RecurDyn and Particleworks efficiently solve multi-body and fluid dynamics coupled problems

Marelli Motori uses ANSYS multiphysics software to optimize products

Lucid Motors boosts electric vehicle performance with modeFRONTIER

Cooling fan module road test simulation

At the edge passive safety performances using an automatic CAE methodology

Optimization of the the Chainsaw kickback

Aviospace uses CAE to clean the Space Debris
Foiling A-Class Catamarans
Application of Cutting-Edge Technologies to Improve Sailing Performance

Multi-objective optimizations, combined with experienced aerodynamic design, is the most efficient strategy to face challenging designs as the improvements of fast foiling catamarans performances in regatta.

“The term used to describe a condition in which a sailboat is lifted up from the water by lifting surfaces. The solutions adopted in the last America’s Cup class catamarans gave a strong impetus to the evolution of smaller multihull classes. The A-Class catamaran has benefited from these experiences and has shown significant improvements in the last few years.

The A-Class is a small high-tech catamaran that is considered the fastest single-handed racing dinghy in the world. It has very simple rules that stimulated a continuous technological evolution during the years. Figure 1 compares an old 90’s A-Cat (top) with the winner of the world championship 2016 (Figure 1).

The study here reported focuses on the geometric parameterization strategy, adopting a mesh morphing technology based on Radial Basis Functions (using the tool RBF Morph), and on its integration within a multi-objective optimization environment (managed by modeFRONTIER).

**Geometric parameterization**

The geometric parameterization based on RBF mesh morphing consists in implementing shape modifiers, amplified by parameters that constitute the variables of the problem, directly on the computational domain. New geometric configurations are obtained imposing the displacement of a set of mesh regions (e.g. walls, boundaries or discrete points within the volume) by using algorithms, based on RBFs, that are able to smoothly propagate the prescribed displacement to the surrounding volume. This approach offers several advantages: there is no need to regenerate the grid, the robustness of the procedure is preserved, its meshless nature allows to support any kind of mesh, and the smoothing process can be highly parallelizable.

The morphing action, furthermore, can be integrated in any solver offering the very valuable capability to update the computational domain “on the fly” during the progress of the computation.

The definition and the execution of a morphing action is, in RBF Morph, completed by three steps:

- **setup** – it consists in the manual definition, from the program GUI, of the domain boundaries within which the morphing action is limited to, in the selection of the source points where fixed and moving mesh regions are imposed, and in the definition of the required movements of the points used to drive the shape deformation.
- **fitting** – during this process, the RBF system, derived from the problem setup, is solved and stored into a file ready to be amplified. This operation has to be performed only once for every RBF problem. Stored RBF solutions are very light (in terms of files dimension) compared to storing all the created morphed meshes.
- **smoothing** – the smoothing action (surfaces and volumes morphing according to arbitrary amplification factors) is first performed applying the prescribed displacement to the grid surfaces and then smoothly propagating the deformation to the surrounding domain volume. It can be performed combining several RBF solutions, each one defined by a proper amplification factor, to constitute the parametric configuration of the computational domain.

Figure 2 reports an example (in this case applied to the sail of an A-Cat) of an RBF problem setup.

**RBF implementation and constraints definition**

A-Class rules state that all foils have to be inserted from the top of the hull (to prevent the adoption of T-foils) and that the minimum distance between the tips must always be larger than 1.5 m (to limit the span of surfaces contributing to the vertical lift). The maximum beam of the boat, including appendages in all positions, must be lower than 2.3 m. In order to insert the foils, furthermore, a minimum value of the angle B, assuming L-shaped foils, is required (Figure 3).

The reference geometry, that has been made parametric for the optimization, was generated by two straight segments smoothly blended in the junction region. The connection with the hulls is located at the external side and both inner and outer segments are oriented inboard. The foils segments are generated by a straight untwisted extrusion of the well-known NACA 63-412 laminar airfoil. The inner section is assumed to have a constant chord while the outer is tapered.

Seven shape modifiers have been setup: four to control lengths and angles of the foil segments (Figure 4), one to set the chord of the inner segment, one for the taper ratio of the outer segment and one to control the foils sweep angle. The last parameter is not exactly a shape parameter. It is a trim that has a direct effect on the horizontal angle of incidence of the foils. Its morphing action is implemented as a rotation of the foils along an axis perpendicular to
Figure 3 – Platform shape models

Figure 4 – Surface cells clustering for the three levels of grid

Figure 5 – Solution of the grid sensitivity to dimension

Figure 6 – Solution of the grid sensitivity to dimension

Figure 7 – Solution of the grid sensitivity to dimension

Figure 8 – Detail of the computational domain

Figure 9 – Flowchart of the optimization procedure

Figure 10 – Pareto solution of the final two-objectives optimization

the boat symmetry plane and passing near the hull/foil junction. The morphing actions are applied in sequence and limited to a volume surrounding the foils region.

Setup of numerical configuration

The operative conditions of sailing boats appendages depend on the equilibrium of the forces and moments acting on the system. To define the design conditions of the A-Cat foils, some simplifications have been, however, adopted. The equilibrium of vertical forces is assumed to be mainly dominated by the weight of the boat and the crew. The modulus of the other components, derived from the 6DoF equilibrium, varies in a range that is, in general, smaller than the range of possible crew weight. It is then considered acceptable, for design purpose, to assume a fixed target vertical component of lift to be generated by the foils. Similar assumptions are accepted for the side force since it is mainly limited by the maximum righting moment generated by the helmsman at the trapeze (for a fixed known centre of buoyancy and height of the sail centre of effort). The task is to identify the shape of the foils that, while respecting the imposed constraints and generating the required lifting force, minimize the drag. The selected variables of design were:

1. total foil draft;
2. outer segment cant angle (angle 8 of Figure 3);
3. angle of the inner segment respect to vertical;
4. inner segment chord (at constant thickness);
5. outer segment taper ratio;
6. foils sweep angle.

The amplification factors of the RBF solutions are defined combining the design input variables in order to fulfill the constraints imposed by the class rules (e.g. when the cant angle 8 is modified, the outer segment is scaled according to an amplification factor that recover the limits reported in Figure 3).

A multi-block structured hexahedral mesh was generated modelling a domain extended up to ten meters upstream and downstream the foils. Three levels of grid were generated (Figure 6) with the aim to evaluate the sensitivity of the solution on the grid dimension. The size of coarse, medium and fine meshes were approximately 1, 7.5 and 25 millions of cells.

Figure 7 reports the solutions obtained, on the baseline geometry, with the three meshes in downwind configuration (VOF analysis trimming the sinkage to maintain the vertical lift component unchanged). The difference between the drag obtained with the coarse grid and the drag obtained adopting the fine mesh is in the order of 5% while the adoption of the medium grid led to a difference limited to half percent. The coarse mesh was the one used in the optimization procedure.

Steady incompressible computations, using a volume of fluid (VOF) technique to model the two-phases (air and water), were setup for the windward analysis. The boat was assumed to sail at a heeling angle of five degree and at a speed of 15 knots. The sinkage was iteratively trimmed to define the attitude that generates the target vertical force. The total displacement was assumed equal to 170 Kg (empty boat weight plus crew). Considering around 30% of this value to be generated by the T-foils of the two rudders, the main foils were then assumed to contribute with the generation of 120 Kg to the sustainment of the boat. The operative leeway, that should be defined from the global equilibrium of forces and moments acting on the boat, was, here, kept fixed to 3 deg. The proper estimation of this value would have, in fact, significantly increased the computational burden since it requires to introduce an additional degree of freedom. The balance between the additional computational cost and the impact this simplification is expected to have on the optimization trend fully justifies, in our view, this choice.

The analysis in upwind sailing was performed at a speed of 10 knots and at a fixed attitude maintaining the computational domain unchanged. One hull is flying while the other one is floating and contributing to the sustenance. A single phase CFD analysis was setup assuming the top inviscid wall boundary of the domain (which, in order to partially account for boundary layer interference introducing uncertainties on the solution. It is, however, considered acceptable, for optimization purpose, since the aim to estimate the drag difference between candidate solutions is prevalent on the necessity of an accurate definition of the absolute value of drag. The missing drag component of the hull is recovered by an analytical formulation developed by a comparison with a matrix of CFD solutions obtained on the isolated demi-hull at several attitudes and displacements. The lift fraction obtained subtracting the lift generated by the foils from the boat operative displacement is used to feed the hull analytical drag model, whose output is added to the foils drag fraction to estimate the total drag. The accurate evaluation of the leeway angle is considered to be important in upwind sailing and adjusted by changing the inflow direction on the far field boundaries. Its operative value is estimated performing two preliminary analyses at two angles and then linearly extrapolating the final leeway angle at which the candidate geometry should generate the required target side force. If the target side force is not generated at the expected angle, the selected configuration is rejected because it does not perform in the linear region of the aerodynamic lift polar. The target side force (in our case defined equal to 70 Kg) was estimated from the equilibrium of moments around the sailing direction.

The time elapsed to complete the evaluation of one valid design, using the coarse mesh, ranged between 15 and 20 minutes on a workstation equipped with 20 CPU. The time required for the morphing action was less than two minutes. More than 400

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The selected optimum was verified in downwind conditions (only) using the fine mesh adopted for the grid sensitivity evaluation. The RBF solutions were applied to the fine baseline grid (the method is meshless) to obtain the fine mesh of the optimum geometry. The analysis also allowed to verify if the evaluation of the improvement is confirmed. The results of this verification is summarized in Table 1. The improvement was overestimated by only 0.24% confirming the coarse grid, despite the lower absolute accuracy it involves, to be suitable to correctly drive the optimization process toward the optimum.

Table 1 – Performance Improvement verification of the selected optimum

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Baseline Kg</th>
<th>Optimized Kg</th>
<th>Drag reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>13.7</td>
<td>13.54</td>
<td>7.65</td>
</tr>
<tr>
<td>Fine</td>
<td>13.99</td>
<td>12.92</td>
<td>7.65</td>
</tr>
</tbody>
</table>

Conclusions
A design procedure, based on multi-objective optimization, has been presented. The core of the method is the parameterization of the geometry implemented by a mesh morphing technique based on Radial Basis Functions. The foils of an A-Class catamaran have been optimized at two sailing conditions. A multi-objective optimization, using genetic algorithms, was setup within the modeFRONTIER environment. The analysis of candidates was implemented by a script procedure executed within the ANSYS Fluent CFD solver. The target of design was the minimization of drag in the two operating environments, to setup optimization configurations that involve large computational domains. The workflow, furthermore, showed to be very robust. The rejected solutions concerned only designs not able to fulfill the requirement of sustain the boat in downwind sailing.

In order to speed up the process, a very light mesh (less than one millions of hexahedral cells) was used in the optimization workflow. It was, however, observed a difference in the estimation of the performance improvement of the selected optimum, comparing the percentages of drag reduction computed using the coarse with a very fine grid, of only 0.24%, indicating the adoption of a so coarse mesh to provide a very efficient compromise between computational costs and optimization trend evaluation.

For more information: Francesco Franchini, EnginSoft f.franchini@enginsoft.com

Non-conventional configurations for small satellite launchers

Small satellites (typically defined as those under 500 kg) are enabling an immense diversity of measurements and observations with clear prospects for developing a new, expanded, and timelier understanding of our world. To date, the vast majority of small satellites have been launched as secondary payloads, piggybacking off of larger satellite launches, or shuttles to the International Space Station (ISS). Most of the major launch service providers now offer secondary payload launches as an option on many of their rockets, although a small number have refused to participate. Secondary payload launch mechanisms are truly a worldwide phenomenon. Obviously, piggyback launches come with a number of caveats, including launch date, deployment location, deployment mechanism compatibility and payload restrictions. Therefore, the advantages of a dedicated launch system would be several:

- Priority as primary payload
- Frequent flight opportunities
- Tailored to unique orbital requirements
- Personalized schedule

A dedicated launch system can then represent an interesting niche market for industries and at the same time a great advantage in terms of costs and launch schedules. Non-conventional launch configurations such as balloon launch and airborne launch to orbit have been analyzed focusing the attention on minimizing the initial mass of the rocket.

Trajectory simulator
To simulate a suitable launch trajectory, it is necessary to solve the equations of motion using a numerical method, that’s why a trajectory simulator has been realized using Maple 2016. Maple is a math software that combines the world’s most powerful math engine with an interface that makes it extremely easy to analyze, explore, visualize, and solve mathematical problems. The simulator uses the function rk45, which can solve numerically ODEs with a Fehlberg fourth-fifth order Runge-Kutta method with

For more information:
Francesco Franchini, EnginSoft
f.franchini@enginsoft.com

Figure 1 - Maple: the technical computing software for engineers and researchers