GARTEUR GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE
FRANCE GERMANY ITALY THE NETHERLANDS SPAIN SWEDEN UNITED KINGDOM

Rotor / Rotor aerodynamic interactions
A Garteur Action Group

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Motivation

Most valuable helicopter characteristics:

- Hovering
- Vertical take off and landing

Some drawbacks:

- Maximum reachable speed
- Mechanical complexity
- Important operating cost

Motivation

Compound helicopter concept to break the speed limit

Sikorsky X2

Airbus Helicopters X^3: 472Km/h

Sikorsky S-97 Raider : 370Km/h

JAXA concept

Airbus Helicopters Racer: 400Km/h

Motivation

Multicopters (manned and un-manned) to lower mechanical complexity and operating cost


NASA GL-10


Volocopter


Embraer DreamMaker


Joby S4


Ehang 216

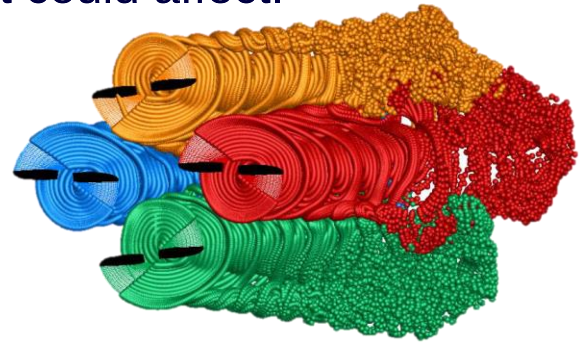
Airbus Vahanna

ALTIS Aergility

Motivation

Strong aerodynamic interactions between rotating parts that could affect:

- Performances, noise, stability, …

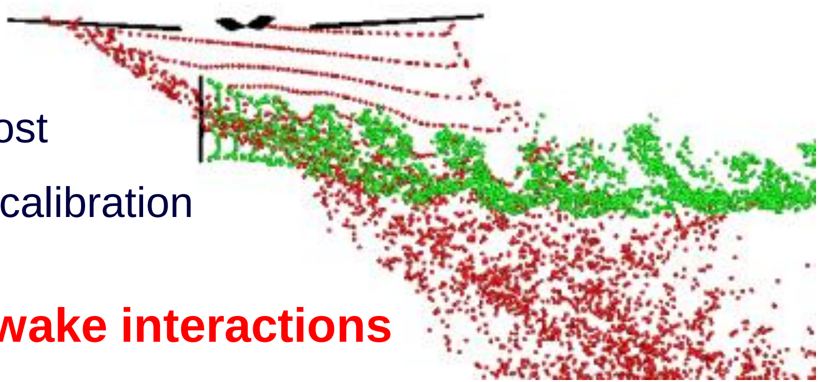


Few literature available on rotor / rotor aerodynamic interactions (back in 2018)

No widely available experimental databases

Can be addressed numerically, but:

- High fidelity numerical methods, have high CPU cost
- Low fidelity methods are not well suited and need calibration and validation



⇒ GARTEUR Action Group 25 : Rotor / Rotor wake interactions

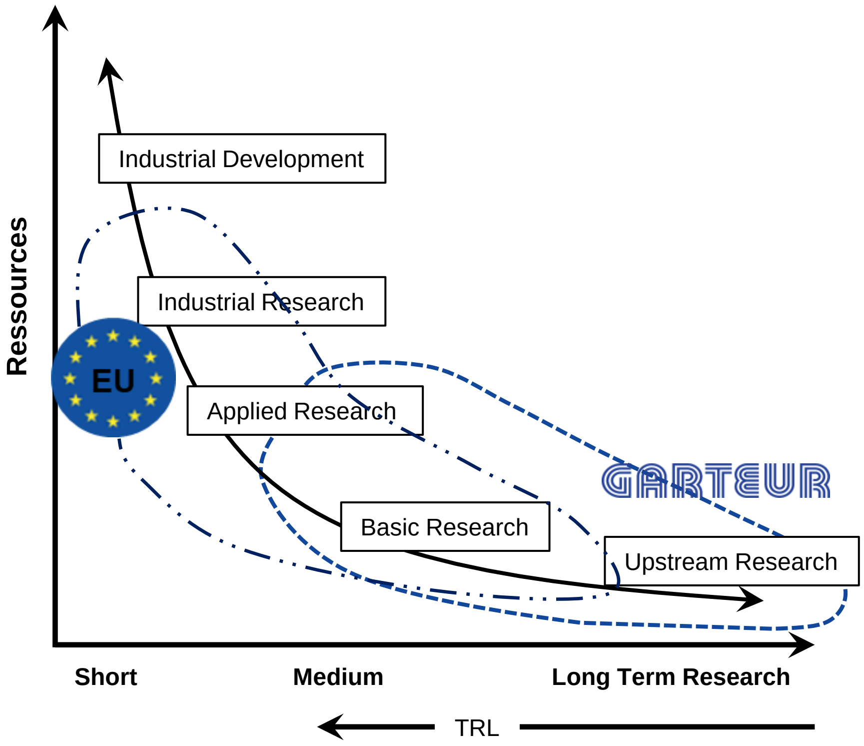
GARTEUR

GARTEUR (Group for **A**eronautical **R**esearch and **T**echnology in **EUR**ope) is an important organization for research collaboration in Europe in the field of aeronautics

Member countries: France, Germany, United Kingdom (1973); The Netherlands (1977); Sweden (1991); Spain (1996); Italy (2000)

Organizations of non-member countries can participate upon authorization of the Council

Each organization participates with its own funding's → low budgets implied



AG25 Facts

Objective:

- Investigate Numerically and experimentally rotor / rotor wake interactions in low speed conditions

Time frame:

- 3.5 Years, November 2019 to May 2023

Participants:

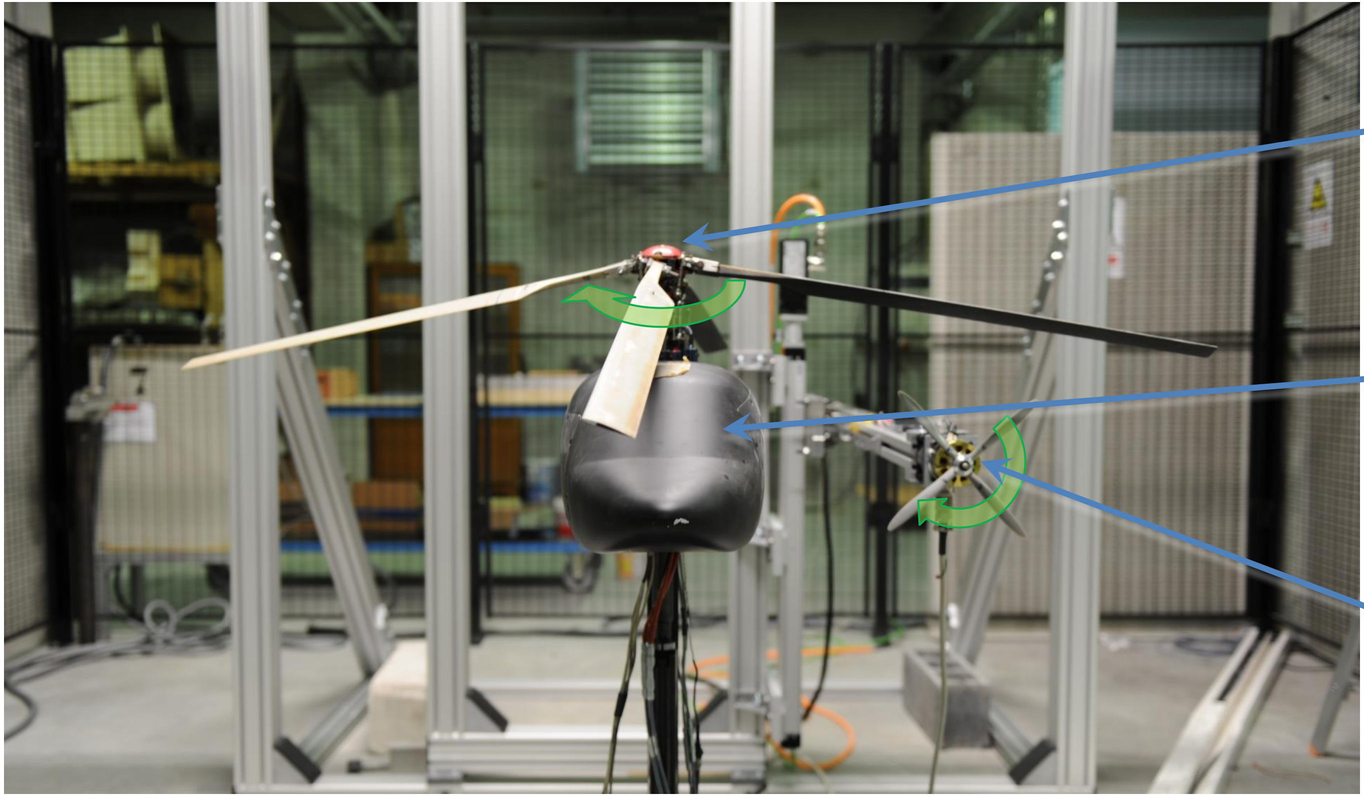
- 4 research centers, 3 Universities, 5 countries
- CIRA (Italy), DLR (Germany), NTUA (Greece), POLIMI (Italy), UoG (United Kingdom), IAG (Germany), ONERA (France)

AG25 Means

- Setting up 3 different, cost effective, wind tunnel test campaigns to produce experimental database
  - Rotor / Propeller Interactions (high speed helicopter)
  - Rotor / Propeller Interactions Mach Scaled (High speed Helicopter)
  - Rotor / Rotor Interaction (Multicopter)
- Validation and cross-comparison of different numerical tools with different levels of modeling

Code	Partner	Description
RAMSYS	CIRA	Boundary element method with free-wake model
GENUVP	NTUA	Boundary element method with free vortex particle wake
UPM	DLR	Panel with free-wake method
PUMA	ONERA	Lifting line with free-wake model
HoPFlow	NTUA	Navier-Stokes solver coupled with particle approach for the far field.
HMB3	UoG	Navier-Stokes solver coupled with particle methods or lattice Bolzmann for the farfield
elsA	ONERA	URANS
FLOWer/CAMRAD	IAG	URANS/DES coupled with aeroelastic model

Rotor - Propeller interactions (Onera)

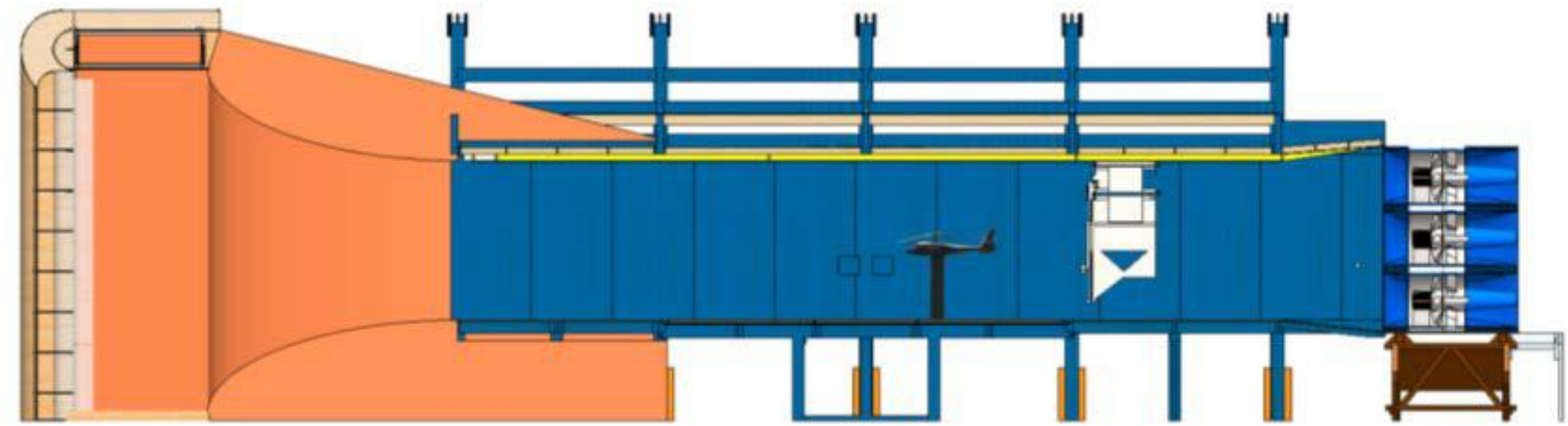


- 4 blades fully articulated
- 1.5m diameter
- No taper, no sweep
- Linear twist
- 1272 RPM
- Vtip 100 m.s-1

- 1/7.7 scale
- Dauphin 365N model

- APC propeller
- 4 blades, fixed pitch
- 28cm diameter
- 7632 RPM
- V_{tip} 112 $m.s^{-1}$
- Variable relative position

Rotor - Propeller interactions (Onera)



L2 Wind Tunnel (Onera Lille, France):

- Closed section wind tunnel
- 6m width, 1.4m height 13m long
- Maximum speed 20 $m.s^{-1}$

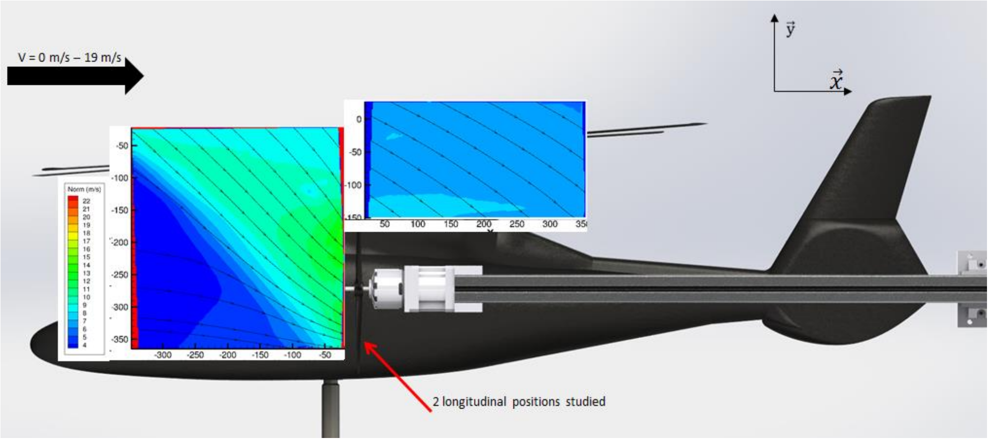
Flight conditions:

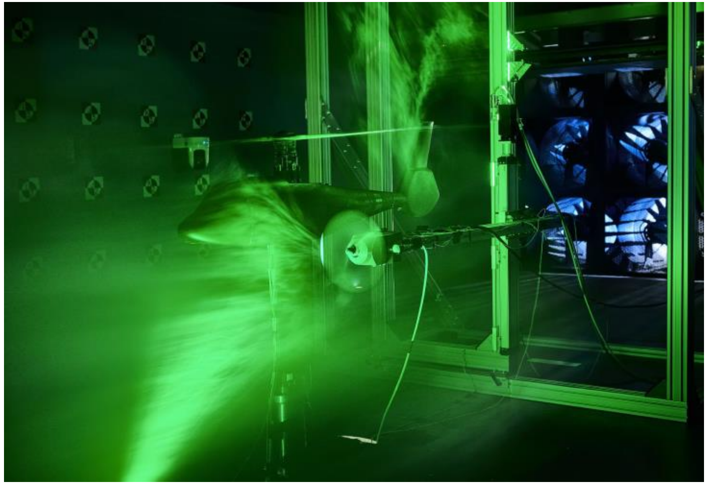
- Rotor Zbar: 14,5
- Rotor trim in isolated conditions (without propeller)
- With and without re-trim in installed conditions
- Axial wind

Rotor - Propeller interactions (Onera)

Propeller position:

- 0.14m ahead of the rotor (≈18% Rotor Radius)
- 0.28m below the rotor center (≈ 36% Rotor Radius)
- 0.375m from the rotor center (≈ 50% Rotor Radius) on the advancing side
- Plus variation around the nominal position





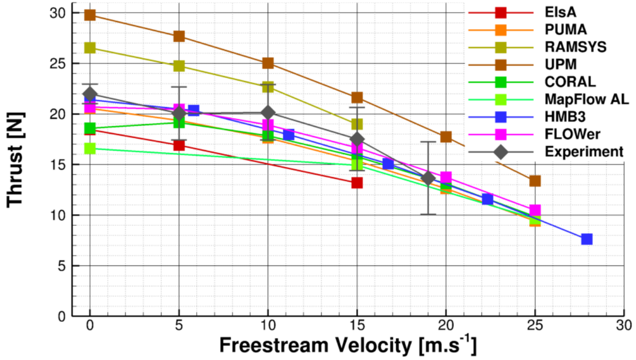
Measurements:

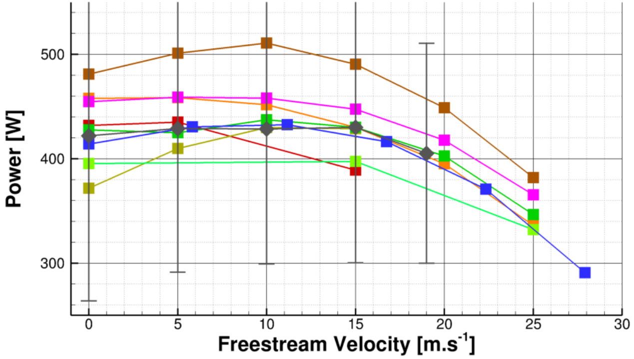
- Six axis balances (one for the main rotor and one for the propeller)
- Accelerometers
- Rotor blades pitch, yaw and lag angle monitoring
- Thermometers and toppers monitoring
- PIV measurements upstream and downstream of propeller

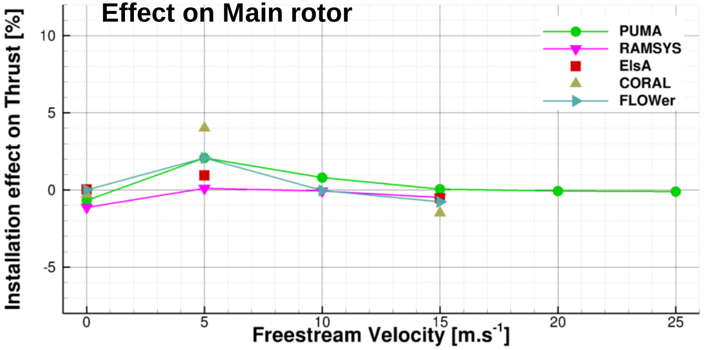
Rotor - Propeller interactions (Onera)

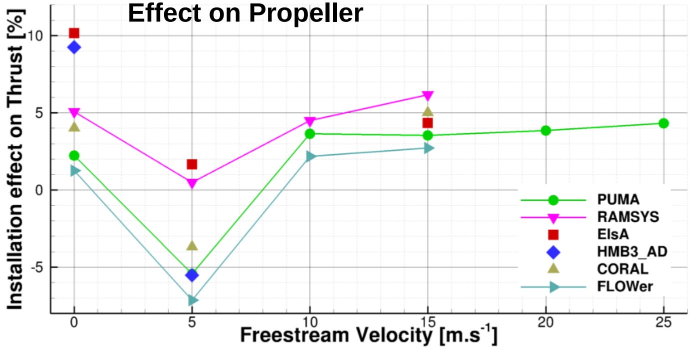
Isolated propeller

- Good comparison with experiment
- Scattering between level of modeling





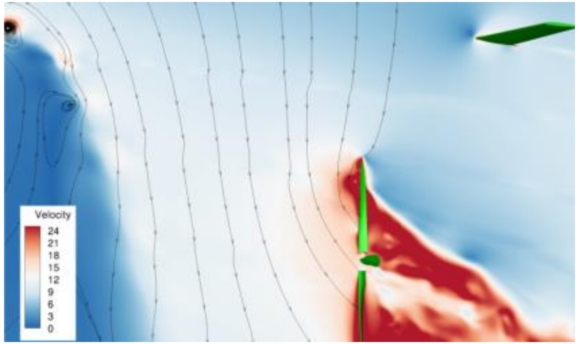




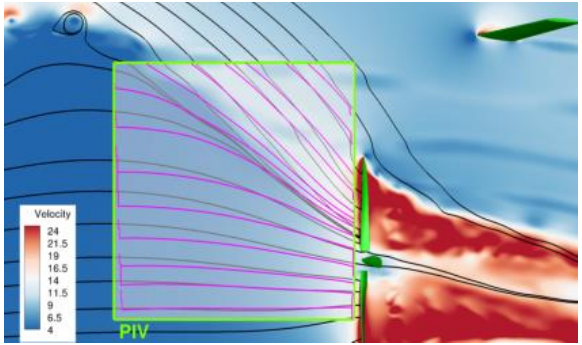
Installation effect

- Overall good correlation between numerical tools

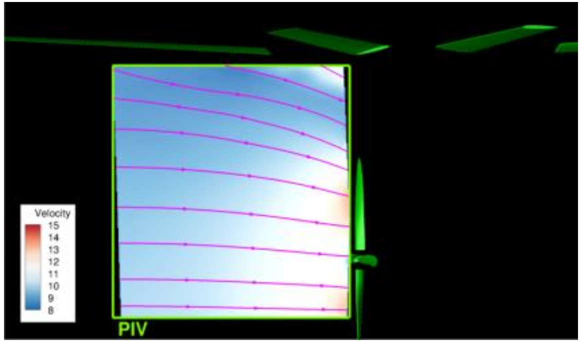
Rotor - Propeller interactions (Onera)



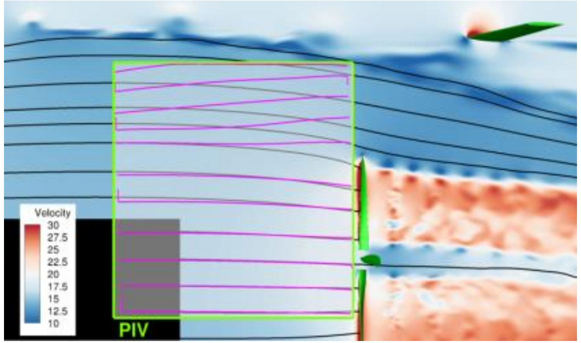
Hover



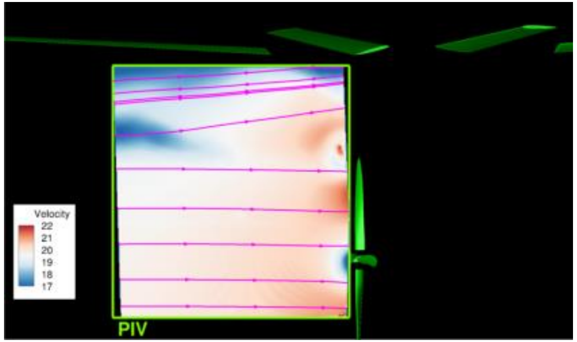
5 m.s^{-1}



10 m.s^{-1}



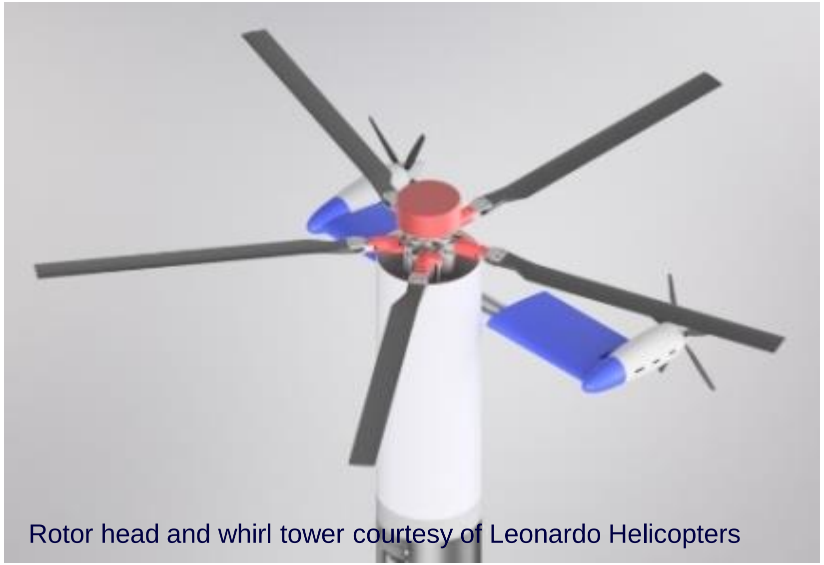
15 m.s^{-1}



20 m.s^{-1}

- Important interactions in low speed and hover
- Good agreement between experiment and computations in terms of main rotor wake interaction with the propeller

Rotor - Propeller interactions, Mach scaled (PoliMi)



Rotor head and whirl tower courtesy of Leonardo Helicopters

Main rotor:

- 5 blades
- NACA0012, rectangular, untwisted
- Radius 0.85m
- Fully articulated
- 2245 RPM
- Tip speed 201m.s^{-1}

Propellers:

- 5 blades
- VarioProp
- Radius 0.15m
- 12800 RPM
- 2 propellers, left and right handed

Test rig:

- Whirl tower
- Pusher configuration
- T-shape configuration
- Wing mounted propellers

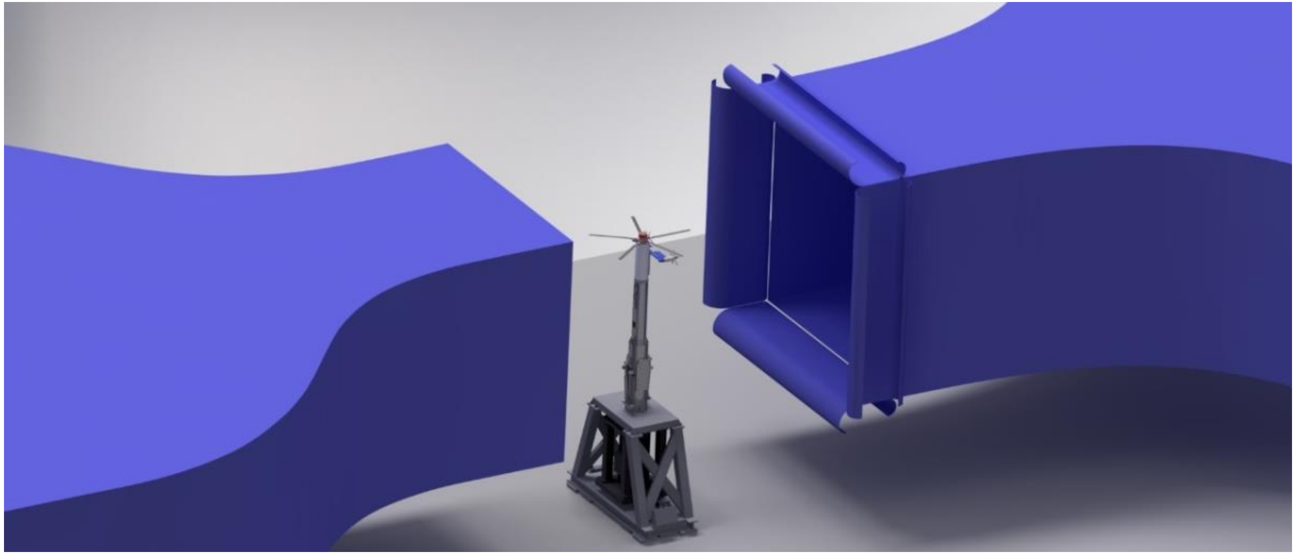
Wings:

- NACA 0018
- High thickness to chord ratio
- 18cm chord

Propellers positioning:

- 50% rotor radius from the center on both side
- 25% rotor radius below the rotor
- 37.5% rotor radius behind the rotor center

Rotor - Propeller interactions, Mach scaled (PoliMi)



Flight conditions:

- Low to moderate advance ratio
- Focus on cross wind conditions

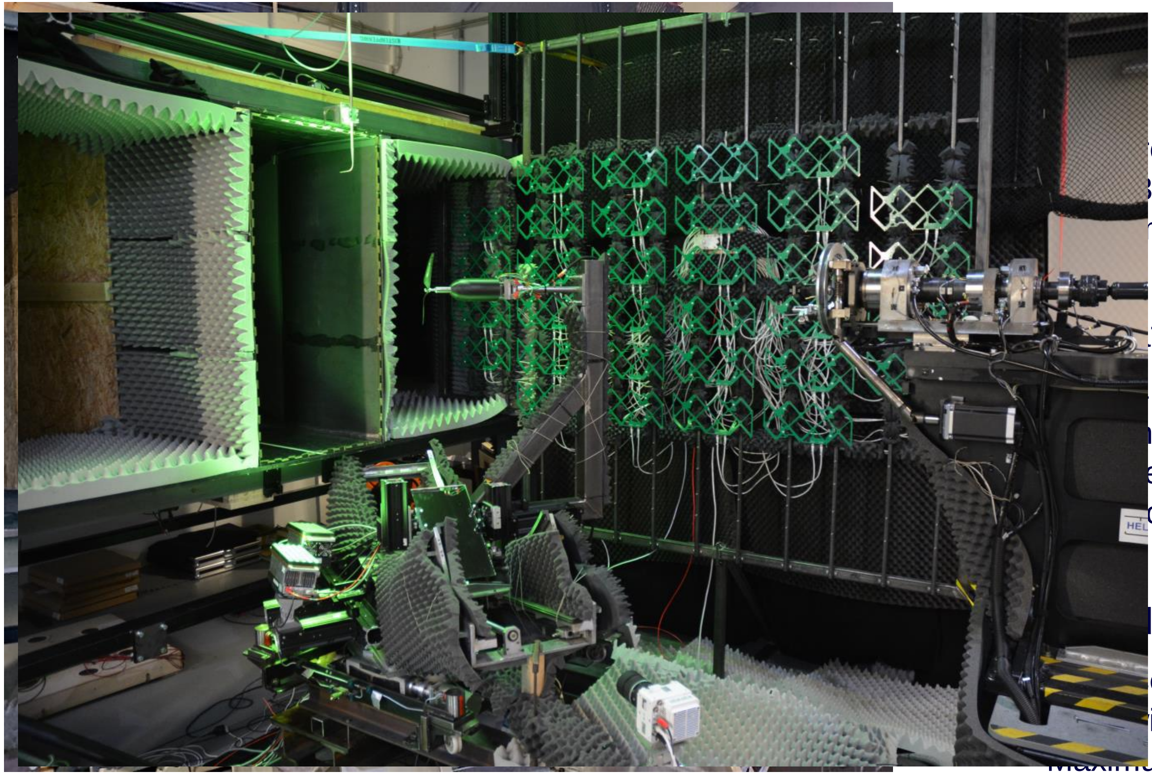
GVPM Wind Tunnel (PoliMi, Milano, Italy):

- Closed circuit, open section wind tunnel
- 4m width, 3.84m height 5m long
- Maximum speed 55 $m.s^{-1}$

Measurements:

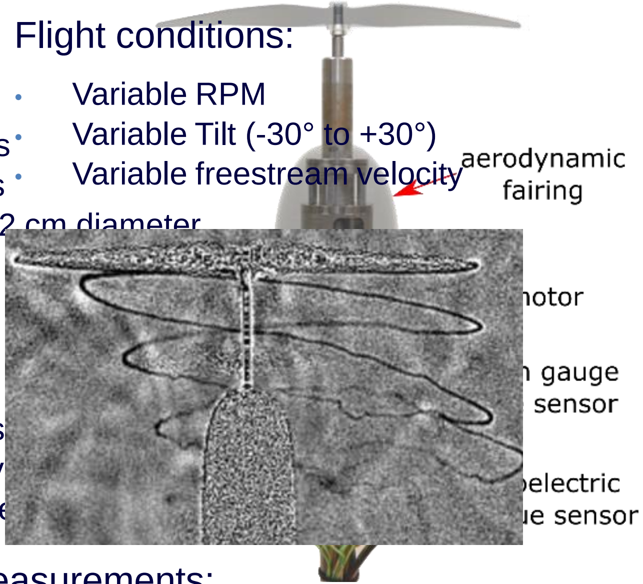
- Thrust and torque for both propellers and main rotor
- Rotor blades pitch, yaw and lag angle monitoring
- PIV measurements

Rotor - Rotor interactions (DLR)



Flight conditions:

- Variable RPM
- Variable Tilt (-30° to +30°)
- Variable freestream velocity



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blades
n to 62.2 cm diameter

tion:

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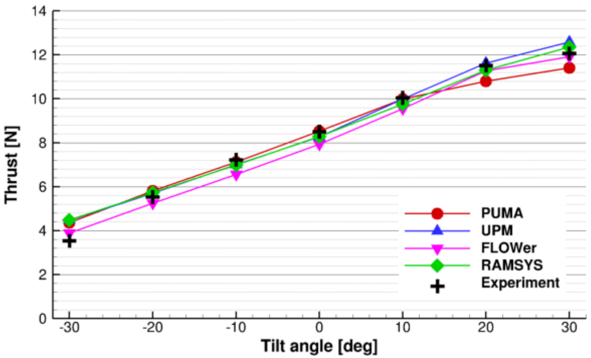
Measurements:

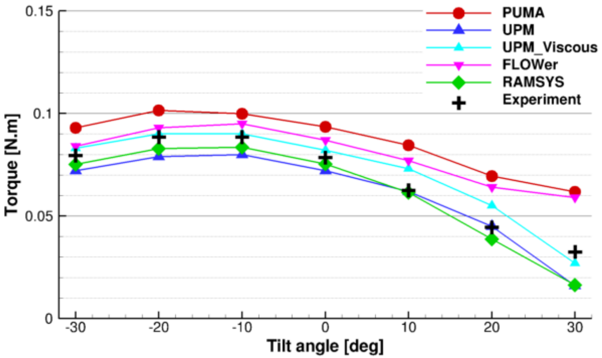
- Thrust and torque of each rotor
- Tip vortices and wake visualization using Background Oriented Schlieren (BOS)
- Microphone array (512 MEMS)

l tunnel (DLR, Göttingen, Germany):

ection wind tunnel
idth, 1.6m height
Maximum speed 23 m.s-1

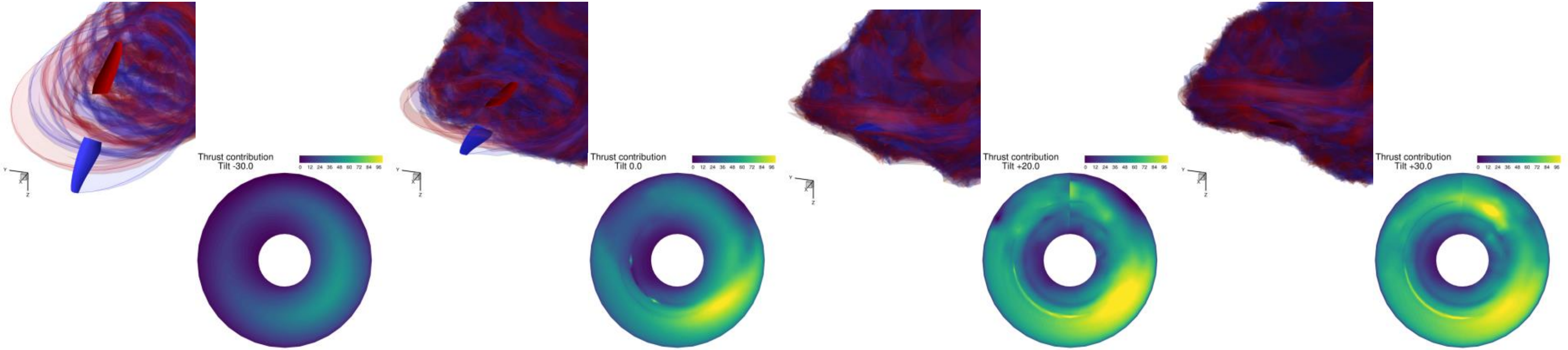
Rotor - Rotor interactions (DLR)



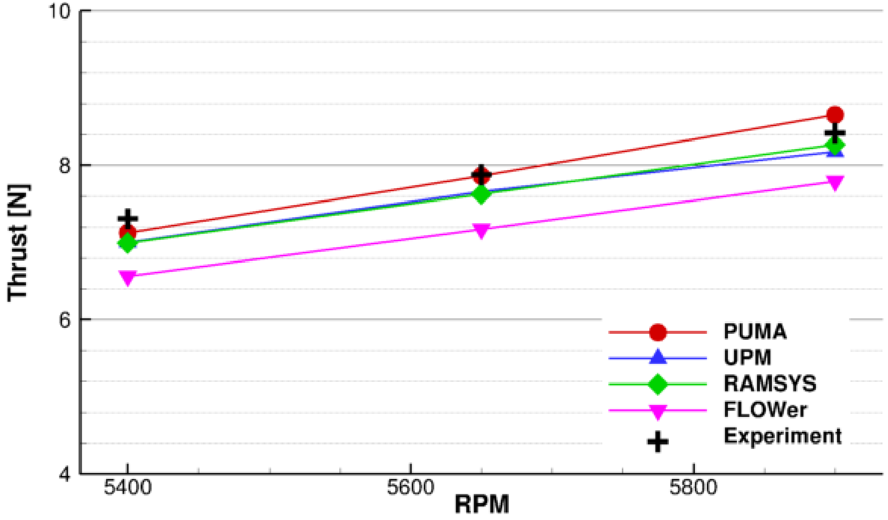


KDE12 - 2 bladed rotor - Isolated conditions - RPM 5400 - 12.9 $m.s^{-1}$

- Good agreement with experiment
- Good agreement between numerical tools on thrust
- More discrepancies on the power
- Discrepancies at high tilt angles due to wake interactions

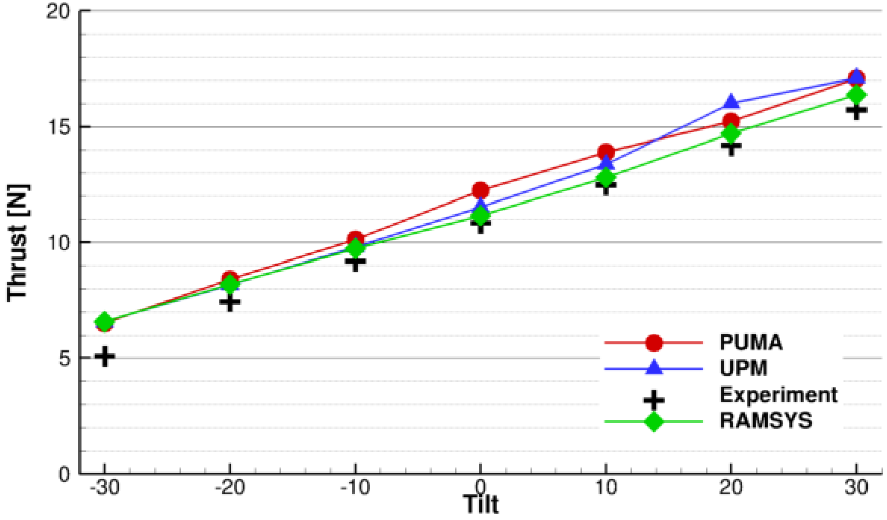


Rotor - Rotor interactions (DLR)



KDE12 - 2 bladed rotor - Isolated conditions - -10°tilt angle - 12.9 m.s^{-1}

- Experimental trends captured
- Acceptable agreement between numerical tools



KDE12 - 3 bladed rotor - Isolated conditions - RPM 5650 - 12.9 m.s^{-1}

- Good agreement with experiment
- Good agreement between numerical tools

Conclusions

- A working group gathering three universities and four research centers across five different European countries has been setup in order to investigate experimentally and numerically Rotor / Rotor wake interactions

- Three different experimental databases, representative of high speed helicopters and multicopters are produced and shared between participants

- A wide range of numerical tools ranging from low fidelity to high fidelity CFD solvers are evaluated against the experimental databases

- Experimental and numerical results are shared with the community through different papers presented at conferences or published in relevant scientific journals

Publications

- ✓ R. Boisard, “Aerodynamic Investigation of Rotor – Propeller Interactions on a Fast Rotorcraft“, 44th European Rotorcraft Forum, Delft, The Netherland, September, 18-20, 2018.
- ✓ R. Boisard and J. W. Lim, “Aerodynamic Analysis of Rotor/Propeller Wakes Interactions on High Speed Compound Helicopter”, 47th European Rotorcraft Forum, Virtual, 2021.
- ✓ T. Zhang, G. N. Barakos, “High-fidelity Numerical Investigations of Rotor-Propeller Aerodynamic Interactions“, Aerospace Science and Technology, 124, 107517, DOI: 10.1016/j.ast.2022.107517.
- ✓ R. Boisard, “ Numerical Analysis of Rotor / Propeller aerodynamic interactions on a high speed compound helicopter“, Journal of the American Helicopter Society, Volume 67, Number 1, January 2022, pp. 1-15, DOI: 10.4050/JAHS.67.012005.
- ✓ F. Lößle, A. Kostek, R. Schmid, “Experimental measurement of a UAV rotor’s acoustic emission“, Notes on Numerical Fluid Mechanics and Multidisciplinary Design, Vol. (2020)
- ✓ A. Kostek, F. Lößle, R. Wickersheim, M. Keßler, R. Boisard, G. Reboul, A. Visingardi, M. Barbarino, A. D. Gardner, “Experimental investigation of UAV rotor aeroacoustics and aerodynamics with computational cross-validation“, 48th European Rotorcraft Forum, Winterthur, Switzerland (2022)
- ✓ L. Lefevre, J. Delva, V. Nowinski, “Experimental evaluation of the aerodynamic rotor/propeller interactions in hybrid compound helicopters”, 47th European Rotorcraft Forum, Sep 2021, Virtual, France. ⟨hal-03386087⟩
- ✓ L. Lefevre, V. Nowinski, “Characterization of the propeller for the experimental evaluation of the aerodynamic rotor/propeller interactions in hybrid compound helicopters”, Onera-DLR Aerospace Symposium ODAS, Nov 2020, Braunschweig, Germany. ⟨hal-03104009⟩
- ✓ L. Lefevre, J. Delva, V. Nowinski, A. Dazin, “Experimental Evaluation of the Aerodynamic Rotor/Propeller Interactions on High Speed Helicopters, Efforts and Velocity Fields Measurements”, 78th VFS Annual Forum, Fort Worth, Texas, USA, May 10-12, 2022.
- ✓ F. Lößle, A. A. Kostek, C. Schwarz, R. Schmid, A. D. Gardner, M. Raffel, “Aerodynamics of Small Rotors in Hover and Forward Flight“, 48th European Rotorcraft Forum, Winterthur, Switzerland (2022)

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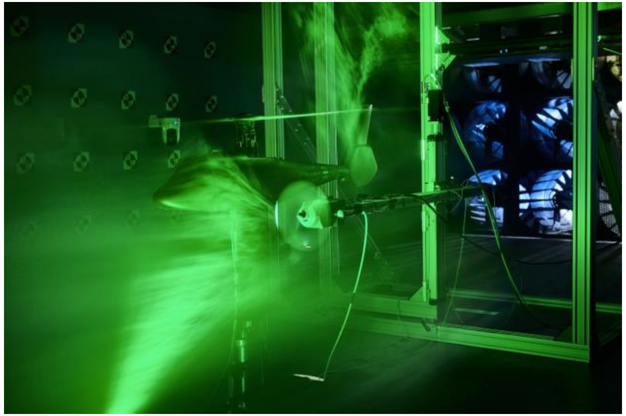

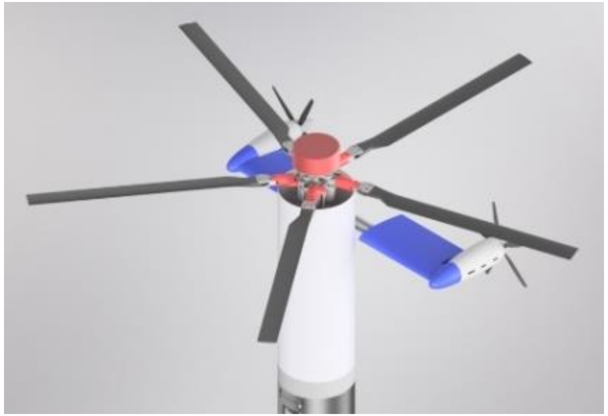

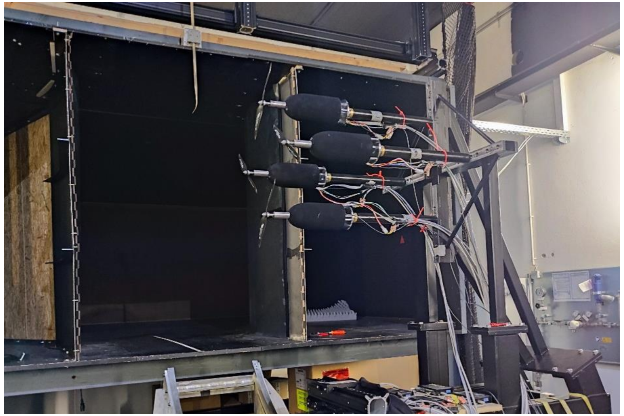

DLR

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