

ENabling Optimized DISruptivE airframe-propulsion integration concepts

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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)	

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1 Introduction

This report outlines guidelines for the deployment of efficient and accurate aeroacoustic simulation and optimisation platforms, derived from contributions by key partners in the project, including ONERA, RWTH, UBRI, SISW, VKI, DLR, and GPUP. These guidelines serve as a practical framework for researchers, industrial engineers, and decision-makers to enhance the efficiency and accuracy of aeroacoustic simulation tools in the design and optimisation of propellers and airframe interactions. By following these recommendations, stakeholders can streamline their workflow and achieve improved results across different platforms.

2 Guidelines for Aeroacoustic Simulation and Optimisation

This section presents guidelines structured into key topics: simulation setup, execution, and optimisation for industry and research applications.

2.1 Simulation Setup Phase

During the initial setup of the numerical simulations, the user should consider the following essential factors:

1. **Installation Effects**: The installation of rotor as observed in realistic aircraft configuration, as shown in Fig. 1 should be considered early in the design process as the installation effects significantly influence the noise generation. Integrating these installation effects as soon as possible ensures more accurate optimisation results and helps mitigate potential issues that could arise later in the development cycle.

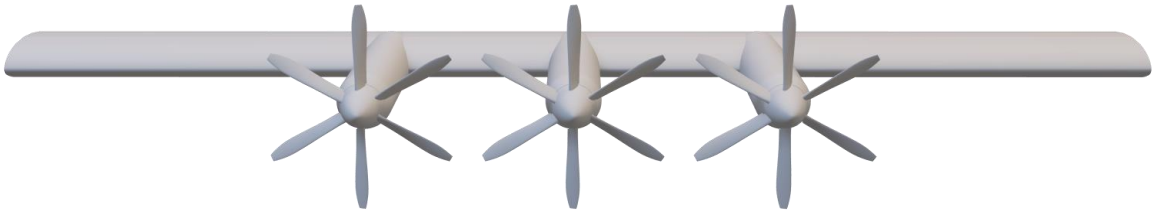


Figure 1: Configuration B1 (CAD data provided by TU Delft).

2. **Low-to-Mid Order Methods**: The use of low-to-mid fidelity methods in the design and optimisation of propellers is recommended for efficiently integrating installation effects. These methods offer valuable insights into the installation noise without the need for overly complex or resource-intensive approaches, making them suitable for both initial design stages and subsequent optimisation efforts. Fig. 3 illustrates the optimisation method used by PVS for multi-rotor optimisation, which utilises panel method aerodynamics through FlightStream and propeller tonal and broadband noise quantification via the BATMAN acoustics toolbox. Furthermore, these low-fidelity methods can be combined with mid and high-fidelity methods, such as scale resolving simulations to improve the accuracy and robustness of the models.

3. **Multi-Fidelity Simulation**: A multi-fidelity approaches includes Unsteady Reynolds-Averaged Navier-Stokes (RANS) models coupled with random particle method for synthetic turbulence generation and Acoustic Perturbation Equations as well as wall-modelled Large Eddy Simulations (LES) on coarse grids accelerated on GPUs. For far-field noise propagation, such methods use the Ffowcs-Williams and Hawkings (FW-H) approach, which offers a cost-effective solution for noise prediction and propeller optimisation. This approach allows for flexible adjustment of simulation fidelity based on the specific noise sources (isolated propeller noise, propeller-wing installation noise or propeller-pylon noise being investigated) ensuring both accuracy and computational efficiency.

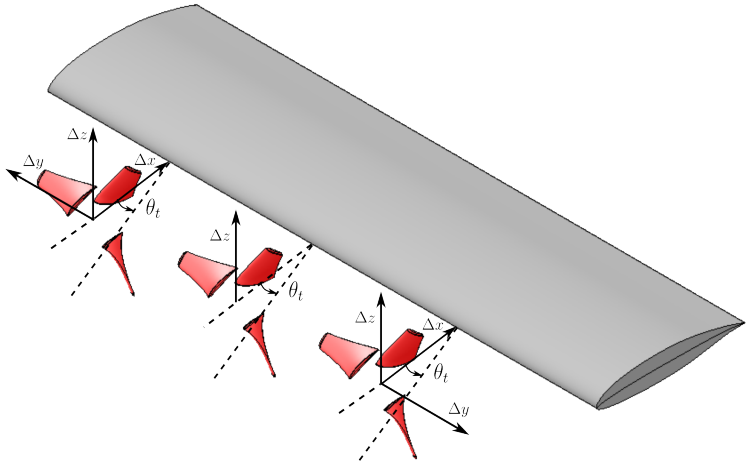


Figure 2: Optimisation variables for multi-rotor optimisation (Figure by PVS)

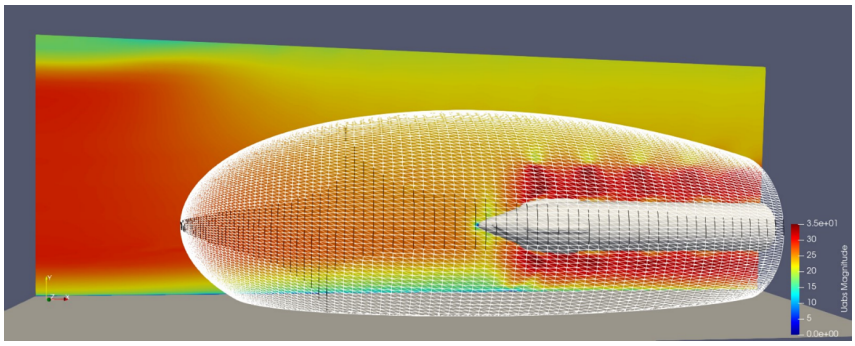


Figure 3: Permeable FW-H surface employed for the modelling of boundary-layer-rotor interaction noise (Figure by GPUP)

2.2 Execution Phase

When conducting the simulation, the following considerations should be taken into account:

1. **Noise Source Consideration**: Simulations based on RANS and low-order models may be sufficient for noise level predictions, depending on the noise source. However, for complex propeller-airframe interactions, which are characterised by turbulence interactions, high fidelity simulations such as those based on wall-modelled LES should be employed.

2. **Surrogate Models for Optimisation**: It is advisable to use fast, multi-fidelity surrogate models to describe propeller-airframe interactions with sufficient accuracy. These models, even if they require numerical calibration parameters (e.g. based on the higher-fidelity calculations), are highly beneficial when used in evolutionary optimisation algorithms, as they significantly reduce computational time while maintaining an acceptable level of accuracy.

3. **Scalability and Robustness**: It is important to validate the scalability, performance, and robustness of simulation tools, particularly when applied to full-scale geometries. Demonstrating the efficiency of these tools in industrial workflows is important to their widespread adoption and practical application.

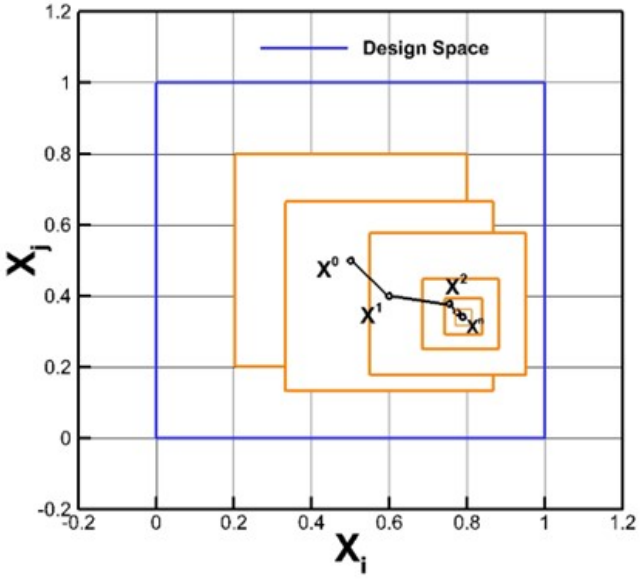


Figure 4: A schematic of the iterative process employed for the development of meta-model and a design parameter for the optimisation (Figure by GPUP)

2.3 Optimisation for Industry and Research Applications

The optimisation of aeroacoustic performance is important in both industry and academic research, providing a pathway for reducing noise levels and improving overall aerodynamic performance. By refining these processes, key challenges of the modelling and simulation such as computational cost, scalability, and data management can be effectively addressed. The following recommendations offer additional insights into how optimisation can be enhanced in various contexts, with contributions from project partners:

1. **Surrogate Models for Propeller-Airframe Interactions**: Robust surrogate models that describe fundamental interactions between propellers and airframes should be employed to balance accuracy and computational cost. Fast low-fidelity approaches, such as panel methods or semi-empirical models, are particularly effective for faster optimisation cycles, making them suitable for industrial applications where time and cost constraints are important.

2. **Low-to-Mid Order Methods for Design Optimisation**: Integrating low-to-mid order methods early in the design and optimisation process ensures a more accurate assessment of installation effects, which are essential for noise reduction. These methods not only optimise propeller performance but also address noise generation, leading to improved outcomes in both research and industrial applications.

3. **Mid-Fidelity Simulation Approaches**: Adopting multi-fidelity simulation approaches like URANS and coarse-grid LES, which can be combined with methods like Ffowcs-Williams and Hawkings (FW-H) for efficient far-field noise propagation modelling, enables a cost-effective yet reliable prediction of aeroacoustic noise. Tailoring the fidelity of the simulation to the complexity of the noise source allows researchers and industry professionals to focus their resources effectively during the optimisation process.

4. **Balancing Accuracy and Computational Cost**: Simulations based on URANS often provide sufficient accuracy for predicting mostly tonal noise, making them ideal for industrial applications where computational resources are limited. For more complex broadband noise sources, higher

fidelity methods like wall-modelled LES may be necessary. Recent advancements in computational architectures, such as GPUs, have made resource-intensive simulations more feasible, helping to balance accuracy with computational efficiency.

5. **Challenges in Mesh Deformation and Optimisation Tools**: High fidelity simulations such as LES offer scale resolving information of the flow. However integrating them with optimisation tools, particularly mesh deformation, remains a challenge. Further research into integrating high-quality mesh deformation tools into flexible unstructured grid generation approaches such as OpenFoam snappy-hexa-meshing within the LES framework is recommended to streamline workflows and make high-fidelity simulations more practical for both industry and research applications. Addressing these challenges will improve the efficiency of optimisation processes and enhance overall simulation throughput time.

By incorporating these optimisation strategies, both industry and academic researchers can reduce time to solution for aeroacoustic applications. The ability to adapt methods of different fidelity to characterise the specific noise sources at hand, whilst dealing with computational resource limitations ensures that these guidelines are applicable across a wide range of applications, from early-stage research to a refined industrial design model.

2.4 Data Management and Validation

Effective data management and validation of simulation tools are critical for ensuring accuracy and consistency:

1. **Data Awareness**: Early identification of the data required from both experimental and numerical approaches is essential for supporting the validation of aeroacoustic simulation tools. Clear communication of data requirements during the planning phase will streamline the validation process, ensuring that all necessary information is collected efficiently and comprehensively.

2. **Re-Running Configurations**: It is recommended that external researchers re-run existing configurations to build a broader dataset for validation purposes. Targeted publications for final users can further facilitate the adoption and use of these tools within the wider research and industrial communities, promoting consistency and reliability in simulation outcomes.

3 Lessons Learned and Recommendations

Several key lessons emerged from the project, which can guide future improvements in aeroacoustic simulation platforms.

1. **Computational Bottlenecks**: Modelling based on wall-modelled LES is computationally intensive, however, advancements in computational architectures such as GPU-computing and numerical algorithms able to utilise these have made such scale-resolving simulations increasingly feasible. Still, integrating optimisation tools with wall-modelled LES solvers, particularly in terms of flexible mesh deformation approaches, remains a challenge. Further research is needed to address this bottleneck and improve the efficiency of these high-fidelity simulations.

2. **Noise Prediction**: URANS simulations can predict tonal noise and some of the broadband noise sources using synthetic turbulence methods, making such approaches a practical and efficient choice for aeroacoustic optimisation. However, for more complex scenarios such as multi-propeller-airframe interactions, URANS can be computationally prohibitive. In these cases, the use of surrogate models is recommended to reduce the computational burden while maintaining accuracy.

3. **Tool Availability**: Tools developed within academic research should be made more accessible to industry at reasonable costs, particularly when they have benefited from public funding. This would enable broader adoption of advanced aeroacoustic tools, facilitating their integration into

industrial workflows and promoting innovation across the sector. Therefore, industrial partners are encouraged to work closely with academic researchers to speed up the evaluation and adaptation of new tools.

4 Conclusion

The guidelines provided in this report offer a viewpoint on deploying efficient and accurate aeroacoustic simulation and optimisation platforms. By following these recommendations, researchers and industrial stakeholders can improve the reliability, scalability, and overall effectiveness of aeroacoustic simulations. This, in turn, will contribute to advancements in propeller design and noise reduction technologies, leading to more efficient and environmentally sustainable solutions in aviation.