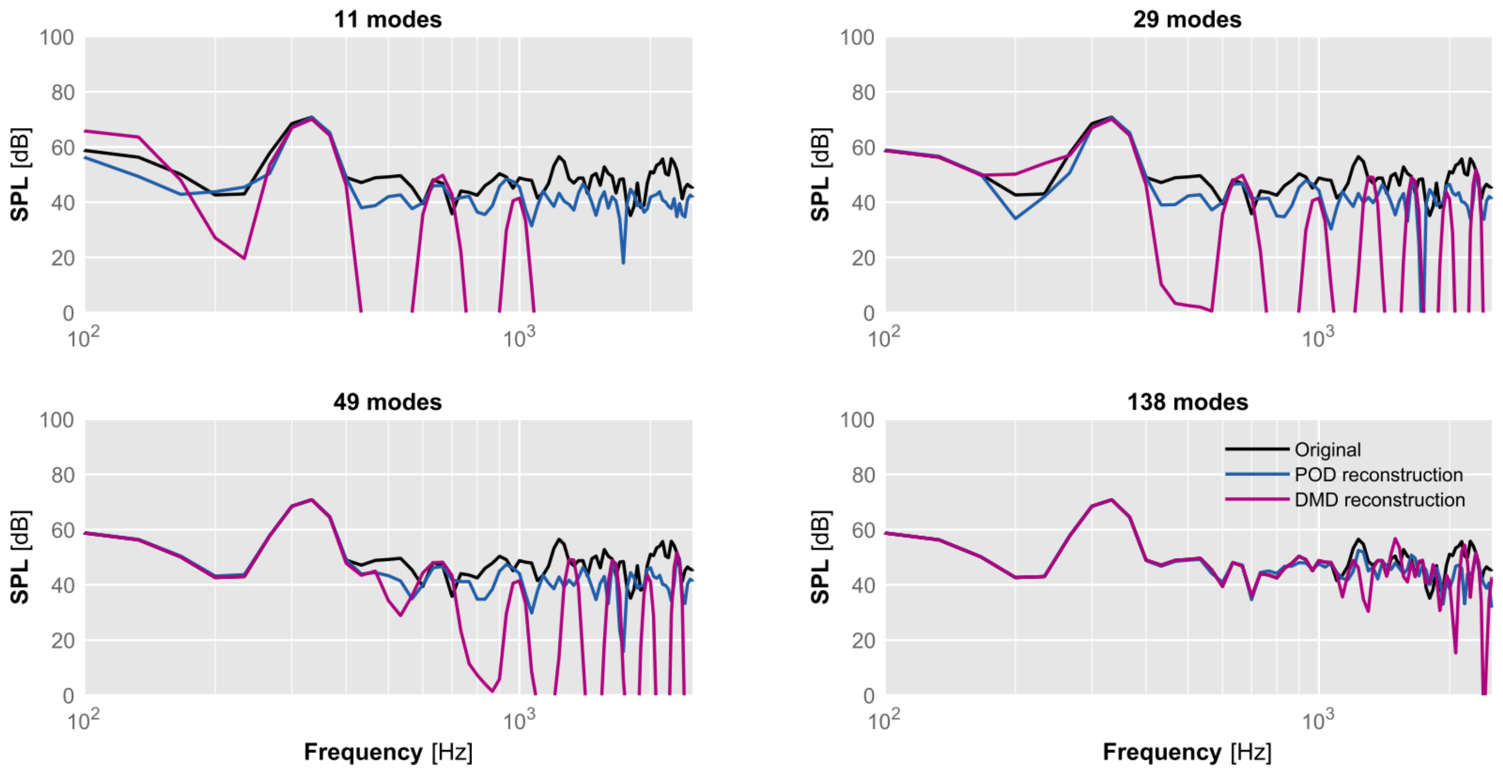

(a) Ψ_1/Ψ_2 (b) Ψ_3 (c) Ψ_4/Ψ_5
(d) Ψ_6/Ψ_7 (e) Ψ_8/Ψ_9 (f) Ψ_{10}





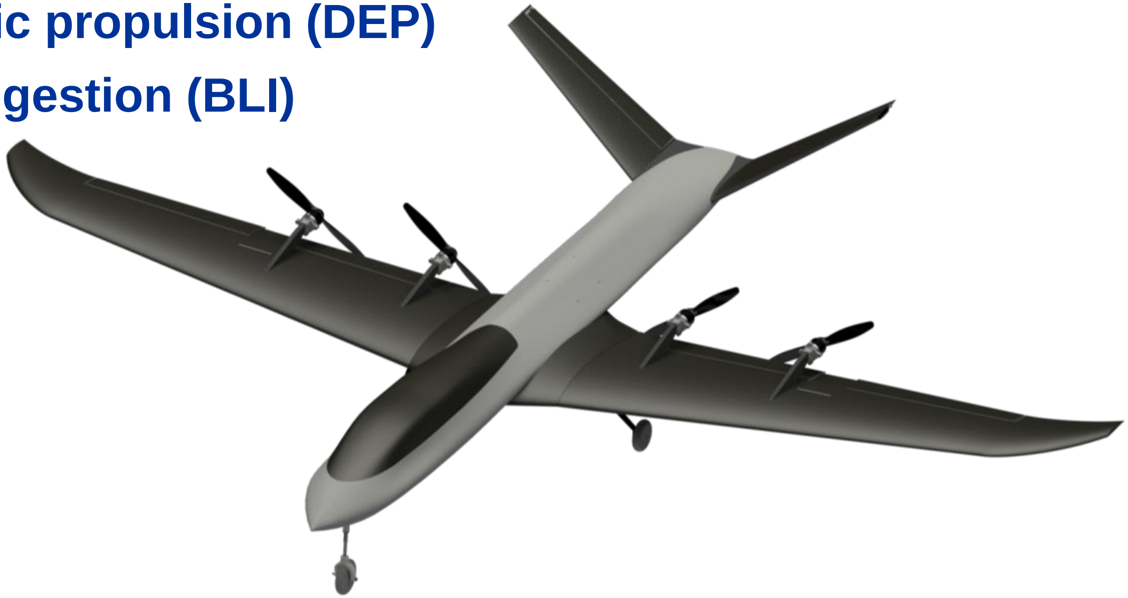
Modal decomposition

- **Reconstruction of pressure field**



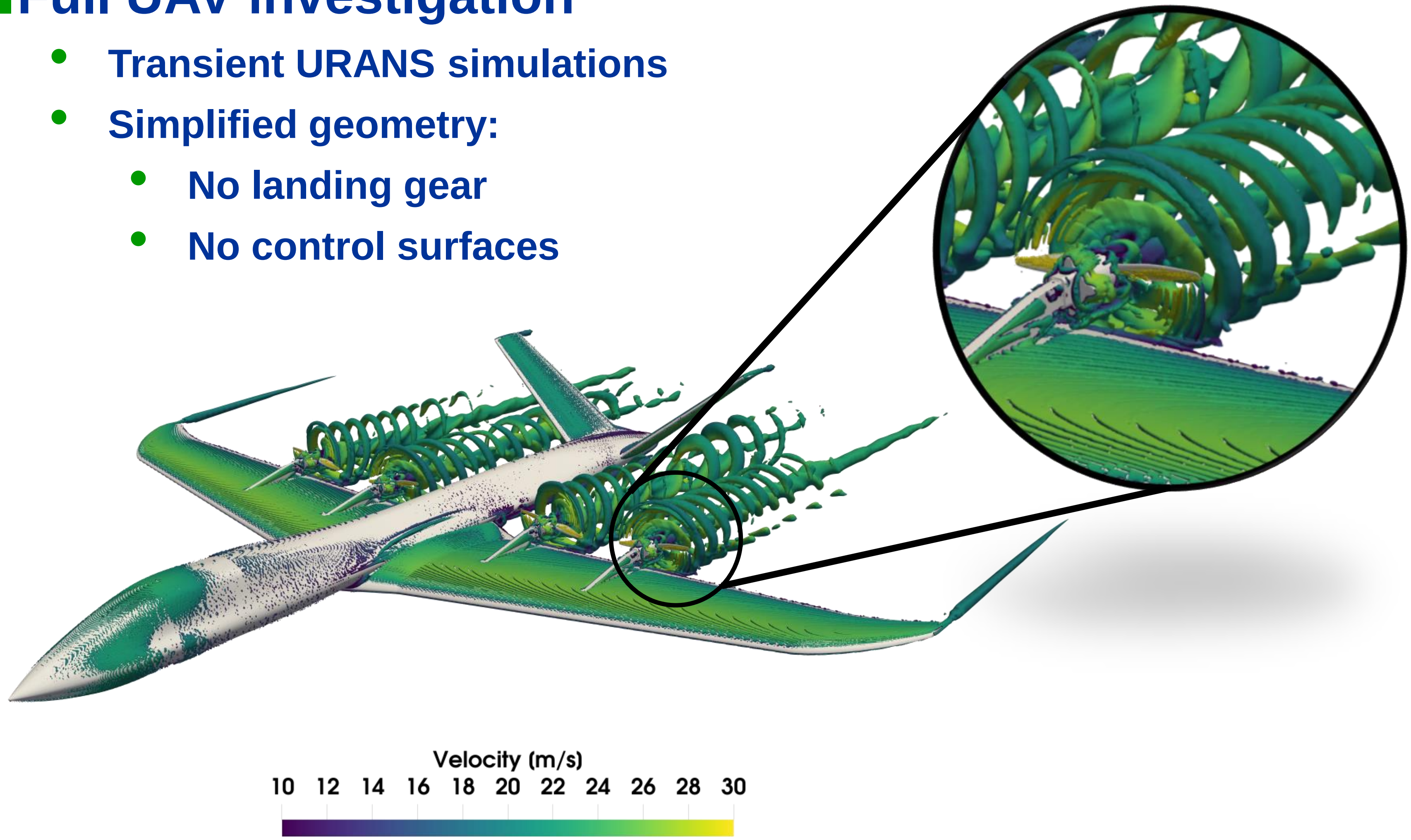
Full UAV investigations

- H-200 prototype (in house design)
- Four propeller fixed wing UAV
- Wingspan of 2.95 m.
- Maximum take-off mass of 15 kg.
- Designed as a platform to study:
  - The use of hydrogen fuel cells in aeronautics
  - Distributed electric propulsion (DEP)
  - Boundary layer ingestion (BLI)



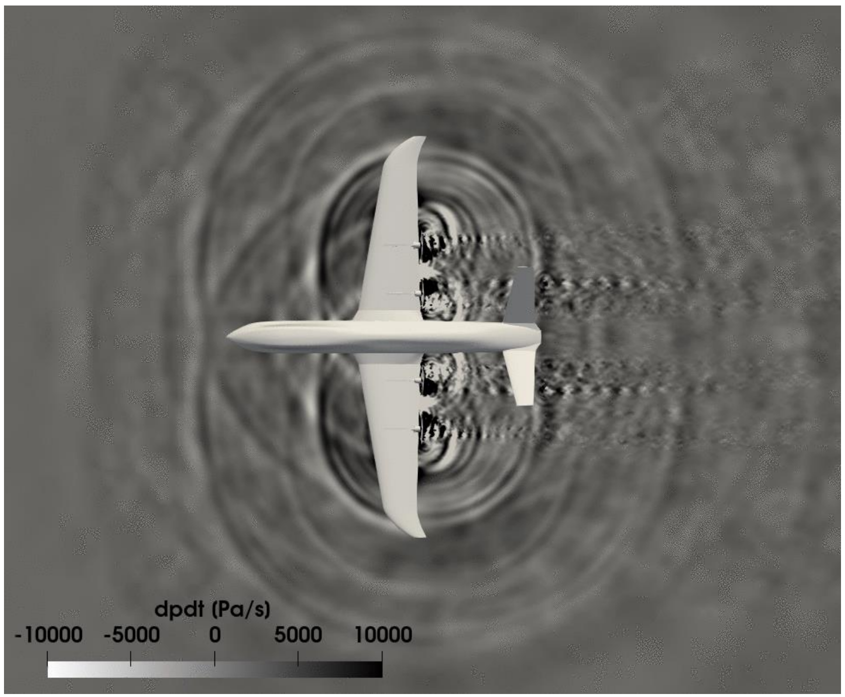
Full UAV investigation

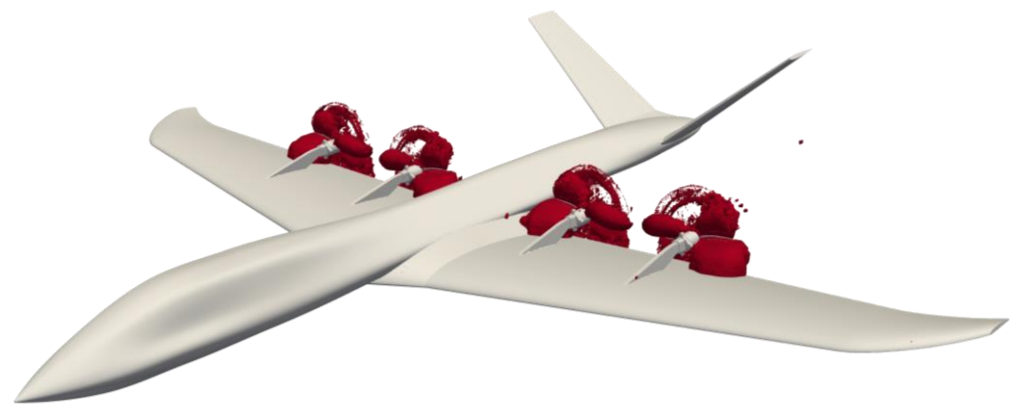
- Transient URANS simulations
- Simplified geometry:
  - No landing gear
  - No control surfaces



Full UAV investigation

- **Complex acoustic field**
- **Strong interaction between the propellers and the wing**

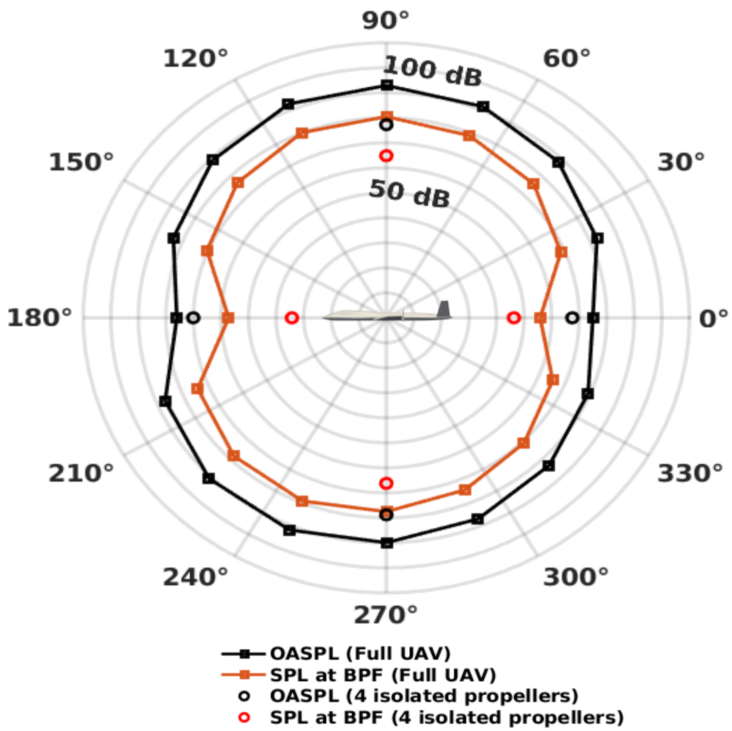




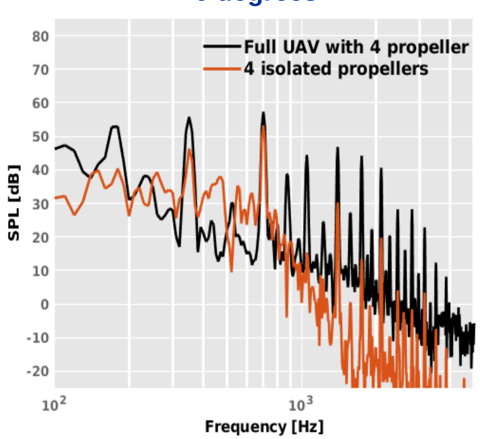
Isosurface of dpdt

Full UAV investigation

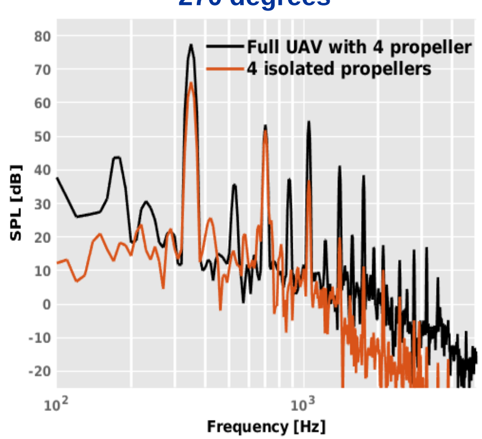
- **Strong interaction between the propellers and the airframe**
- **BLI effect on noise not negligible**
- **Increase on both tonal and overall noise**
- **New peaks appear at the shaft frequency and harmonics**



0 degrees



270 degrees



Current research and next steps

- New models
  - Transient Blade Element Theory + CFD
  - Vortex Particle Method (VPM)
  - Hanson acoustic model
- Multi-fidelity propeller optimization
- Parameters influence
  - Surface Roughness, Young’s moduli, anisotropy…
- In-depth study of fuselage and wing influence in aeroacoustics of distributed propellers vehicles
- Study of multi-copter configurations
- Noise propagation on urban environments