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APPLICATION OF OPTIMIZATION METHODS IN 2D HYDROFOIL DESIGN

Abstract

Modern computer technologies allow us to conduct rather complex mathematical calculations in a relatively short period of time. Thus, it has become possible to employ optimization methods during the design of different technical objects in the variety of engineering scopes and Industries, even when calculations require large computational resources (structural, thermal, and gasdynamics or hydrodynamics calculations).

In this paper we provide an introduction to the method and some results of 2D hydrofoil optimization design tasks "with cavitation free" and "cavitation on" parameters of external water flow.

The proposed automatic optimization procedure consists of several points: 1) we need to prepare parameterized geometry for the object under consideration (we used CAD software to do that) 2) we need to perform automatic mesh building based on the new geometry. This is so-called mesh-geometry translation (we used ANSYS Icem CFD as a mesher) 3) we need to launch CFD-solver and automatically analyze new results (we used ANSYS CFX as CFD solver) 4) we need to use optimizer and project integration tool to automatically link these processes into a project optimization cycle (we used IOSO NM software for this purpose)

1. ADVANTAGES OF THE IOSO TECHNOLOGY ALGORITHMS

The main advantages of this algorithm over traditional mathematical programming approaches are the following:

- convolution approaches are not used in solving multi-objective problems;
- the algorithms determine the desired number of Pareto-optimal solutions, so that these solutions are uniformly distributed in the space of objectives;
- it is possible to solve the optimization problems for the objective functions of complex topology: non-convex, non-differentiable, with many local optima;
- it is possible to naturally employ the parallelization of the computational process.

2 FLOW AND MODEL PROBLEM STATEMENT

It is well-known that for some temperature of external water flow the key parameters of this flow are the Reynolds number, Re, and the cavitation number, σ.

$$Re = \rho U_\infty l/\mu \quad (3)$$

$$\sigma = (P_\infty - P_v)/((1/2)*\rho U_\infty^2) \quad (4)$$

where ρ – flow density at inlet, U_∞ - inlet velocity, l – chord length of a hydrofoil, μ - flow dynamic viscosity, P_∞ - inlet pressure, P_v – saturation pressure

For our tasks we chose two values of the cavitation number (two inlet pressures): one when the cavitation is absent (for this case we switched off the cavitation model in the CFD solver) and the other when the cavitation is present σ = 0.99975 (for this case we switched on the cavitation model in the CFD solver).

We used Rayleigh Plesset Model with saturation pressure criterion, turbulence model - k-e.

3 GEOMETRY PARAMETERIZATION

The problem of the adequate parameterization of geometry is one of the most important problems engineers encounter when solving design optimization tasks. For example, poor parameterization may lead to bad results because of infeasibility of theoretically optimal geometry forms.

We used our own approach to the parameterization of a hydrofoil. We used two fixed constraints for geometry: chord of hydrofoil l = 0.3 m and angle of attack = 5 grad. Geometry parameterization was accomplished using 7 independent variable parameters. This geometry representation features two independent focuses of curvature in the leading and trailing edges.

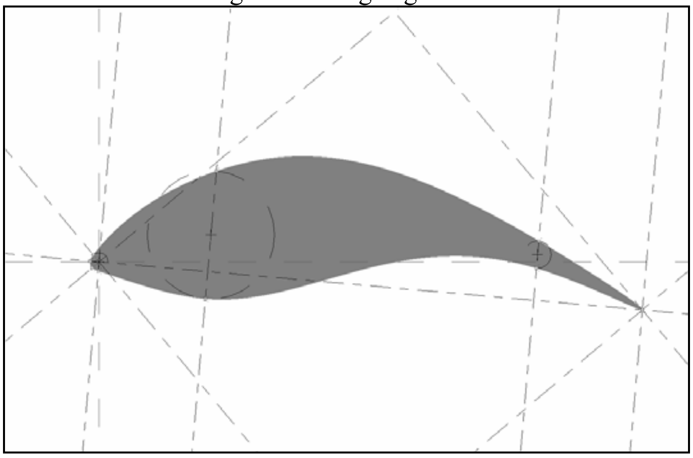

Fig 1 Parameterized geometry

We also need to employ quite robust optimization methods which are sustainable to the model crashes during optimization, IOSO optimization methods meat this requirement.

4 MESH RECONSTRUCTION

We used fully hexahedral mesh with boundary layer resolution. First time it was built “by hands” than was associated with the parameterized geometry and was rebuilt automatically every optimization iteration. The mesher should also answer several requirements one of which is that it should support automatic script-regime. We used ANSYS Icem CFD which satisfies all our needs.

5 CFD TASK STATEMENT

To successfully solve 2D task for both “cavitation free” and “cavitation on” cases the following conditions were set: inlet velocity boundary condition at inlet, outlet static pressure boundary condition at outlet, 2D symmetry plane boundaries.

For the “cavitation free” we solved steady state task. We chose transient task statement for “cavitation on” tasks. We used averaged in time values of the forces acting on the hydrofoil.

6 MAIN RESULTS

1. Two-objective optimization task for simultaneous maximization of lift force Fy and minimization of drag force Fx on a hydrofoil (cavitation is off) is stated. Fig 2 shows a Pareto set of optimal solutions (optimal geometries) after 500 analysis calls with the results for two margin points:

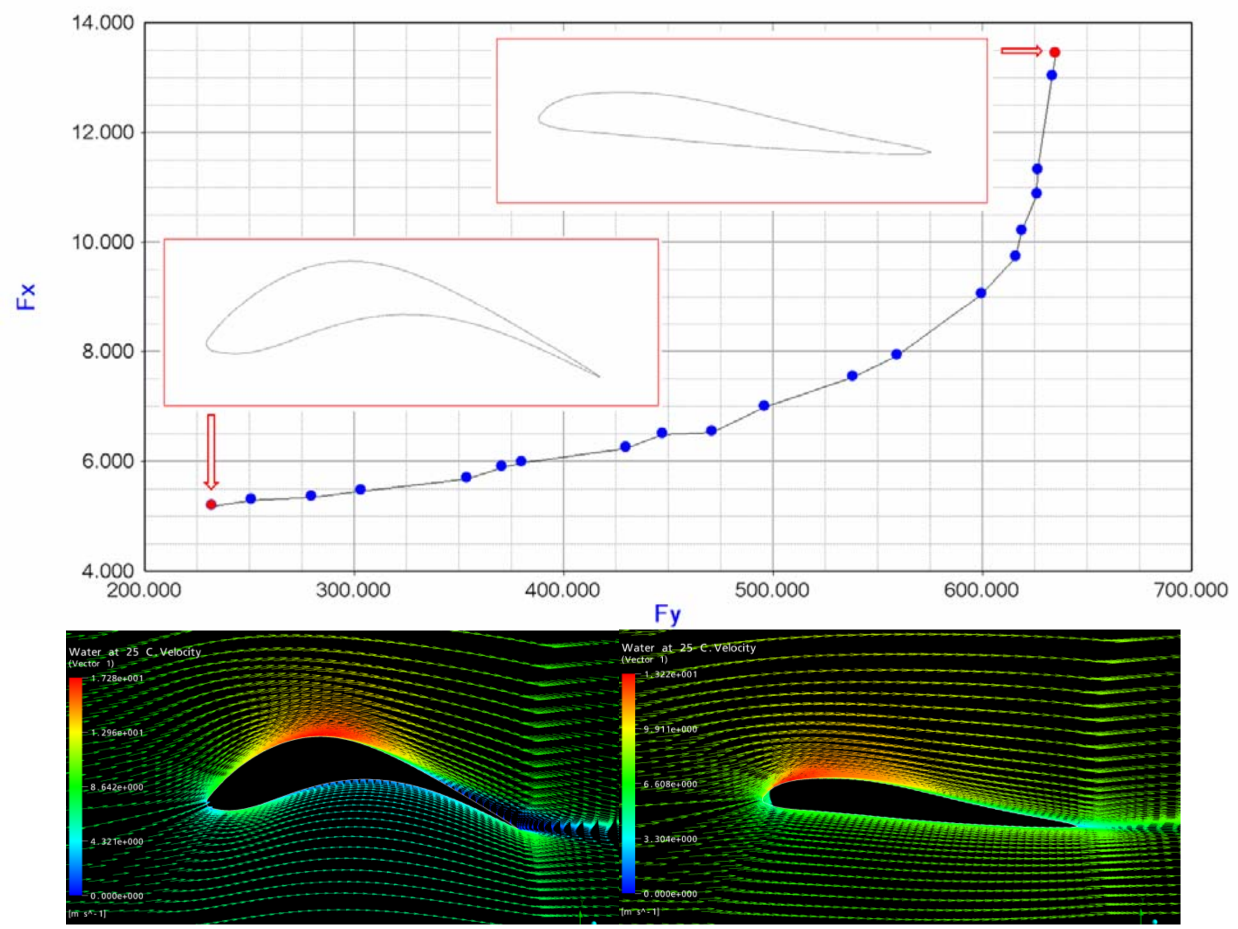

Fig 2 Pareto Set (Fy – maximize, Fx – minimize) with two margin point results (vel vect Plots)

1a. On the basis of previous task two-objective optimization task is stated for simultaneous maximization of hydrodynamic quality Fy/Fx and maximization of lift force Fy. (cavitation is off). Fig 3 shows Pareto set of optimal solutions (optimal geometries) with two geometry results after additional 100 analysis calls:

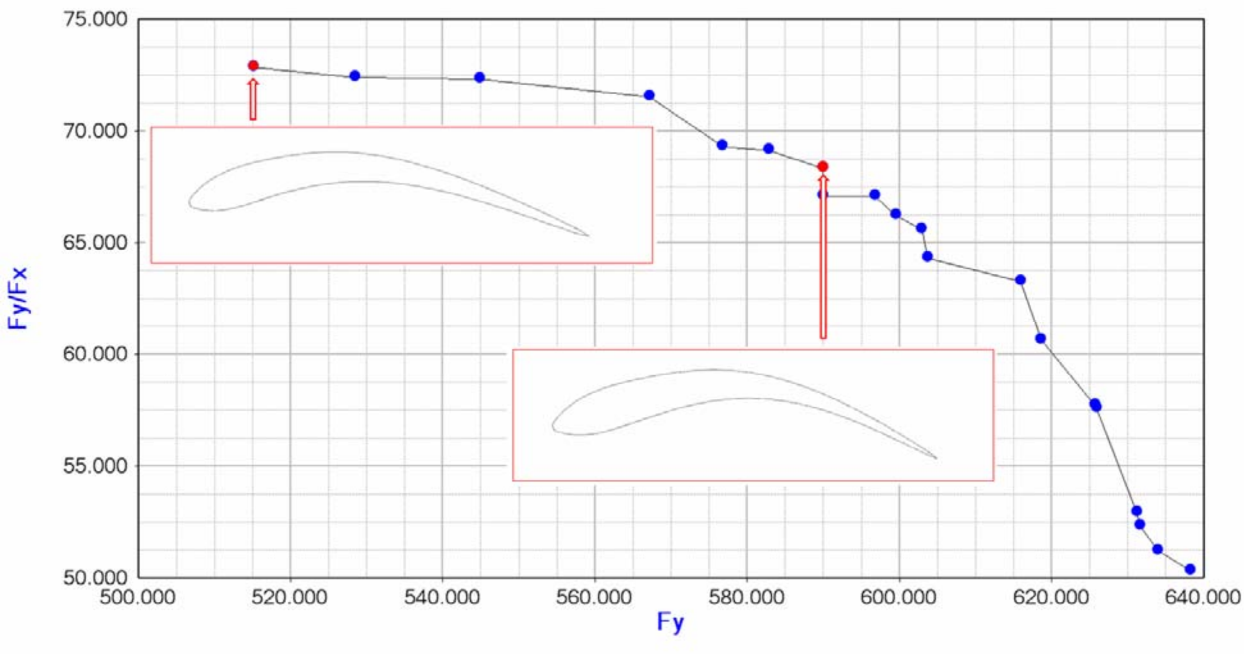

Fig 3 Pareto Set (Fy/Fx – maximize, Fy – Maximize) with two geometry results

2. Two-objective optimization task for simultaneous maximization of lift force Fy and minimization of drag force Fx on a hydrofoil (cavitation is on) is stated. Fig 4 shows a Pareto set of optimal solutions (optimal geometries) after 500 analysis calls with the results for two margin points:

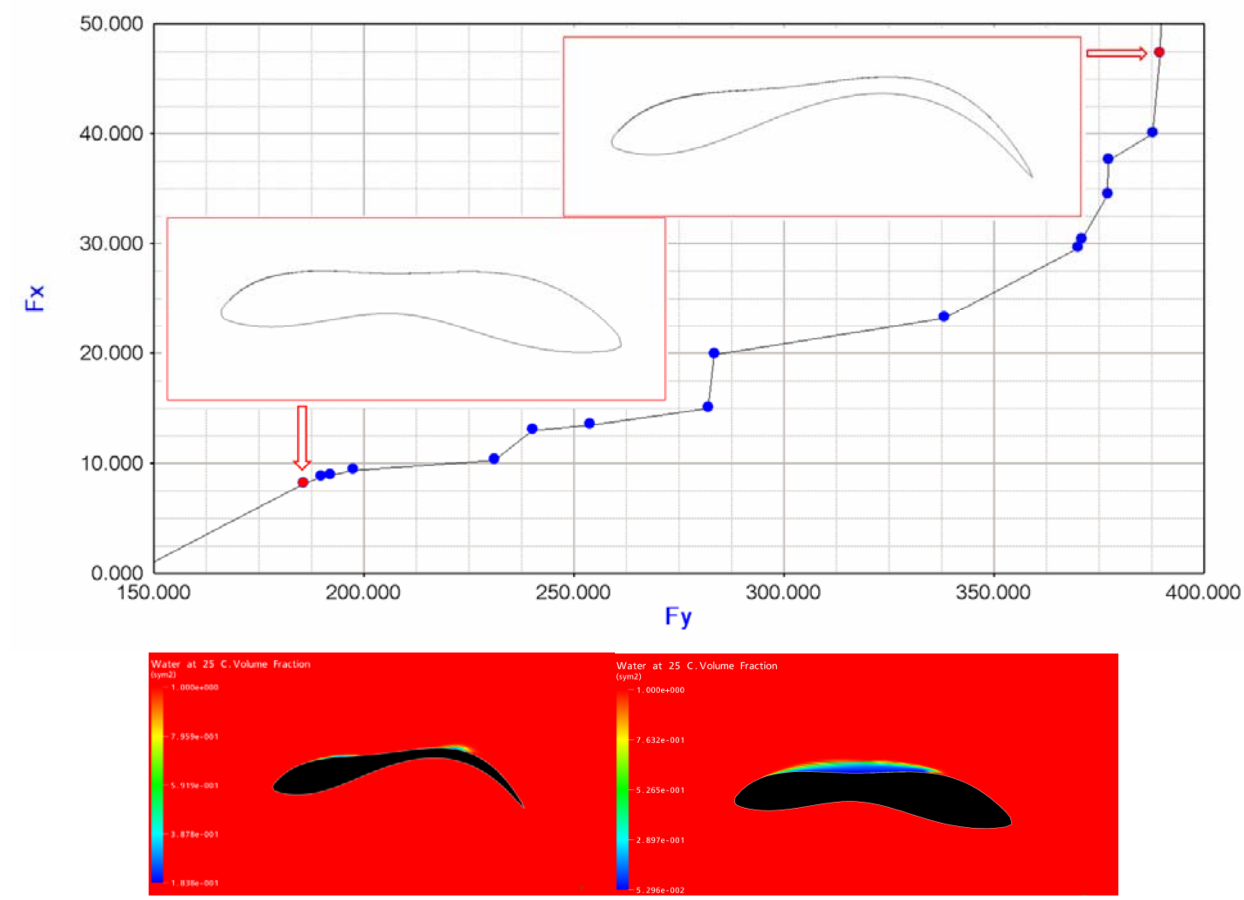

Fig 4 Pareto Set (Fy –maximize, Fx – minimize (cavitation is On)) with two margin point results (VOF plots)

2a. On the basis of previous task two-objective optimization task is stated for simultaneous maximization of hydrodynamic quality Fy/Fx and maximization of lift force Fy (cavitation is on). In Fig 5 one can see a Pareto set of optimal solutions (optimal geometries) with two geometry results after additional 200 analysis calls:

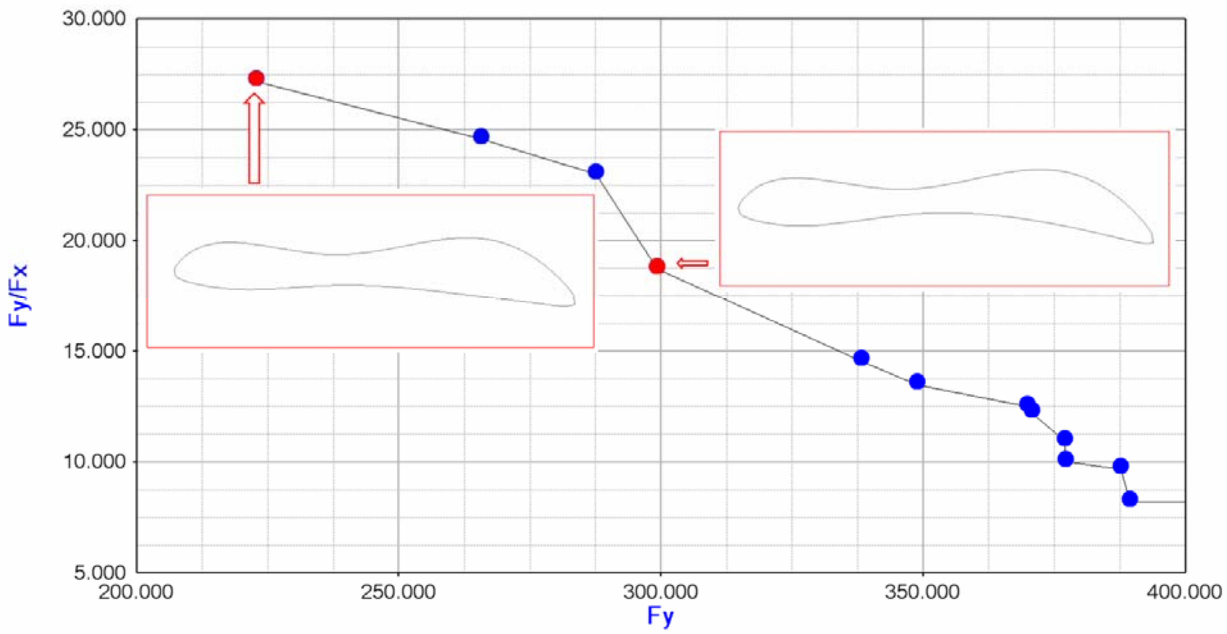

Fig 5 Pareto Set (Fy/Fx –maximize, Fy – maximize (cavitation is On)) with two geometry results

As a summary, let us mention that such untypical hydrofoil geometries in the cases of optimization tasks with cavitation on were obtained due to our initial parameterization of the hydrofoil geometry with two independent focuses of curvature in the leading and trailing edges of it.

7 CONCLUSION:

This work and qualitative results showed an implementation of a modern method employing the optimization technology linked with CAD, Mesh and CFD software for fully automatic design of hydrofoils. The results demonstrate considerably different optimized forms of hydrofoils for “cavitation free” and “cavitation on” external water flows.