Study on Optimization for High Lift Devices of Civil Aircraft Based on Rapid Calculation Method

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Abstract. For the requirements of aircraft high lift device design, sorts out the key links of aerodynamic calculation, optimization design process and optimization strategy selection required for the parameters optimization. By selecting accurate and efficient calculation and analysis software, compiling high lift devices 3D model forming program and calculation analysis software pre-processing program, engineering application research of aerodynamic characteristic analysis software and the establishment of calculation analysis platform are carried out. Combined with the optimization software to establish the optimization process and define the optimization objectives and constraints, the optimization design platform for the parameters of the civil aircraft high lift device based on the multi-control section and multi-airfoil is realized. The optimization results of the calculation examples are in good agreement with the wind tunnel test results, which provide guarantee for the parameters optimization of the high lift devices of civil aircraft.

1. Introduction
The high lift devices design is a key technology for modern civil aircraft to increase taking-off weight, shorten taking-off and landing distances and enhance airport adaptability. It is one of the most effective means to improve aircraft international competitiveness. Different from the early days which mainly focused on the maximum lift coefficient requirements to meet the wing load requirements during the cruise phase and the field length requirements during the taking-off and landing phase, the modern lift device system design has turned its attention to reducing the system complexity and structural weight as much as possible under a certain maximum lift requirement \cite{1}. The high lift devices have a significant impact on the manufacturing cost of traditional jet civil aircraft. This is because the design and testing of the devices is time-consuming, and its flow mechanism, geometric configuration, actuation and support mechanisms are very complicated, the weight of the structure, the number of parts and the need for a lot of maintenance are determined. Rudolph's research shows that the cost of a typical jet aircraft's lift system is about 6%-11% of the entire aircraft \cite{2}. This fully shows that slight changes in the aerodynamic performance of the lifter may cause changes in the empty weight and performance of the aircraft, which directly affects the operating cost of the aircraft, thus highlighting the important role of the design of the lifter in the aircraft design process.

The configuration and flow characteristics of the high lift devices are very complicated \cite{3}, and there are many technical difficulties, such as the boundary layer of the confluence, the separation of
the flow, the mutual interference of the wakes of different components, and the difficulty of geometric formation and low-speed calculation. The current CFD technology is difficult to fully meet the design and accuracy requirements of the complex configuration of the lifting device. The design of the high lift devices is very difficult and costly [4]. It is often necessary to use wind tunnel tests to understand its main flow physical phenomena and improve CFD method to solve the aerodynamic problem of a certain type of high lift devices.

How to quickly and effectively obtain the best shape design that is simple in configuration and meets the overall requirements is a hot spot in the current research on the aerodynamic optimization design of high lift devices [5].

2. Engineering application research of calculation tools for high lift devices

With the rapid development of computer technology and the continuous improvement of numerical calculation methods in recent years, the application of computational fluid dynamics in modern aircraft design has become more extensive and practical. The CFD method can greatly reduce the number of wind tunnel tests and design cycles for aircraft design. The scope of application of the CFD method covers many aspects such as wings, wings/engines, high lift devices, tail wings, wing body rectifiers and fuselage rear bodies, including the panel method and full-potential equations, Euler equations, RANS. Numerous calculation methods and methods, including LES, DES, etc., use structured grids, unstructured grids, adaptive grids and other technologies [6]. These methods and technologies have played a very important role in all stages of aircraft design.

2.1. Selection of calculation software

The aircraft design process needs to quickly and accurately predict the aerodynamic performance of the configuration, but the calculation accuracy and the calculation efficiency are often contradictory and difficult to meet at the same time. Among the many numerical calculation methods, although with the advancement of technology, the NS equation calculation method is gradually becoming the main method of aerodynamic analysis, but the most widely used aircraft design engineering is still the early fast aerodynamic analysis method software and programs. Compared with traditional fast analysis methods, NS equation calculation can provide more accurate calculation results and clearer flow details, but it is always difficult to apply it to model design. The calculation of NS equation takes up huge resources, the calculation cycle is very long, and there are many problems such as reliability, calculation accuracy and efficiency, practicality and ease of use. There are many factors influencing the calculation results of the NS equation, including grid generation, calculation format, turbulence model and so on. For a new aerodynamic layout, a reliable calculation grid often requires a lot of trials and adjustments. The problem faced by the design department is that the design shape is almost new. At present, there is no universal, mature and reliable grid definition method and evaluation standard, and grid generation is not only related to calculation software, but also closely related to the configuration characteristics and the engineering experience of the designer. The calculation results are often depends on people who carried out the job. Compared with the calculation of the NS equation, although the accuracy and scope of application of traditional fast analysis methods such as the panel method have certain limitations, it is difficult to predict flow separation and stall characteristics, and requires designers to have a lot of experience in use, but its advantages is also very obvious. For example, computational grids often only need to generate surface grids to perform iterative calculations. The amount of calculation is small, and the aerodynamic results can be quickly obtained, and the results are stable and reliable within the effective range, which can greatly reduce the workload.

In the specific engineering application of civil aircraft design, the calculation accuracy and speed requirements of different design stages of the high lift devices are very different, so the CFD calculation methods and software that can be used are also different. In view of these characteristics, combined with the requirements of rapid optimization in the initial design of the high lift devices, in order to improve the efficiency of the initial design of the high lift devices, the panel method
calculation software commonly used in engineering design is selected as the fast aerodynamics calculation tool of the high lift devices.

The advantage of the panel method is that iterative calculation can be carried out only by generating the surface mesh for calculating the grid, the calculation amount is small and the aerodynamic result can be obtained quickly. This makes this method have a small workload and rapid calculation in the aerodynamic analysis and design of complex aircraft, and it has a very wide range of applications in the world. The disadvantage is that the calculation of complex flow is difficult, the layout of the wake has a great influence on the calculation results, and the user's engineering and calculation experience are greatly dependent; the calculation results are only valid for the linear section, and the calculation accuracy is not good enough as Euler equation and the NS equation does. The requirements for calculation tools for aerodynamic characteristics in the aircraft design stage and preliminary design stage are mainly distinguish the difference of schemes and the requirements for time consuming and others engineering application. The panel method calculation tool used at this stage is suitable to optimize the parameters of the high lift devices.

In order to check the calculation and analysis capabilities of the software, the SCCH model is used for aerodynamic verification calculation. The schematic diagram of the surface grid and the analysis of the calculation results are shown in Figure 1 and Figure 2.

The surface grid used in the calculation is about 4500, and the calculation time is about 5 minutes. From the results’ comparison between calculation and test, it can be seen that the calculation result and the test result is basically parallel in the linear section, and there is an offset about 0.1. It can be seen that the calculation and analysis results of the linear section of the software are reasonable and reliable. However, due to the defect of the panel method to capture the stall, the calculation results close to the stall phase are generally not used. Therefore, it is appropriate to use the software in the preliminary design phase to perform rapid calculation and analysis of the complex configuration of the high lift devices for a large number of optimization options.

Figure 1. SCCH model and surface mesh.

Figure 2. SCCH model iteration results.
2.2. Calculation and analysis software platform

In order to build a software platform for the high lift devices according to the design process and method, it mainly include the application research of CFD engineering of the high lift devices, the research of the automation of pre-processing and the research of 3D surface mesh generation.

2.2.1. Development of 3D model forming program. The basic premise of the design of the high lift devices is to have an accurate configuration that can meet the requirements of shape accuracy and design principles. With this goal, follow the design constraints of the lift device, carry out the research on the geometric shape parameterization of the lift device, develop the 3D forming program, and realize the multi-section airfoil of the control section to the single multi-section wing and the wing body combination with the lift device Geometric transformation, which is shown on Figure 3. The program realizes the conversion from multi-airfoil to 3D forming of the high lift devices, and iteratively solves the functions of slot parameters, flaps and slat shafts, and structure trajectories. It is mainly used as a pre-processing tool for the calculation tool and other computing software using surface mesh.

![Figure 3. 3D model generated by program.](image)

2.2.2. Pre-processing automatic generation. In order to improve calculation efficiency and reduce human interference factors, carry out the research on the automatic generation of input files for pre-processing of calculation software. Research on the software input file, compile the pre-processing program according to the format required by the input file, and realize the generation of separate wing, wing body assembly, multi-segment wing with flap and slat devices, etc. The model and calculation results generated by the programs are shown in Figure 4.

![Figure 4. Calculation results of automatically generated input files.](image)
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3. Preliminary optimization platform for parameters optimization of high lift devices

After the construction of the calculation and analysis platform, it can quickly realize the optimization of geometric parameters such as the shape, deflection angle, and slot parameters of the high lift devices under the given constraints.

The optimization design model of the high lift devices includes design variables, objective functions, constraints and optimization algorithms. According to the performance requirements of the civil aircraft, determine the objective function required for the optimization design of the high lift devices.

According to the design process of the 3D high lift devices, the main design parameters are the skewness of the front and rear edge devices, the amount of seam overlap, and the width of the seam when the control section multi-segment airfoil is given and the plane shape is determined [7].

The optimization target of the high lift devices includes the stall characteristics, and the prediction of the stall characteristics is a difficult point in CFD calculation, which leads to greater difficulty and uncertainty in the design. Taking into account the complexity of the design of the high lift devices and the arduousness of the calculation, in order to make the optimization process converge to the optimal seam parameters as soon as possible, the optimization design model needs to consider how to add artificial experience in the numerical optimization process. The traditional aerodynamic design method is based on the designer's design experience, and approach the design goal through "trial and error".

According to the current design experience and the characteristics of calculation and analysis tools, six sections are selected as the control sections for the optimization design of the high lift devices, and there are 10 control parameters for the optimization design.

On this basis, the 3D model forming program, aerodynamic calculation and analysis software, its pre-processing program and post-processing, that is, the processing script extracted from the calculation and analysis results, are integrated into the optimization software platform. The schematic diagram of the process is shown in Figure 5.

![Schematic diagram of optimization process](image)

**Figure 5.** Schematic diagram of optimization process.
4. Parameter optimization examples

4.1. Window traversal optimization example

In order to verify the practical performance of the preliminary optimization platform of the high lift devices, a test case of the optimization platform was carried out. In order to better investigate the reliability of the optimization platform and the calculation and analysis tools, the given design parameters were traversed and calculated within the limited optimization window.

The optimization parameters of this calculation example are that the flaps and slats each have 4 deflection angles and 5 sets of corresponding seam parameters known as O/L and Gap, and the calculation example is 400, investigate the single-point calculation of the lift coefficient at 20° angle of attack instead of the maximum lift coefficient. Figure 6 shows the calculation and analysis results of lift for each configuration at 20° angle of attack. It can be seen from the figure that there are several abnormal data jumping points in the middle. Checking the calculation result file is caused by the divergence of the calculation iteration. Therefore, such points need to be eliminated in the analysis, and it is necessary to check the calculation results, especially the calculation results of the better solutions.

Compare the calculation results and trends with the wind tunnel test results, according to the 5 groups of slat parameter optimization tests, the best configuration selected is the third group. Check the corresponding traversal optimization calculation and analysis results as shown in Figure 7. The same results show that the third group of parameters has certain advantages. The optimized calculation results well reflect the real aerodynamic characteristics of each configuration, so the optimized platform is feasible as a rapid calculation and analysis tool for preliminary design.

![Figure 6. Wind tunnel selection test results.](image)

![Figure 7. Calculation and analysis results.](image)
4.2. Examples of genetic algorithm

In order to test the optimization platform’s ability to use advanced algorithms for optimization, genetic algorithms were used to test the optimization examples of high lift devices parameters.

The optimization goal is to maximize the lift coefficient of the design point, and the design variables are 10 variables in total to control the seam and skewness of the profile, with geometric and trajectory constraints added.

The optimization method uses the NSGA-II algorithm for global optimization. The initial population size is 32, and the genetics are carried out for 40 generations. The optimization basically converges after about 360 iterations. The lift coefficient of the initial value is 2.828, and the lift coefficient after optimization is 2.949, the lift coefficient is increased by 4.3%, and a more ideal optimization is obtained.

5. Conclusions

In the paper, the establishment of the calculation and analysis platform is carried out by selecting accurate and efficient calculation and analysis software, programming the high lift devices parameterized forming program and the calculation software pre-processing program. The optimization design platform is realized for the parameters of the civil aircraft high lift devices. The verification of calculation examples and comparison with the test results show that the design optimization platform can meet the accurate and rapid design requirements of the preliminary design phase.

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