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A study of airfoil parameterization, modeling, and optimization based on the computational fluid dynamics method

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Class/Shape function Transformation (CST) Method

Class/shape function transformation (CST) method can model a wide array of smooth geometries with a small number of equations and parameters. The geometry can be defined as:

$$\varsigma(\varphi) = C_{N_2}^{N_1}(\varphi) \times S(\varphi)$$

where: $C_{N_2}^{N_1}(\varphi) = \varphi^{N_1}(1-\varphi)^{N_2}$ $\quad S(\varphi) = \sum_{i=0}^{n} B_i \cdot \binom{n}{i} \varphi^i (1-\varphi)^{n-i}$

CST method owns high airfoil parametric accuracy and the comparison between CST and Polynomial method in NACA 1412 airfoil parameterization is given in Fig.1 and Fig.2.

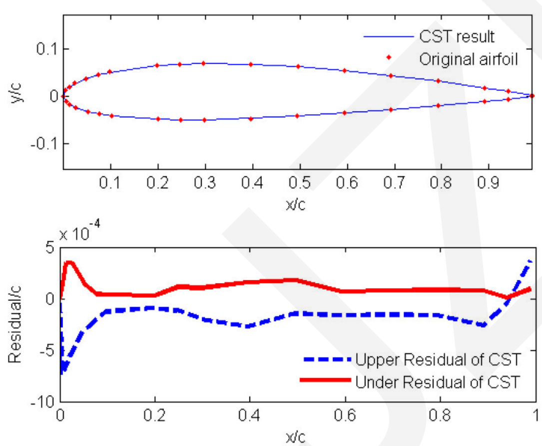

Fig.1 Comparison between NACA 1412 airfoil and the fifth-order **CST** imitation result.

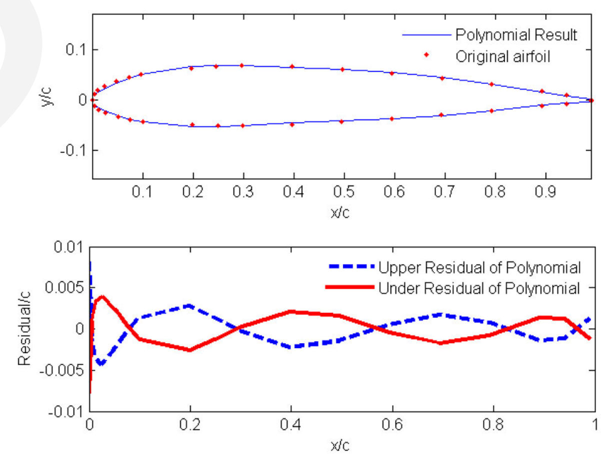

Fig. 2 Comparison between NACA 1412 airfoil and the fifth-order **Polynomial** imitation result.

Refined CST Method

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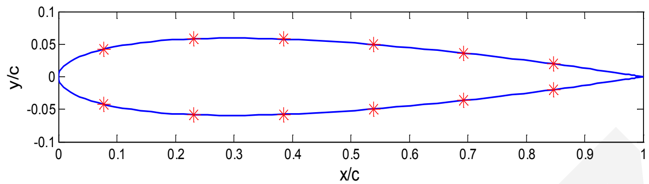
In order to improve the matching accuracy of the nose and tail region, the authors redistributed the sample points on the airfoil. The comparison between the refined and original methods is illustrated:

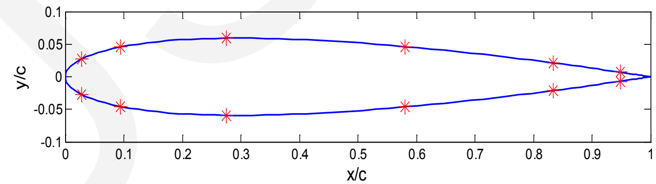
Original method to get control points:

$$\varphi_j = \frac{N_1 + j}{N_1 + N_2 + n} \qquad j = 0,1,2,\cdots n$$

Refined method to get control points:

$$\varphi_j = 0.5 + 0.5 \cdot \tanh\left(\lambda \cdot \left(\frac{N_1 + j}{N_1 + N_2 + n} - 0.5 \right) \right) \qquad j = 0,1,2,\cdots n$$





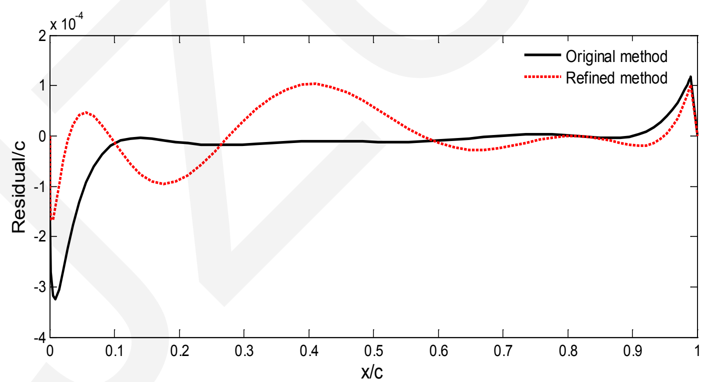


Fig. 3 Residual comparison to imitate the upper side of NACA 0012 between original and refined methods.

Numerical Method and Grid Independency Analysis

RANS is utilized in flow-field stimulating of airfoil with Spalart–Allmaras turbulence model and second upwind scheme applied.

C-grids are generated around the standard airfoil NACA 0012 with different grid densities to verify grid independency. The local grid distribution and the wall pressure coefficient comparison figures are listed:

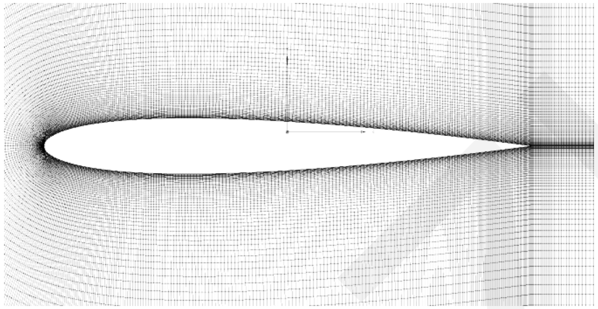


Fig.4 local grid distributions around NACA 0012.

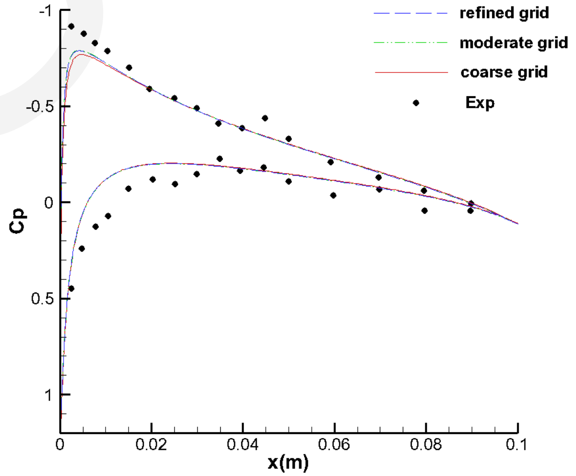
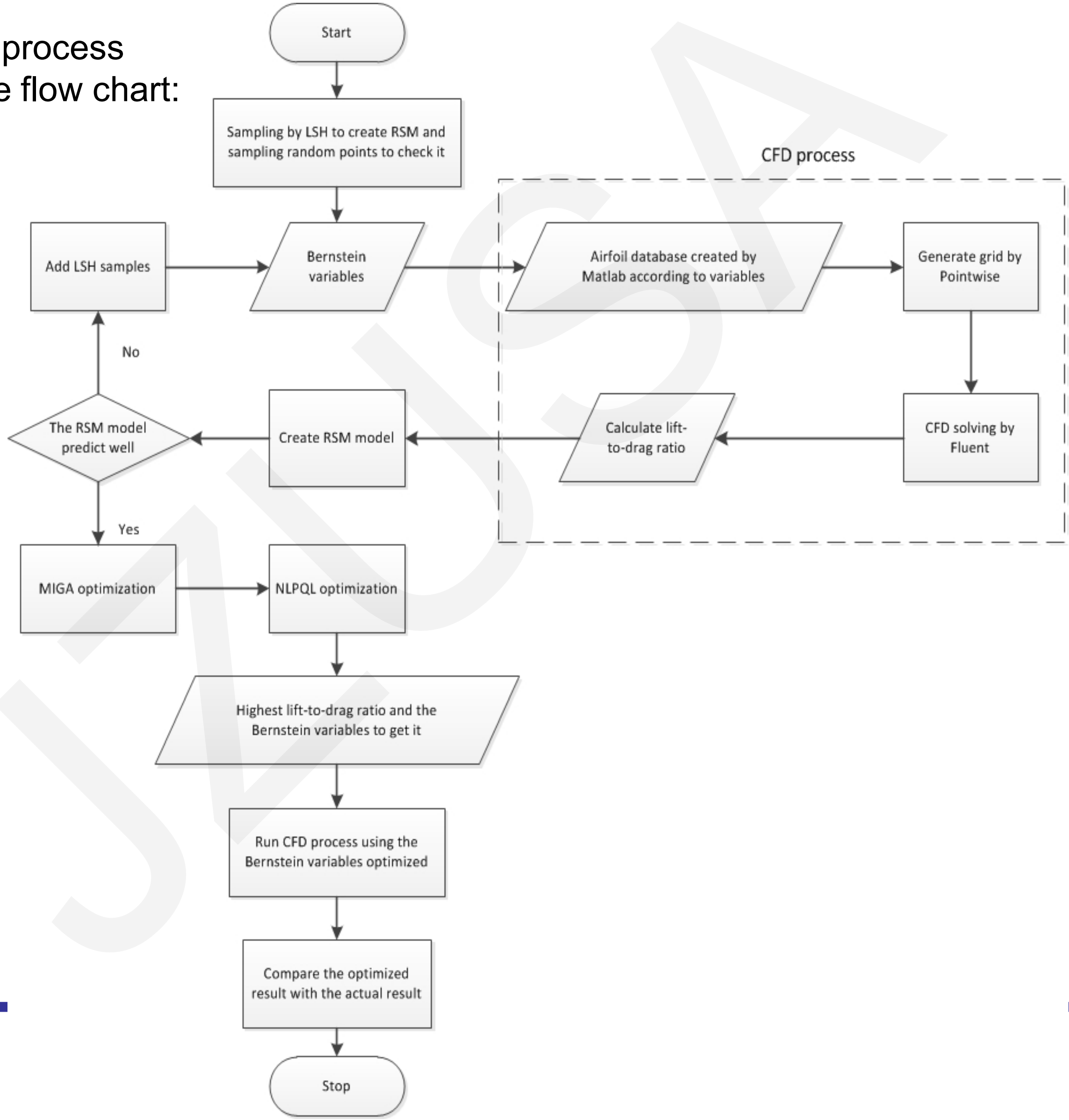


Fig.5 Wall pressure coefficient comparison of NACA 0012.

Airfoil Optimization Based on the Surrogate Model

The airfoil optimization process can be illustrated by the flow chart:



Optimization result

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The line contours graphs of pressure coefficient in the flow-field around the airfoils before and after optimization are compared in Fig.6 while the Lift-to-drag ratio properties are compared in Fig.7.

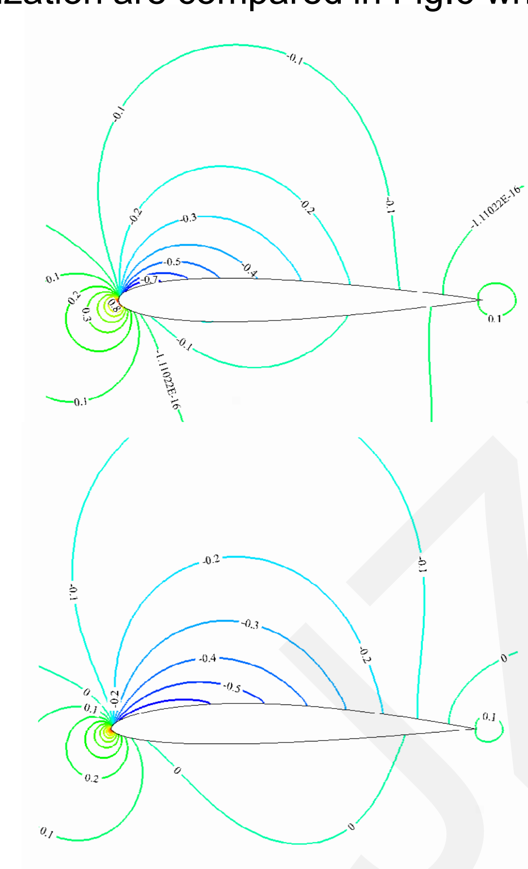


Fig. 6 Pressure coefficient in the flow-field around the airfoils before (up) and after (down) optimization.

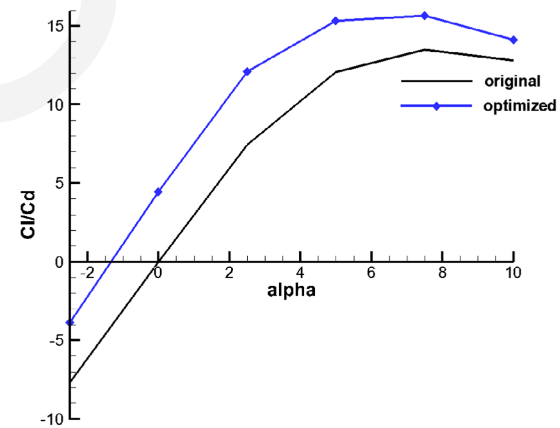


Fig. 7 Lift-to-drag ratio properties comparison.

Conclusion

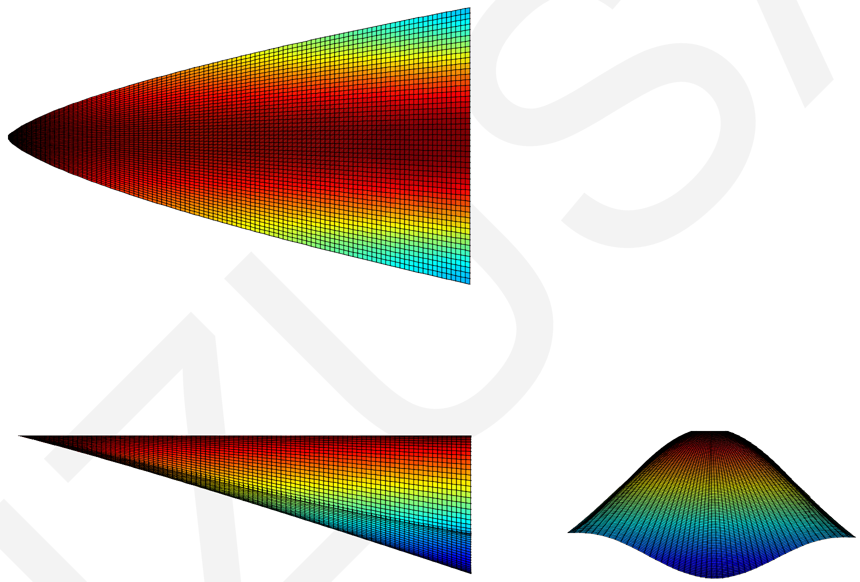
In this paper, parameterization methods of airfoil have been compared and numerical method has been utilized to optimize the airfoil with better aerodynamic performance based on response surface model. The results show that:

- Class/Shape function transformation method has been modified by redistributing the control points of shape function in this paper, which allows a better definition of the nose and tail area of the airfoil.

- Nonlinear Programming by Quadratic Lagrangian optimization method is utilized after Muti-Island Genetic Algorithm, which may search the airfoil with the highest lift-to-drag ratio. The comparison of the optimization results tells that the combination of the two optimization methods can get better result than the methods used separately.

Further Study

Three-dimensional CST approach can define the geometrical shapes by a few of parameters and it is refined to enhance the parametric ability. Wave-rider generated by 3-D CST method is shown below as an example:



The work related to refined 3-D CST method and hypersonic-glide vehicle optimization has been submitted for review to "*Journal of Aerospace Science and Technology*" with the title of "**Parameterization and Optimization of Hypersonic-Gliding Vehicle Configurations during Conceptual Design**".