

ENabling Optimized DISruptivE airframe-propulsion integration concepts

H2020 Research and Innovation Action
Grant Agreement No 860103

Deliverable Reference Number: D8.10

Deliverable Title:
White paper on disruptive aircraft architectures

Lead participant: ONERA
Contributing participant(s): all

30 October 2024

Start date of project: 1st of June 2020
Duration: 54 months

Type		
R	Document, report	X
DEM	Demonstrator, pilot, prototype, etc.	
DEC	Websites, patent fillings, videos, etc.	
ORDP	Open Research Data Pilot	
Dissemination Level		
PU	Public	X
CO	Confidential, only for members of the consortium (incl. Commission Services)	

APPROVAL

Title	Issue	Revision
White paper on disruptive aircraft architectures	1	1
Author(s)	**Date**	
E. Manoha (ONERA)	28/10/2024	
Revised and Approved by	**Date**	
C. Schram (VKI)	28/11/2024	

Contents

1 Introduction **4**

2 TRL assessment of propulsion systems/concepts **5**
2.1 Wall-mounted and buried propulsion systems 5
2.2 Distributed pylon- and control surface-mounted propulsion systems 6
2.3 Multi-rotor systems 7

3 TRL assessment of prediction and optimization methods/approaches **7**
3.1 High-fidelity CAA methods for optimization 7
3.2 Low-CPU prediction tools for optimization 8
3.3 Optimization methods for installation effects 8

4 TRL assessment of noise reduction technologies **9**
4.1 Blade Leading Edge / Trailing Edge serrations 9
4.2 Porous materials and advanced liners 9

5 Conclusion **9**

1 Introduction

This white paper outlines the essential steps needed to transition from the current low-to-mid Technology Readiness Level (TRL) milestones achieved by the ENODISE project towards the maturation of innovative, sustainable airframe-propulsion integration solutions. These concepts are pivotal for the future of small aviation, Urban Air Mobility (UAM), and commercial aviation. The document will provide a strategic roadmap to accelerate the development of greener, disruptive technologies, highlighting the key areas for research, collaboration, and investment to enable a cleaner and more efficient aviation ecosystem.

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge / technology gaps (within scope of ENODISE)	Targeted post-ENODISE TRL
Wall-mounted and buried propulsion systems	2	Effect of interactions with incoming turbulent boundary layer on noise generation and propulsive efficiency?	4
Distributed pylon- and control surface-mounted propulsion systems	Airworthiness: 6-7 Noise: 1-2	Effect of potential / viscous interactions on noise generation and propulsive efficiency? Acoustic interactions between propulsors?	5
Multi-rotor systems	Airworthiness: 6-7 Noise: 1-2	Importance of multi-stage rotor-stator-rotor potential and viscous interactions on noise generation and propulsive efficiency?	4
High-fidelity CAA methods for optimization	2	CPU costs compatible with optimization constraints (especially evolutionary algorithms)?	4
Low-CPU prediction tools for optimization	2-3	Capabilities to model accurately enough the interaction of the propulsion system with nonuniform turbulent flows?	5
Optimization methods for installation effects	2-3	Solving multi-objective problems accounting for noise, propulsive efficiency and gaseous emissions?	4
Blade LE/TE Serrations	2	Efficiency to reduce incoming turbulent boundary layer, pylon and multi-stage rotor interaction noise?	4
Porous materials and advanced liners	2-3	What are the physical mechanisms involved in flow-porous interactions and how to model them?	4

Figure 1: TRL of the concepts and technologies involved in the development of future aircraft architectures, estimated at the start at the project, identified knowledge/technology gaps that were addressed by ENODISE, and targeted TRL by the end of the project

The content of the white paper is the outcome of a dedicated internal TRL assessment and Roadmap definition workshop, organized at the end of the project. The workshop aimed to evaluate the project outcomes concerning the key aspects addressed throughout the course of ENODISE, specifically: (i) the analysis of both favorable and adverse aerodynamic and aeroacoustic interactions within tightly integrated propulsion architectures, (ii) the development of reliable experimental databases across multiple aeroacoustic facilities, along with their cross-validation, (iii) the implementation of efficient and accurate simulation and optimization frameworks tailored for both small aviation and the broader aircraft industry, (iv) the curation, documentation, and analysis of extensive experimental and numerical datasets, and finally, (v) the exploration of the potential for advanced noise mitigation technologies, both within the aeronautical sector and in other industries such as automotive and wind energy. The workshop sought to synthesize the main conclusions in a manner that is both insightful and accessible, catering to newcomers in the field, young researchers, and industrial R&D managers. The ENODISE Advisory Board members, as well as key stakeholders and policy-makers were invited to take part in the discussion.

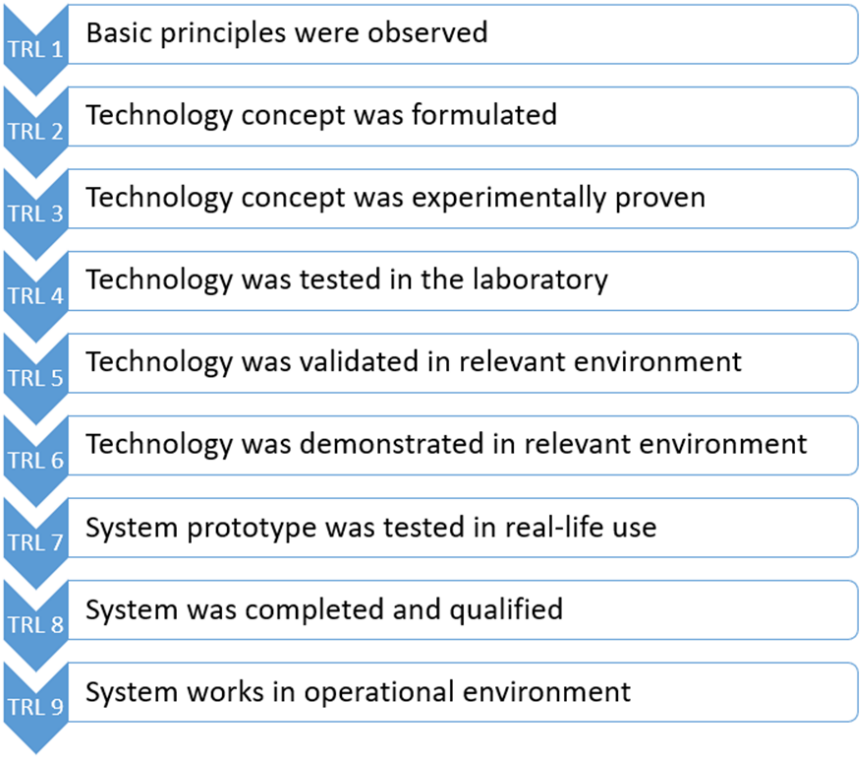


Figure 2: Technology Readiness Levels 1-9

2 TRL assessment of propulsion systems/concepts

2.1 Wall-mounted and buried propulsion systems

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge / technology gaps (within scope of ENODISE)	Targeted post-ENODISE TRL
Wall-mounted and buried propulsion systems	2	Effect of interactions with incoming turbulent boundary layers on noise generation and propulsive efficiency?	4

This technology was tested in the laboratory.

Roadmap Recommendations:

- For future studies on these concepts, participants recommend increasing the size of the configurations under investigation, as well as the corresponding Reynolds and Mach numbers, to make the studies more representative. This should include considerations of shock noise, which is relevant at higher speeds.
- Participants also suggest generating a more representative incoming turbulent boundary layer (TBL) by using longer development distances along an axisymmetric body, rather than relying on plane plates with simple S-shaped surfaces.

- It was advised that shrouded rotor-stator configurations be made more realistic, particularly in terms of solidity, to better reflect practical conditions.
- The operational parameters, such as pressure ratio and varying angle-of-attack, should be made more realistic to ensure the studies better represent real-world scenarios.
- Future research should focus on complete aircraft systems, rather than academic configurations, to account for more realistic acoustic installation effects. Additionally, a more pertinent analysis of the net thrust of the system should be conducted, considering various operating conditions. The goal should be to approach the theoretical limit of achieving no kinetic energy in the wake, which could result in fuel savings of approximately 15-20%.

2.2 Distributed pylon- and control surface-mounted propulsion systems

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge / technology gaps (within scope of ENODISE)	Targeted post-ENODISE TRL
Distributed pylon- and control surface-mounted propulsion systems	Airworthiness: 6-7 Noise: 1-2	Effect of potential / viscous interactions on noise generation and propulsive efficiency? Acoustic interactions between propulsors?	5

This technology was validated in a relevant environment (Pipistrel Vertical Solutions' mock-up, built using realistic dimensions/wing shape, test will consider both lift and noise).

Roadmap Recommendations:

- For future studies on these concepts, participants recommend scaling up the configurations under investigation, thereby increasing the Reynolds and Mach numbers, to better reflect real-world conditions.
- It is suggested that further investigation be conducted into the aerodynamic interactions within multi-rotor configurations, potentially including staggered rotor arrangements.
- The effects of the system's angle of attack should be considered across different phases of flight, as well as the relative angle between the rotor axes and the airframe.
- It would be beneficial to explore the potential advantages of reducing propeller sizes and loading while increasing blade counts. This approach may help mitigate adverse aerodynamic interactions and noise production, while still preserving net thrust.
- A key objective could be to gain a deeper understanding of the physics behind the interactions between the Distributed Electric Propulsion (DEP) system and the wing, particularly when high-lift devices are deployed or control surfaces, such as ailerons, are in operation.
- There is also interest in investigating the potential aerodynamic benefits of modulating thrust along the span of the propellers. This could impact the spanwise lift distribution and induced drag, potentially offering performance improvements.
- Lastly, participants recommend investigating the technological requirements for efficiently synchronizing the phasing of propellers to reduce noise.

2.3 Multi-rotor systems

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge / technology gaps (within scope of ENODISE)	Targeted post-ENODISE TRL
Multi-rotor systems	Airworthiness: 6-7 Noise: 1-2	Importance of multi-stage rotor-stator-rotor potential and viscous interactions on noise generation and propulsive efficiency?	4

This technology was tested in the laboratory.

Roadmap Recommendations:

- It is recommended to conduct further investigation into the aerodynamic and acoustic benefits of synchronizing the phasing of co-rotating propellers.
- Future performance analyses and predictions should incorporate the effects of incoming flow misalignment, accounting for flight phases beyond hovering.
- The advantages and drawbacks of shrouded rotors should be further explored, particularly with regard to safety, noise scattering and amplification, noise mitigation through duct treatments, and the introduction of additional noise sources.
- Consideration should be given to more realistic shroud designs, weighing the trade-off between added weight and increased thrust, as well as the impact of misaligned incoming flow.
- Finally, it is advised to include more realistic installation scenarios in future studies, particularly the effects of pylons on noise generation.

3 TRL assessment of prediction and optimization methods/approaches

3.1 High-fidelity CAA methods for optimization

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge / technology gaps (within scope of ENODISE)	Targeted post-ENODISE TRL
High-fidelity CAA methods for optimization	2	CPU costs compatible with optimization constraints (especially evolutionary algorithms)?	4

This technology was tested in the laboratory.

Roadmap recommendations:

- Development of Advanced Algorithms to generate synthetic turbulence at the inlet of the computational domain.
- Reduction of CPU Costs for Scale-Resolved Simulations to below 1000 CPU-hours per evaluation. Achieving this will facilitate the use of evolutionary algorithms for optimization purposes, thereby improving simulation performance and enabling more extensive parameter studies.
- Improvement of Non-Reflecting Boundary Conditions (NRBCs): Accurate aeroacoustic numerical simulations necessitate the development of enhanced Non-Reflecting Boundary Conditions (NRBCs).

- Advancement of Mesh Deformation Techniques in Large Eddy Simulations (LES)

3.2 Low-CPU prediction tools for optimization

This technology was validated in a relevant environment (Pipistrel Vertical Solutions' full-scale mock-up)

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge / technology gaps (within scope of ENODISE)	Targeted post-ENODISE TRL
Low-CPU prediction tools for optimization	2-3	Capabilities to model accurately enough the interaction of the propulsion system with nonuniform turbulent flows?	5

Roadmap recommendations:

- Improved integration of non-hierarchical multi-fidelity tools, spanning from canonical analytical solutions to semi-empirical and mid-fidelity methods (such as panel methods, BEMT, etc.), in order to enable the use of evolutionary algorithms for optimization.
- Enhancement of low-order models to better account for anisotropic turbulence, as encountered in Turbulent Boundary Layers (TBLs) or wakes.
- Refinement of low-order models to more accurately represent realistic shrouded rotor-stator configurations.
- The impact of inflow distortion on the development of turbulent wakes past a rotor (i.e., rotor-stator interaction noise) should also be considered.

3.3 Optimization methods for installation effects

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge / technology gaps (within scope of ENODISE)	Targeted post-ENODISE TRL
Optimization methods for installation effects	2-3	Solving multi-objective problems accounting for noise, propulsive efficiency and gaseous emissions?	4

This technology was tested in the laboratory.

Roadmap recommendations:

- Investigating hybrid optimization methods that combine gradient-based techniques with deterministic heuristics.
- Exploring hybrid optimization methods that dynamically integrate experimental and numerical tools for the development of a surrogate model across the design space.

4 TRL assessment of noise reduction technologies

4.1 Blade Leading Edge / Trailing Edge serrations

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge /technology gaps (within the scope of ENODISE)	Targeted post-ENODISE TRL
Blade LE/TE Serrations	2	Efficiency to reduce incoming turbulent boundary layer, pylon, and multi-stage rotor interaction noise?	4

This technology was tested in the laboratory (GPU Prime's simulations)

Roadmap recommendations:

- A promising way forward is to further investigate the performance of LE/TE serrations in combination with a shrouded rotor and for varying rotor angles of attack.
- Another recommendation is to encourage research on the extrapolation of the LE/TE benefits from low-Reynolds number experiments at the laboratory scale to full-scale applications.

4.2 Porous materials and advanced liners

Concept / Technology	Pre-ENODISE estimated TRL	Knowledge /technology gaps (within the scope of ENODISE)	Targeted post-ENODISE TRL
Porous materials and advanced liners	2-3	What are the physical mechanisms involved in flow-porous interactions and how to model them?	4

This technology was tested in the laboratory.

Roadmap recommendations:

- It is considered of primary importance to improve our understanding of the physical mechanisms responsible for the observed noise attenuation, with a view to modeling them in numerical prediction tools.
- It is also suggested to explore the potential benefits of porous mitigation in a DEP configuration, where the interaction is strong enough to result in noise reduction.

5 Conclusion

The ENODISE project has demonstrated a clear pathway toward the maturation of greener and more efficient aircraft technologies. Continued support for scaled experiments, targeted R&D funding, and collaborative efforts will be vital to bridging the gap to operational readiness and achieving sustainable aviation goals in line with the FlightPath 2050 objectives.