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A RESEARCH ON ACCELERATED SEARCH GENETIC ALGORITHM OPTIMIZATION PLATFORM ORIENTED TO AIRCRAFT AERODYNAMIC DESIGN

Zhen Xu*, Degang Cui, Hai Du*****
***Beihang University , **AVIC, ***Chinese Aeronautical Establishment**

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Abstract

This article exhibits a research on an aerodynamic optimization platform oriented to aircraft aerodynamic design.

As one of the most important elements of aircraft aerodynamic design, the optimization of civil planes' high lift devices needs this platform. The optimization platform uses a nested double-cycle optimization working flow which is established on a distributed automatic computing system. During the optimization process, the platform uses adaptive genetic algorithms improved by sensitivity analysis as its main optimization method, in order to accelerate the searching process and decrease the computing cost.

For running simulation, optimization cases of gap parameters of three-element airfoils have been implemented. The results indicate that the overall aerodynamic performances including lift coefficient, drag coefficient, pitching moment coefficient and lift-drag ratio of this airfoil have been improved, and this optimization is capable for a certain sort of high lift devices in the form of multi-element airfoils.

1 General Introduction

Aircraft aerodynamic design plays an important role in the aircraft system engineering. Due to numerous parameters, complex operating environments, and interrelated performance indexes in modern aircraft aerodynamic design, it is more difficult and less efficient to find the optimum design condition by the means of design experiences, and experiments of simple numerical simulations [1-3]. Therefore, the necessity for an integrated optimization platform, which aims to explore the design space and find the global optimum solution with high efficiency, has been increasing. In addition, the optimization platform needs to be capable of accelerating search processes, in case more complex optimization requirements develop in the coming years.

Efficiency and reliability have become some of the most important aspects of modern aircraft aerodynamic optimization, due to the complex calculations, influencing factors and repeated iterations in its long design period. Therefore, the integrated Aircraft Aerodynamic Optimization Platform (AAOP) should be based on not only suitable equation solvers and vortex models, but also advanced optimization methods.

1.1 Optimization Platform Application Scenario

The AAOP, which is established and applied here, mainly consists of optimization algorithm components, CFD simulation modules, and mesh deformation technique modules. The AAOP does not use commercial CFD software as its aerodynamic force calculation module. The CFD simulation modules and mesh deformation technique modules used in AAOP have been developed by Chinese project partners. Meanwhile, the study on adaptable optimization algorithm is based on this platform, and some suitable algorithm components are integrated in the platform for users' convenience.

1.2 Sensitivity Analysis

Sensitivity is the derivative information of system state parameters or outputs to design variables, reflecting the changing trend and the degree of the system's condition along with the design parameters. In engineering applications, sensitivity values of design parameters could be expressed as the partial derivatives of objective functions to design variables. Sensitivity analysis uses the sensitivity values as criteria of design parameters influence factors [4].

The sensitivity analysis of design parameters is an efficient way to reduce the search region and the dimension of a design space, which is expanded by design parameters. With this sensitivity analysis strategy, the optimization system can decrease requirements of computing time and speed up the searching process.

2 Optimization System

2.1 The Improved Optimization Method Based on Genetic Algorithm

The optimization algorithm is the core of the optimization method in AAOP. The Genetic Algorithm (GA) is one widely used optimization algorithm, suitable for a variety of engineering systems and optimization problems [5]. However, the Simple Genetic Algorithm (SGA) cannot be used directly in the aerodynamic optimization. On one hand, since the aerodynamic design usually deals with a large amount of design variables, and CFD calculation costs huge quantity of computing time, so that the optimization process often leads to low efficiency and unsatisfactory results. On the other hand, an inappropriate set of GA parameters can also cause the GA deceptive problems, which might lead to inappropriate optimization results [6]. Consequentially, the algorithm component should be adapted for the AAOP. Based on the above reasons, the core optimization algorithm has been improved.

This optimization algorithm is based on SGA, and is improved in two main ways. One way is through the embedding of sensitivity analysis functions into the optimization components to make the optimization process be a nested double-cycle process. The other way is adding the Adaptive Genetic Algorithms (AGA) into algorithm components. The algorithm components also contain a group of optimization operators to be selected by users.

In addition, this optimization algorithm has both single objective optimization function and multi-objective optimization function for the sake of different optimization strategies.

2.2 Optimization Workflow Process

The Optimization workflow is divided into three parts (shown in Fig. 1):

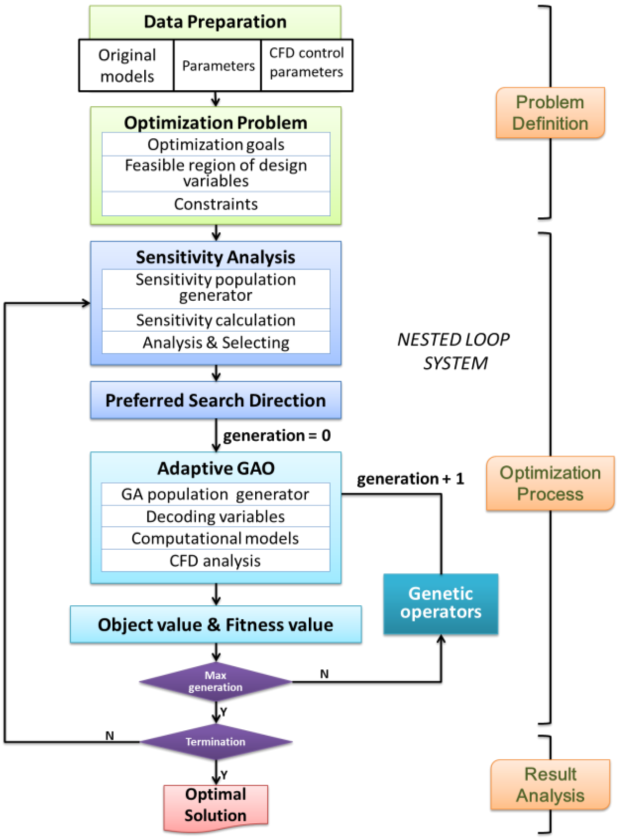

Fig. 1 The Workflow of AAOP

- The Problem Definition Part determines the optimization objectives, the design variables and parameters, and the constraint condition. Meanwhile, this part prepares for input data for the computing environment.
- The Optimization Process Part has a nested double-cycle structure. The

external loop is called the Sensitivity Analysis Loop (SAL), and the internal loop is called the GA Loop (GAL).

The SAL is responsible for determining the sensitivity selection strategy, calculating sensitivity values, and selecting the optimum search direction based on the ranking of sensitivity value results. The selected direction, pointing at the preferred search region in the design space, means a higher probability for better individual design points existing in the region (shown in Fig. 2, Fig. 3).

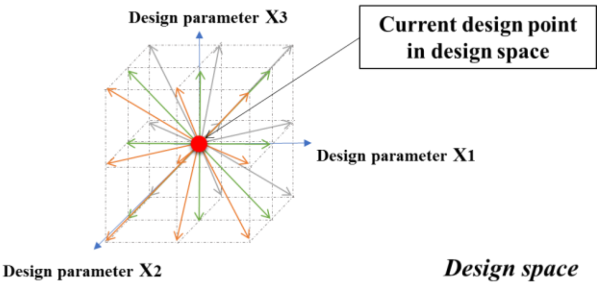

Fig. 2 The Sensitivity Directions of a Current Design Point in Design Space

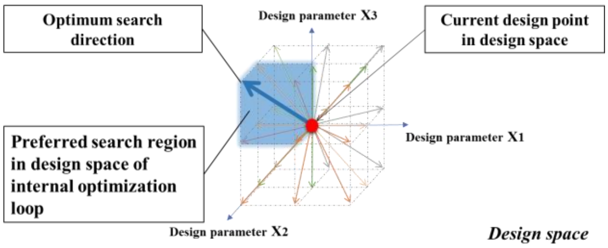

Fig. 3 Selecting the Optimum Search Direction and the Preferred Search Region

The GAL is actually an AGA Loop. GAL does the local search for better individual points in the preferred search region which surrounds the current design point, under the guidance of the sensitivity analysis. The GAL also generates the initial population with the Latin Hypercube Sample (LHS) method and then starts the evolution of GA optimization population (shown in Fig. 4). After several generation evolution processes, The GAL would find the best individual point among the current offspring generation, which represents a better solution (also a better design point in the design space) in the neighborhood region. Thus, the space has been explored more deeply, and the internal loop should stop processing. Then the current best design point will substitute for the original design point in the next SAL. This method avoids the blindness on searching and speeds up the optimization to some extent.

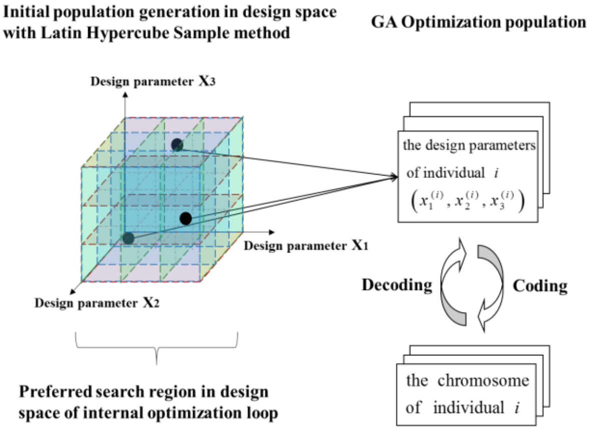

Fig. 4 Initial Population Generation with LHS Method and Optimization Population Generation

- The Result Analysis Part is responsible for the best solution analysis and post treatment. And this part is defined by the requirement of optimization problem.

2.3 Optimization Platform

This AAOP consists of four layers, which are the application layer, the service layer, the interface layer, and the execution layer (Shown in Fig. 5). The application layer is the direct functional part oriented toward users, which means users can start the aerodynamic optimization design function here. The service layer provides problem definition service, process integration service, and some other CFD services, based on the application layer. The interface layer consists of the flow component, the algorithm component, the file operation component and the component integration. The execution layer uses the workflow automatic scheduling and the distributed parallel computing system to drive optimization components, the mesh deformation module and the aerodynamic force calculation module in order to fulfill users’ optimization tasks [7, 8].

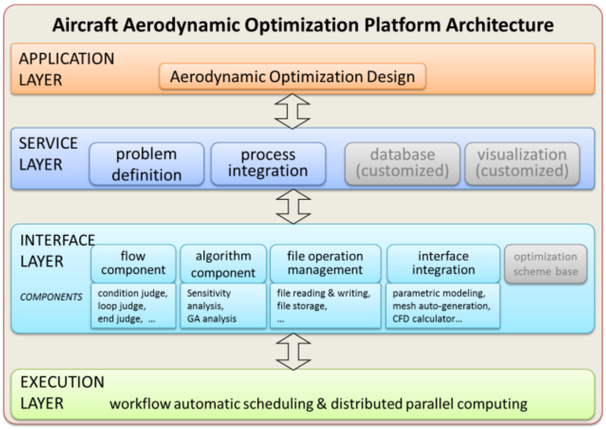

Fig. 5 The Aircraft Aerodynamic Optimization Platform Architecture

3 Optimization Results

3.1 An Introduction of the Optimization System Running

3.1.1 The Optimization Object

High lift devices are widely used on most civil transport aircraft, since they have played an important role in improving the conventional take-off and landing performance, reducing noise, and promoting environmental protection [9]. The multi-element airfoil design is the basis of the three-dimension high lift device design in aircraft design and engineering [10]. The geometrical profile and mesh model of 30P30N airfoil are shown in Fig. 6.

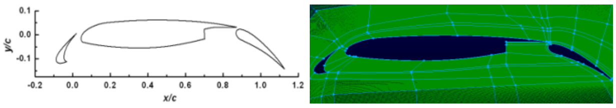

Fig. 6 The Geometrical Profile and Mesh Model of 30P30N Airfoil

3.1.2 The Optimization running Examples

For system running tests, two optimization running examples about multi-element airfoils of high lift devices have been planned and implemented sequentially. These running examples aim for a better aerodynamic performance. Example 1 is a single objective optimization case, which plans to discover an optimum position of the trailing edge flap, based on the optimization objective of the entire airfoil's lift-drag ratio. While Example 2 is a multi-objective optimization case, which aims to discover the optimum positions of both leading and trailing edge flaps, based on combined optimization objectives of the higher Cl and lift-drag ratio, and the lower Cd and Cm, in condition of no lower Cl constraints.

The test conditions for both running examples mainly include the high Reynolds number at 9.0E+6, and the low Mach number at 0.2.

3.2 Optimization System Running

The optimization for these two running examples has been performed on AAOP a few times and obtained similar results. Each run requires 30 to 50 internal loops and takes approximately 36 to 48 hours to complete. The system has not encountered severe reliability problems during the operations.

3.2 Running Results

By using this AAOP with accelerated search genetic algorithm, both running examples succeeded to reach their optimization goals

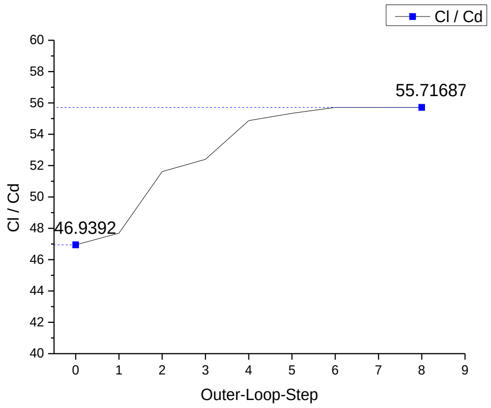

Fig. 7 The Single Objective Optimization Procedure of Lift-drag Ratio in Example 1

The final optimized flap position of Example 1 has been identified which achieves the goal of significantly higher lift-drag ratio of 55.71687, compared with the original ratio of 46.9392. The optimization results generated by the outer-loop steps is shown in Fig. 7.

Referring to Example 2, the optimum results indicate that the final optimized slat and flap positions have achieved the goal of higher Cl and lift-drag ratio, with lower Cd and Cm.

The optimization results of the whole optimization procedure are shown in Fig. 8, Fig. 9, Fig. 10 and Fig. 11.

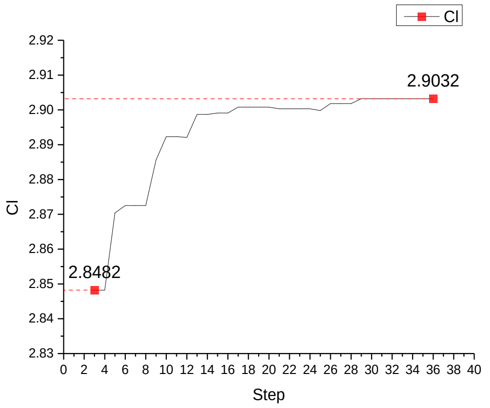

Fig. 8 The Multi-objective Optimization Procedure of Cl in Example 2

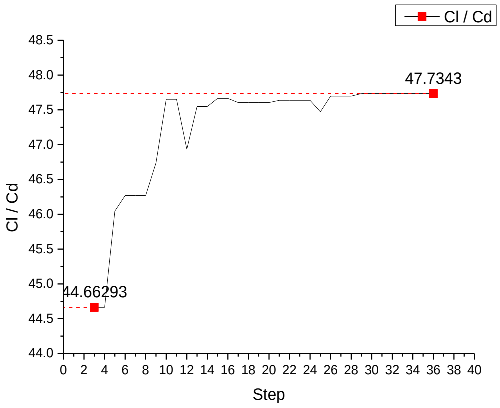

Fig. 9 The Multi-objective Optimization Procedure of Lift-drag Ratio in Example 2

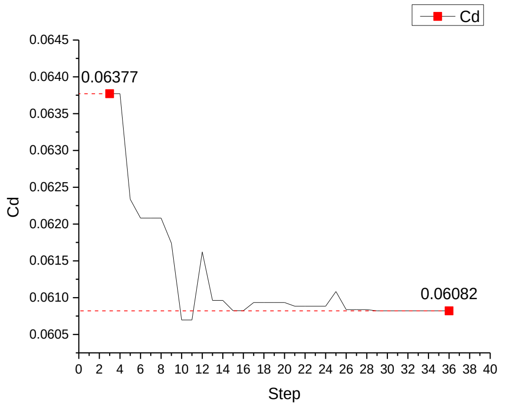

Fig. 10 The Multi-objective Optimization Procedure of Cd in Example 2

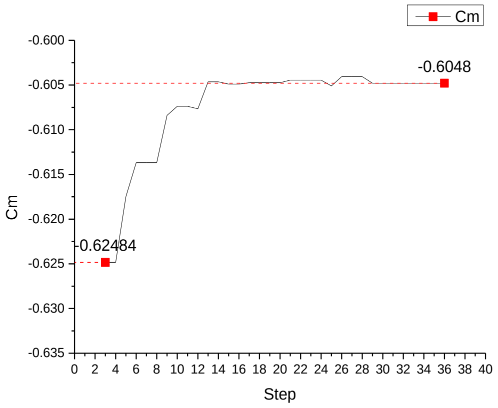

Fig. 11 The Multi-objective Optimization Procedure of Cm in Example 2

4 Conclusion

Under the support of the China national high technology research and development program 863 (Project Number: 2012AA01A304), the research and applications of the optimization platform with this improved optimization method have been successfully developed. The optimization procedures of running tasks indicate that this platform is stable and robust when operating. Meanwhile, it decreases the computing cost by decreasing the amount of optimization population by its nested double-cycle process.

For further development, those who have been conducting this research will develop more optimization strategies which could be integrated in this optimization platform based on the foundation of Project 2012AA01A304.

5 Contact Author Email Address

Degang Cui: dgcui@vip.163.com

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