

LIGHTinPARIS		Marie Skłodowska-Curie Actions Second call for COFUND PhD fellowships
Employer	ONERA (French aerospace laboratory)*	
Doctoral School	EDOM (Waves and Matter)	
Domain	ONERA (Waves and Matter)	
Supervision		
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* The requirements for obtaining access authorisation to the DOTA laboratory are very strict as ONERA (the employer) is a research centre under the supervision of the French Ministry of the Armed Forces.		
PHD THESIS PROJECT		
WILIA-HR - Ultra-High-Resolution Wind Lidar for Aerodynamics using frequency modulation		
Summary / Abstract		
Doppler lidars measure the velocity of distant targets and atmospheric wind by analyzing the Doppler shift of light backscattered by aerosols. They are key tools for atmospheric and aerodynamic studies, but their spatial resolution, typically tens of meters, is limited by laser pulse duration. ONERA has developed a promising approach using fast frequency modulation, inspired by FMCW (frequency-modulated continuous-wave) ranging, achieving sub-meter resolution but requiring further optimization and dedicated signal processing. This PhD aims to significantly enhance the spatial resolution of 1.5-μm coherent Doppler wind lidars through modeling, simulation, and the development of a laboratory prototype. The work includes instrument simulation, signal-processing design, component selection, experimental validation, and real-wind measurements, with strong potential impact in experimental aerodynamics, especially in non-intrusive optical methods for flow sensing. Principal 3i dimension: intersectorial. Additional 3i dimensions: interdisciplinary; international		
Keywords		
• Instrumentation (sensors, detectors, LIDAR, optical diagnostics, ...) • laser • turbulence, wind tunnels • aerospace • non-intrusive metrology		

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Key Objectives

The objective of this thesis is, on the one hand, to deepen understanding of this fast frequency modulation technique by developing an instrument simulator that will optimize measurement parameters and design appropriate signal processing methods, and on the other hand, to develop a prototype of a hyper-resolved wind lidar that will demonstrate the gain in resolution, first in the laboratory and then in real wind conditions. The improvement in resolution opens up the possibility of observing aerodynamic phenomena that were previously inaccessible to conventional lidars, such as small turbulent structures or edge effects in flow characterization.

Project

Context and state-of-the-art of Scientific Research project

Various efforts have been made to improve the spatial resolution of coherent wind lidars, both in terms of signal processing and lidar architecture. ONERA has been a pioneer in this field, developing algorithms that have increased anemometric resolution by a factor of 2, a result obtained as part of Théo Martin's thesis, which is currently being finalized.

At the same time, teams at the University of Science and Technology of China have developed new coherent wind lidar architectures incorporating rapid phase modulations. After a demodulation stage, these techniques enable the lidar signal to be encoded spatially and temporally, thereby increasing the resolution. They have achieved sub-meter resolutions with significant ranges and are now state-of-the-art in this field.

Finally, several demonstrations of coherent wind lidars based on the FMCW technique have been carried out. However, this work did not exploit the signal from large particles and therefore did not benefit from the gain in resolution. The originality of this project lies in the use of signals from individual particles in a frequency modulation architecture to achieve centimeter-level resolutions that will be state-of-the-art in terms of wind lidar resolution.

Description

The work is structured around two complementary areas. The first area, modeling, aims to deepen understanding of the technique by developing a measurement simulator (MATLAB/Python) that integrates instrumental, statistical, and physical parameters; this simulator will be used to optimize the measurement method and design an appropriate signal processing technique. This phase will also make it possible to theoretically determine the achievable resolution limits according to the modulation characteristics and to guide the choice of components for the experimental implementation.

The second area, which is experimental and closely linked to the first, concerns the creation of a lidar prototype in the laboratory. It will include a design phase, followed by the assembly and characterization of the components. Initial tests on hard targets (distance and speed measurement) will validate the proper functioning of the prototype. Subsequently, short-range real wind tests will be conducted in the laboratory to evaluate the speed accuracy and spatial resolution of the system, and then to compare the experimental results with the simulations. The prototype will also be used to observe fine flow structures, on the order of

a few centimeters, using a dedicated laboratory setup. In the longer term, demonstrations at higher average speeds will be considered, using ONERA's experimental facilities.

The expected results of the thesis include the development of a comprehensive simulator to optimize system parameters and anticipate performance, the design and construction of a transportable prototype of a high-resolution wind lidar, and its experimental validation through a series of demonstrations in the laboratory and then in realistic wind conditions. This work should not only identify and overcome the main limitations of the technique, but also highlight its contribution in terms of resolution and accuracy for the study of aerodynamic flows. All of the advances made will be scientifically promoted through publications in peer-reviewed journals and presentations at international conferences.

Bibliography

- [1] <https://info.bridgerphotonics.com/blog/frequency-modulated-continuous-wave-fmcw-lidar>
- [2] <https://doi.org/10.35848/1347-4065/ad2f19>
- [3] <https://doi.org/10.1364/OL.566273>
- [4] <https://doi.org/10.1103/PhysRevFluids.8.L022701>
- [5] <https://doi.org/10.1364/OE.499407>

Facilities and quality of research environment available for the researcher

The doctoral student will be hosted in a stimulating research environment at ONERA Palaiseau, alongside several dozen other PhD students. She/He will work closely with specialists in lasers and lidars, benefiting from ONERA's long-standing expertise that spans laser-atmosphere interaction, laser source physics, system electronics, and advanced signal processing. The student will have the opportunity to attend weekly scientific meetings, present progress, and receive feedback from colleagues. Participation in French and international conferences and workshops is also planned.

In addition, collaboration with the Aerodynamics Department (ONERA/DAAA) will offer valuable exposure to the field of experimental aerodynamics and its challenges, including wind tunnel and laboratory flow measurements. Throughout the project, the student will be involved in all stages of the work: developing and running simulation codes, processing and analyzing experimental data, selecting and characterizing components, assembling the optical and electronic system, and evaluating the performance of the prototype.

3i Dimension - intersectorial interdisciplinary international

Description and expected outcomes

The project aligns with the 3i scope. ONERA, as the French aerospace lab, maintains strong ties with the aeronautics industry, offering the PhD fellow direct exposure to industrial contexts, needs, and contacts. The work itself is inherently interdisciplinary, positioned at the interface between laser physics, lidar instrumentation, signal processing, and experimental aerodynamics. The presence of a specialist in aerodynamic experiments within the supervision team ensures that the student will engage with real aerodynamic challenges, including wind-tunnel measurements and the associated constraints of aerospace applications. The project also has an international dimension: ONERA hosts researchers from various countries, participates in numerous European collaborations, and the co-supervisor (W. Patiño) is Colombian, reinforcing the multicultural environment. The expected outcome is to strengthen cooperation between optics and aerodynamics within Paris-Saclay and contribute to future developments of interest to the aeronautics sector.

Approximate timeline of internships / external stays corresponding to the 3i dimension

- Year 1 (October 2026 – September 2027) (~1 week) Visit to the ONERA aerodynamics department in Meudon to become familiar with the work environment, explore the facilities, meet the experts, and present the project.
- Year 2 (October 2027 – September 2028) Periodic visits (~4 per year) to the aerodynamics team to present progress, receive feedback, prepare experimental demonstrations, and attend wind tunnel tests for familiarization.
- Year 3 (October 2028 – September 2029) (~1 month) Planning, organization, and execution of lidar demonstrations in experimental aerodynamics facilities (to be defined with the team), followed by presentation and analysis of the results.

It is expected that the PhD student will undertake regular stays at the ONERA aerodynamics department, also located in the Paris metropolitan area (Meudon). Initially, these visits will allow the student to become familiar with the work environment, explore the facilities, and meet the experts. They will continue throughout the thesis to design experiments using the lidar in the aerodynamic facilities and ultimately to conduct demonstrations and present the results. The timeline for these visits is to be determined.

Profile of PhD fellow

PhD studies and research work require curiosity, creativity, rigour, teamwork, and organisational skills. A minimum B2 level of English is mandatory. The below criteria are specific to the thesis project.

pre-requisite	Strong academic background in optics (Fourier optics, light-matter interaction, laser physics, fibre optics or optoelectronics), with strong motivation for laboratory work and interest in physical phenomena.
pre-requisite	Solid academic background in mathematics for signal processing (Fourier transforms, basic statistics, random processes, and filtering).
advantageous	Proven skills in signal processing and signal simulation using Python and/or MATLAB.
advantageous	Experience with laser-based experimental setups for sensing, handling of fiber optics and/or free-space optics, as well as spectral signal analysis.
advantageous	Experience working in interdisciplinary projects and ability to communicate scientific results, both orally and in writing.

Ethics issues in the project as per Horizon Europe Ethics Self-assessment

Section 1. Human embryonic stem cells (hESCs) and human embryos (hEs)			No
Section 2. Humans	No	Section 3. Human cells and tissues	No
Section 4. Personal data	No	Section 5. Animals	No
Section 6. Third Countries	No	Section 7. Environment, health and safety	Yes
Section 8. Artificial Intelligence	No	Section 9. Other ethics issues	No
Section 10. Crosscutting issue: potential misuse of results			No

7. Environment, health and safety

All French labs are required to have health and safety procedures in place, which takes into account the use of high-energy light sources such as lasers of class 3 and above, and the use of hazardous / toxic chemical and biological products. The institution and the laboratory comply with the highest safety requirements, and PhD fellows have mandatory health and safety training, with additional training if required.