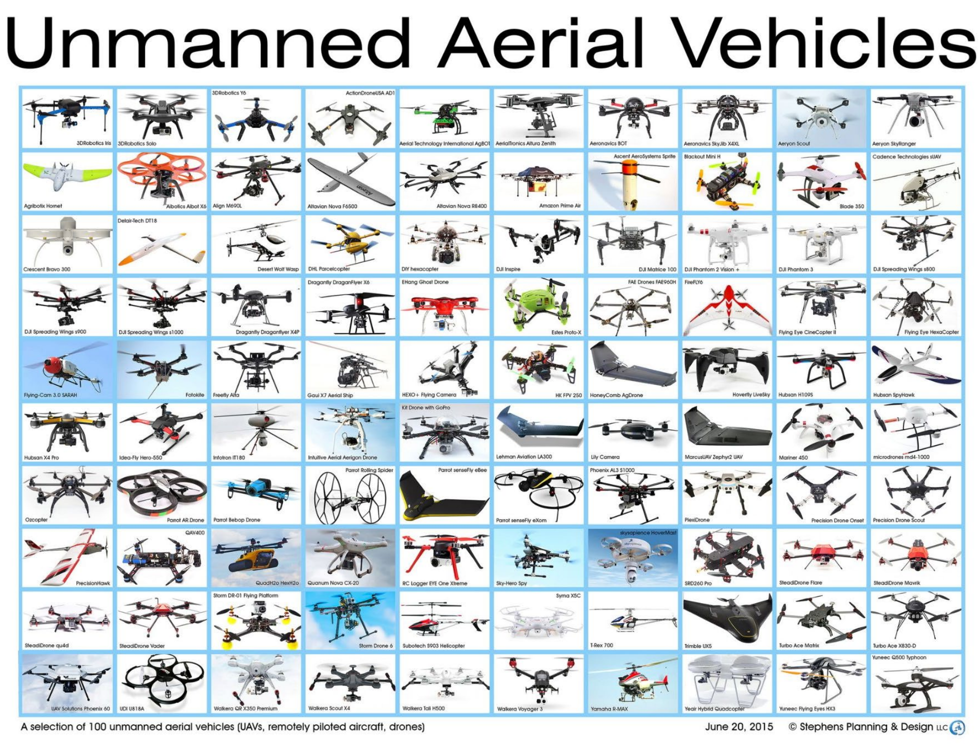
Improving the Performance of a Quadcopter Drone with OMNIS™

Drones have proven to be an efficient solution for a large range of applications within the military, industrial, and private consumer domains. In the last decade, their use has been soaring. It is estimated that 274 600 drone units were sold in 2018 while the market is anticipated to rapidly develop at an annual growth rate exceeding 50% [1].

There are two main categories of aerial drones, namely rotorcraft capable of vertical take-off and landing (VTOL) and fixed-wing vehicles. Multirotor or multicopter rotorcraft drones are employed in a wide range of applications. They offer numerous advantages over the fixed-wing systems such as the ability to hover (maintain a constant altitude), take-off, and land vertically as well as ease of control and operation in general. Such capabilities allow for unique applications such as, for instance, indoors operations or wind turbine and construction site inspection where fixed-wing vehicles could not be efficiently used.



Examples of modern commercial drone configurations [2]

On the other hand, multicopters have several inherent shortcomings such as flight time and range. The principal rotorcraft phenomena such as vortex interaction and vortex ring state remain applicable as well.

Even modern and innovative electric drones suffer from a short flight time, limited to around 20-30 minutes depending on flight conditions. A quadcopter flight time can vary significantly between the forward flight and hover modes [3]. Only very few conventional electric multicopter drones in the high-end class can reach flight times close to 1 hour. The application of Computer-Aided Engineering (CAE) techniques and Computational Fluid Dynamics (CFD) in particular can help to improve the efficiency of drones and extend their flight time and range.

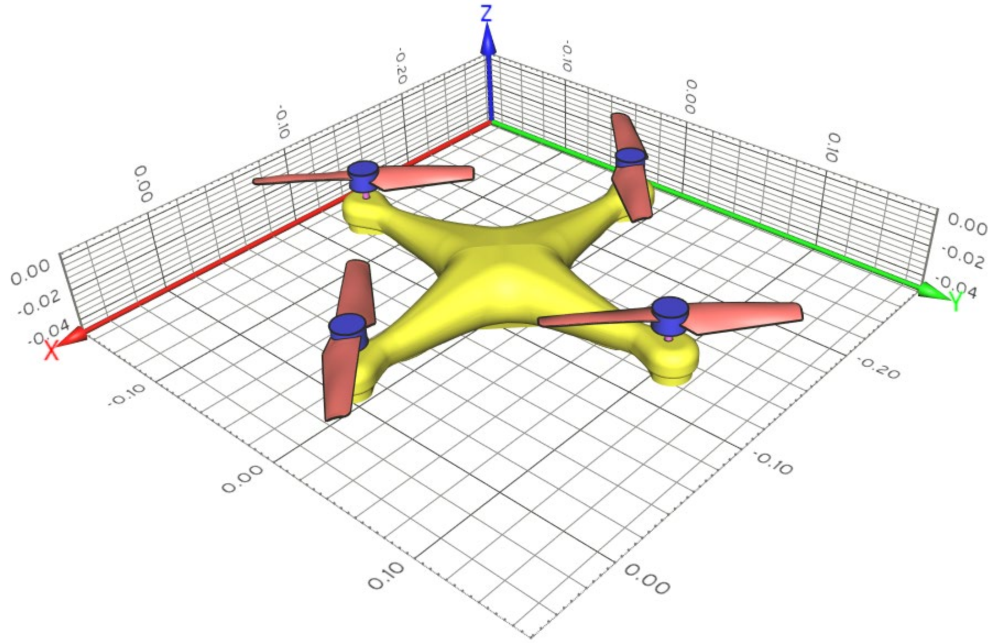
Cadence CFD software features a wide range of tools allowing efficient simulation and optimization of multirotor drones. The fully integrated multidisciplinary environment OMNIS™ paves the way for faster and more accurate quadcopter simulations by employing techniques such as the combination of structured and unstructured meshes within the same solver and high-fidelity unsteady simulations using the Nonlinear Harmonic Method (NLH). Cadence's NLH module has proven to be a cost-effective solution for unsteady simulation being up to two orders of magnitude faster compared to a conventional unsteady simulation. A case study presented in this article demonstrates the application of these techniques to a simulation and optimization of an industrial drone.

Case Study: Quadcopter Drone Meshing and Simulation

The present case study is devoted to demonstrating the possibility of an efficient computational aerodynamic simulation and optimization of drone performance by means of the Cadence CAE software suite with OMNIS™ at its core. The hover mode that represents the minimum flight time case is considered.

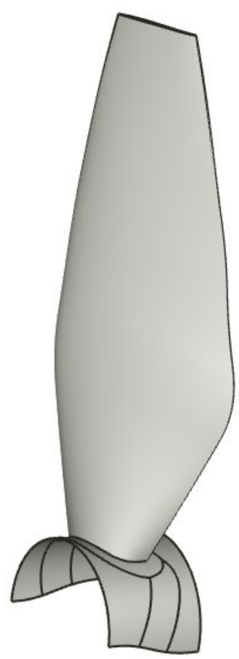
Geometry

The studied geometry corresponds to the most widely used rotorcraft drone configuration. The drone manufacturers for the private consumer sector (amateur video shooting, racing drones, drones for kids, etc) predominantly rely on such a drone configuration. The quadcopter geometry was described in the paper [4] and was kindly provided by its authors. The CAD model was generated by Miguel Monasor Pascual, Mechanical and Aerospace Engineer. Compared to the provided geometry, a new propeller geometry was generated and is retained for the study.



The considered drone geometry and its dimensions. The drone CAD files are provided by the authors of [4].

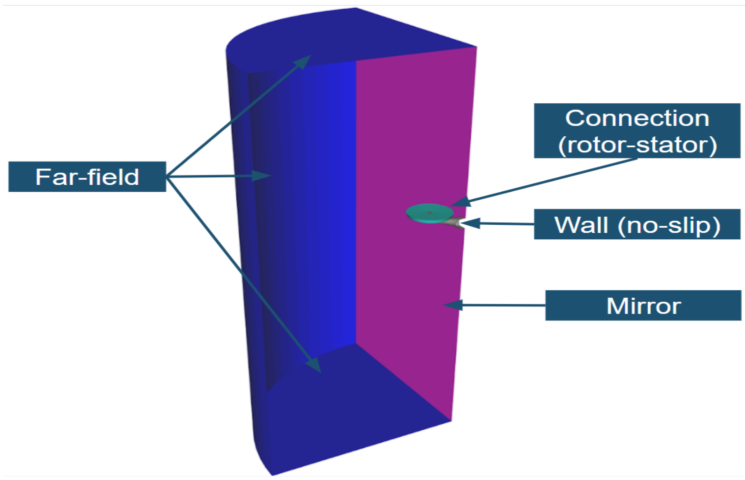
The propeller blade was modelled with Cadence parametric modelers taking into account the required thrust. Multiple sections were extracted from the original geometry and they were stacked together in order to build the 3D blade. An appropriate twist distribution was also provided so that the parametrized blade resembles the original geometry as close as possible.



New blade geometry model (Span length = 0.1095m, Root chord = 0.0051m, Tip chord = 0.0036m)

The setup benefits from the symmetry of the drone geometry. One-fourth of the drone is included inside the computational domain, hence including only one arm. The domain features the following boundary conditions (see also the figure below):

- Solid no-slip walls assigned to the airframe and propeller,
- External (far-field) boundaries, placed sufficiently far from the body,
- Mirror boundaries, to take the presence of the neighboring rotors rotating in the opposite direction into account.



Computational domain indicating assigned boundary conditions and internal connections

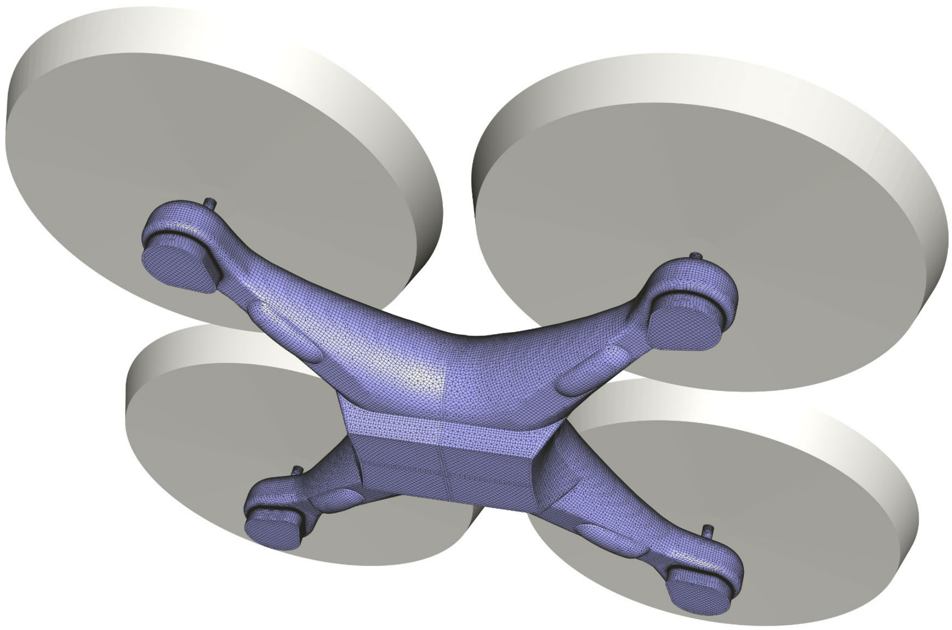
The chosen domain definition represents a practical case. It corresponds to a “free air” simulation at a hovering altitude that is high enough to neglect any ground effect.

Meshing

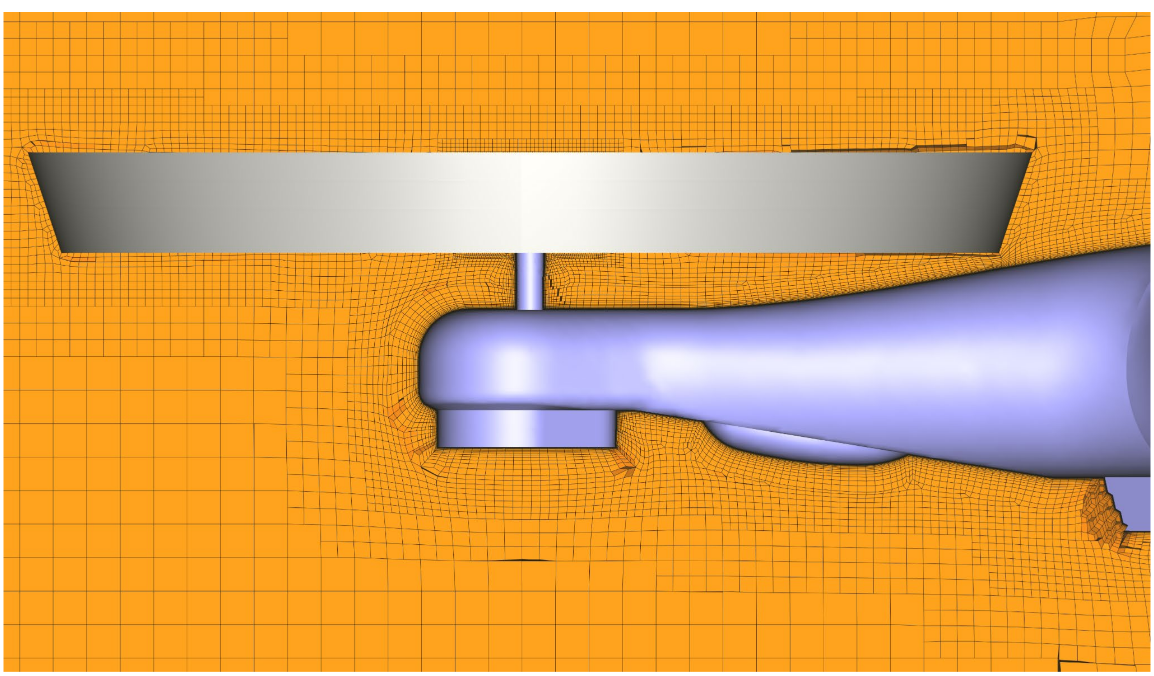
Due to the complexity of the drone domain, an automatic unstructured mesh is generated using OMNIS^{TM}/Hexpress. OMNIS^{TM}/Hexpress automatically refines the mesh near high curvature areas and edges of the geometry, thus minimizing user interaction. This leads to a high-quality mesh that is also sufficiently robust to be used within an optimization.

One blade of the propeller is meshed using the multiblock structured mesh generator OMNIS^{TM}/AutoGrid. AutoGrid can use a wizard-type approach for meshing various types of turbomachinery configurations with different characteristics, such as centrifugal pumps, axial compressors, etc. This approach makes it very easy and fast to generate a high-quality structured mesh with multiple grid levels. A variable tip gap is applied to the blade. Also, a matching periodic connection between the two periodic faces is automatically ensured and computed. Meshing only one blade combined with such a connection leads to a two-fold cell count reduction, with the corresponding simulation speed-up.

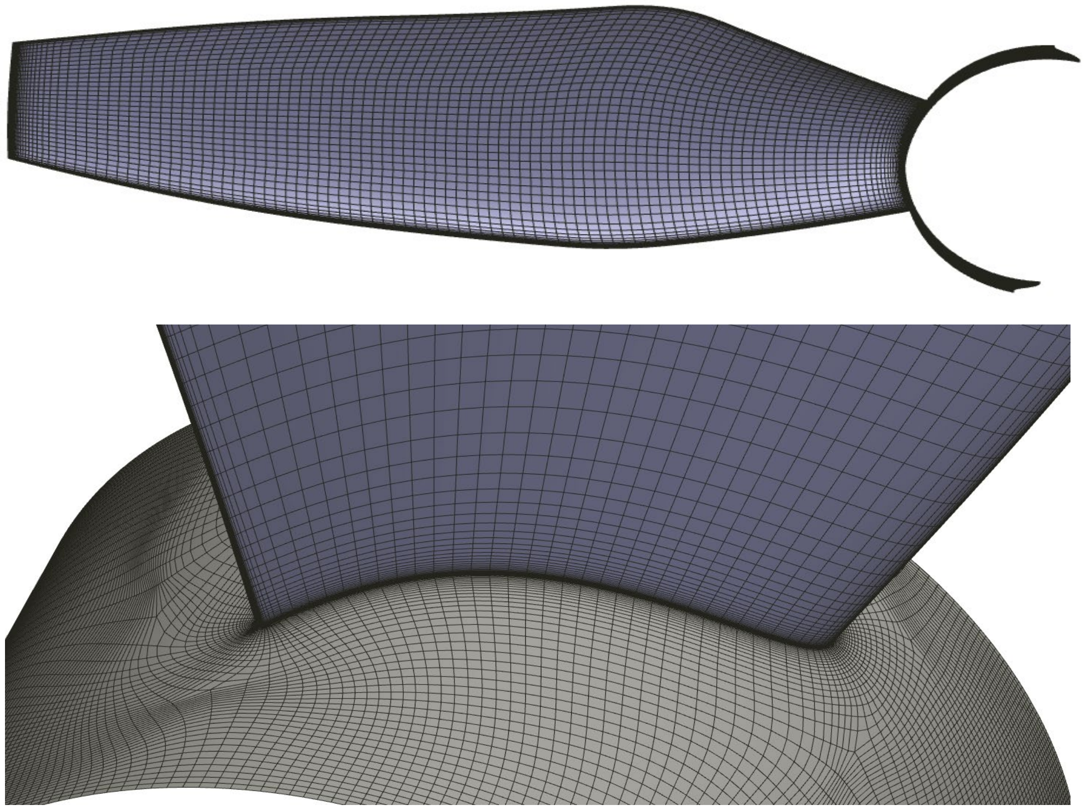
Both meshes are assembled together and a rotor-stator interface is set up between the two domains. It is worth noting that OMNIS™ allows the user to combine and run structured and unstructured meshes in the same computation, taking advantage of the intrinsic speed advantage of using structured meshes and of the robustness of the unstructured ones. This also reduces RAM and disk consumption. The approach does not require tuning any solver settings.



Rotating blocks (in grey) and surface mesh on the quadcopter airframe. A graphical mirroring is applied to a sector to recover a full drone geometry for visualization purposes



Rotating block (in grey) and volume mesh around the quadcopter airframe



Mesh on the quadcopter blade and hub for the rotating block

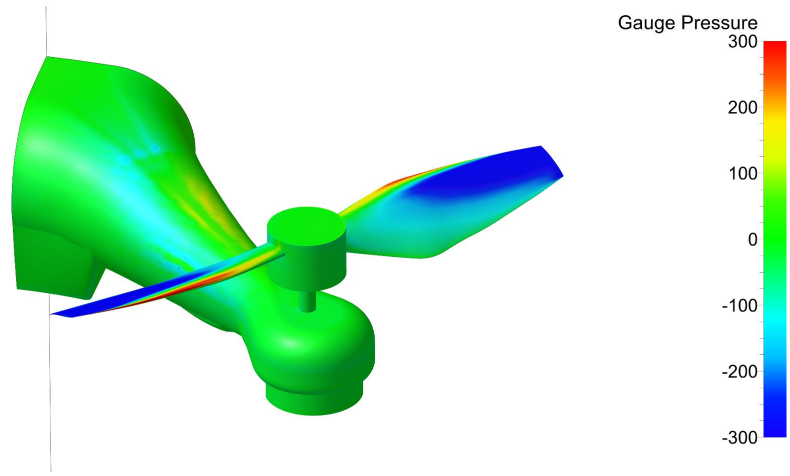
Simulation

The Open solver allows both steady and Non-Linear Harmonic (NLH) [5] simulations to be performed. The propeller is set to rotate at 5,000 RPM whereas the drone arm is stationary. The Spalart–Allmaras model is used to predict the turbulence in the flow. For the steady simulation, a mixing-plane interface is used, while for the NLH simulation, a specific treatment based on Fourier decomposition is applied. This provides the benefits of a domain scaling approach with a computational cost similar to the mixing plane.

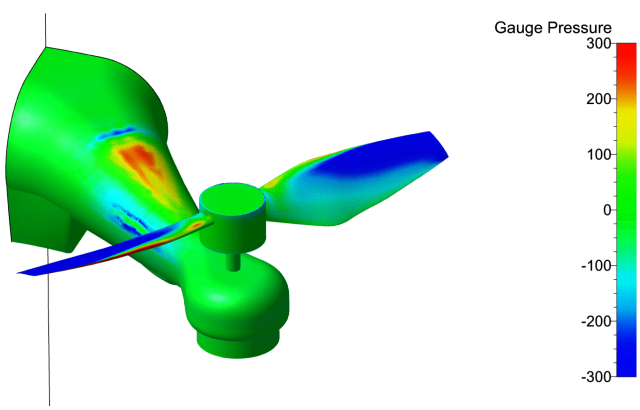
The simulations employ Cadence's convergence acceleration techniques such as full multigrid with a coarse grid initialization.

OMNIS™ Non-linear harmonic method provides unsteady flow results with considerably less constraints than the domain scaling and phase-lagged methods. For this project, one harmonic per domain is added to capture the unsteady perturbation in the domain.

The comparison of the results obtained in the framework of steady and unsteady simulation reveals the presence of strong unsteady features in the flow field. The pressure distribution on the airframe is largely impacted by the instantaneous position of the propeller. The velocity field around the drone is subject to strong periodic oscillations linked to the rotor rotation.

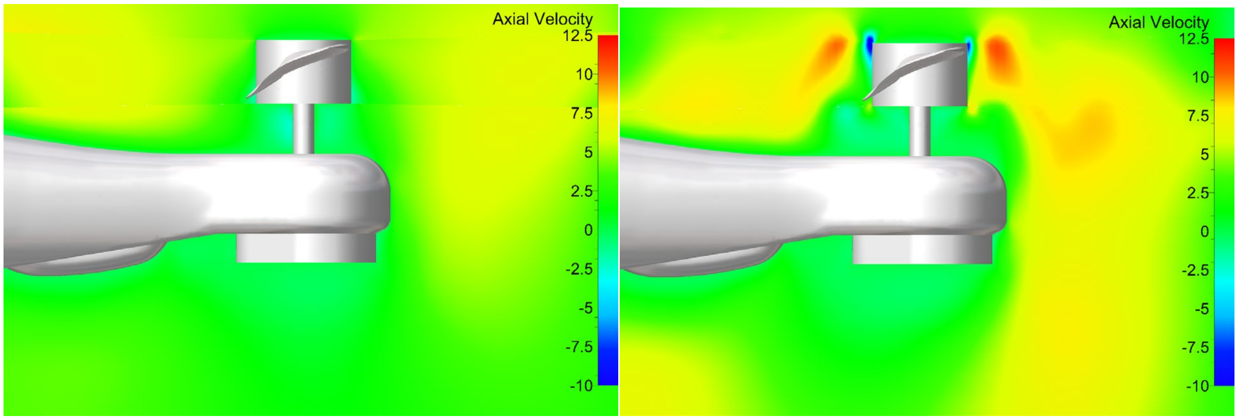


a)



b)

The threshold contour of gauge pressure field on propeller and airframe for a) steady (mixing plane) and b) unsteady (Nonlinear Harmonic Method) approaches



a) b)

The threshold contour for the fields of a) averaged axial velocity for the steady (mixing plane) approach and b) instantaneous axial velocity for the unsteady (Nonlinear Harmonic Method) approach

The results comparison shows that a steady simulation can provide a sufficient representation of the mean flow field. However, the NLH analysis can provide accurate information on the unsteadiness of the flow field, offering a large scope of valuable data for an engineer in terms of unsteady flow physics, blade and airframe loading as well as blade tip vortex and bluff body recirculation dynamics, at a cost comparable to a steady simulation

Drone Design Optimization

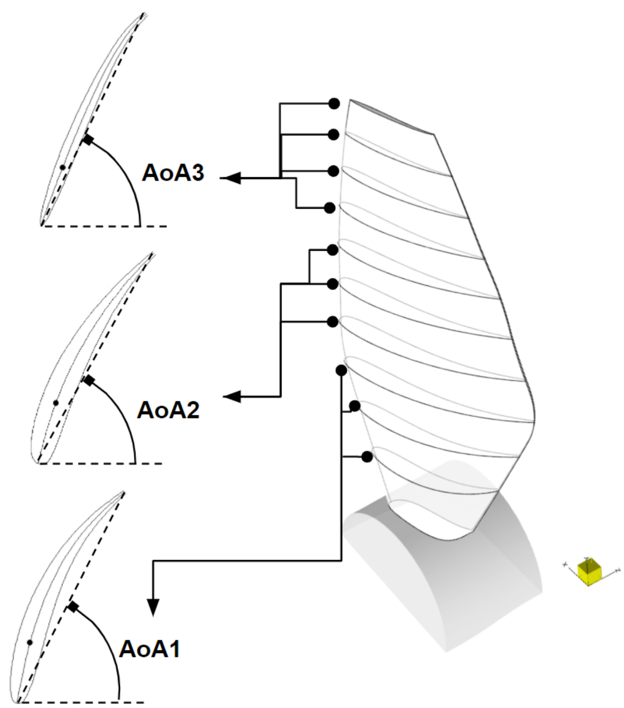
Cadence CFD software offers multiple possibilities for design parametrization and optimization. The available optimization methods range from single-objective optimization to multi-objective and robust design optimization that takes into account the operational and manufacturing uncertainties. A drone optimization process can benefit from all these methods. The final choice of the technique depends, among all, on the expected operation modes. The options may include:

- Optimization of propeller(s) isolated from an airframe in terms of Figure of Merit as defined in work [6], thrust, and torque
- Optimization of a drone performance for a hover or forward flight mode
- Optimization of a drone for a combination of modes. The weights between the hover and one or multiple forward flight regimes can be chosen according to the target operation regime or the expected distribution of flight time by the regime. The approach has proved to be efficient for rotorcraft optimization in general as presented by McDonnell Douglas Helicopter Company [7]

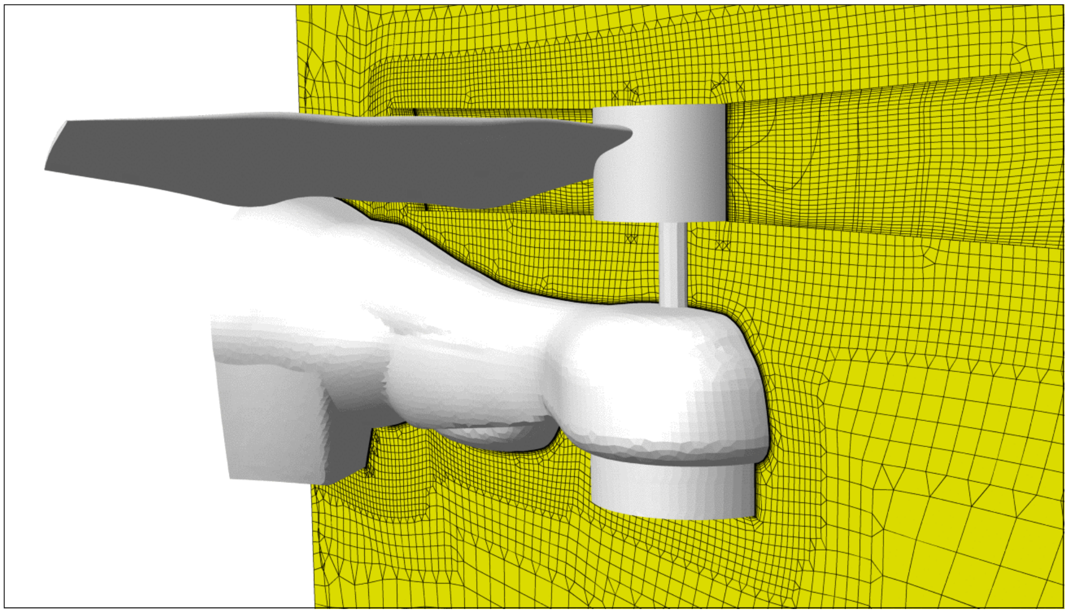
The last optimization option can be considered as a multi-objective process that provides a resulting Pareto front of designs, in other words, multiple best candidate drone designs. The final design in this case is chosen by an engineer that can take into account the Design for

Manufacturing and other considerations. The problem can also be considerably simplified by applying scalarization to define a single objective. In this case, the objective function can include performance characteristics at multiple flight modes and conditions. It can be as simple as an arithmetic summation of individual objectives (for instance quadcopter performance in hover and in forward flight mode) with coefficients defined based on importance or flight time share of considered regimes.

The following images present an example of geometry parametrization and its variation in the framework of the optimization study. The propeller geometry used for the optimization study is parametrized on the CAD model level. The angle of attack of the propeller at 3 spanwise sections is taken as the design variable. Each geometry is automatically re-meshed in AutoGrid5™. The drone arm is parametrized using 3 morphing vectors placed in the geometry. They allow the optimizer to optimize the shape of the drone using the morphing technique while also satisfying multiple constraints that are applied to ensure feasible designs.



Parametrization of the blade using angle of attack (AoA) at 3 spanwise sections



An example of variation of a quadcopter drone geometry in the framework of an automated optimization

Cadence's optimization routines are based on gradient-free algorithms that are considered to be much more efficient than gradient-based optimization for optimization of complex multi-component systems such as drones. The employed optimization processes benefit from a great speed-up thanks to the use of built-in surrogate models or artificial neural networks. The properties of the underlying evolutionary and genetic optimization algorithms ensure that the converged solution corresponds to a global optimum in terms of defined objectives such as for instance maximization of flight time for the target flight regimes. The practical use of such algorithms confirms that it can lead to a novel, innovative, and sometimes even unexpected optimum system design.

Summary

Simulation technologies became an important component of drone design. The rapidly growing and highly competitive market drives a large effort from commercial drone manufacturers in improving efficiency, expanding the flight envelope and the range of applications. The maximum flight time and range remain an important issue to address for multicopter electric drones. Cadence CAE suite with OMNIS™ at its core is being efficiently applied to the simulation and optimization of drones.

The presented case study of a quadcopter drone meshing and simulation demonstrates a set of powerful capabilities such as the combination of structured and unstructured meshing techniques and high-fidelity unsteady simulations using the Nonlinear Harmonic Method. The speed and robustness of the workflow allow performing a fully automated optimization based on efficient modern evolutionary algorithms in conjunction with Cadence's geometry parametrization and morphing features. The properties of the algorithm ensure that the resulting converged drone design represents a global optimum in terms of defined objectives such as, for instance, maximization of flight time for the target flight regimes.

If you would like to use OMNIS™ for designing more competitive solutions, please contact us and request a demo.

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