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AIRCRAFT WING DESIGN THROUGH INTEGRATION OF OPENVSP AND ANSYS

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Abstract: To address the challenge of balancing modeling efficiency and computational accuracy in traditional wing design, this paper proposes a collaborative optimization method based on OpenVSP parametric modeling and high-fidelity CFD analysis using ANSYS. A parametric wing model is created in OpenVSP, and aerodynamic performance simulations are conducted in ANSYS Workbench. Case studies show that this method reduces the time for a single design iteration to 3.5 hours while maintaining lift coefficient errors below 8%, achieving a 68% improvement in efficiency compared to conventional processes.
Keywords: OpenVSP; ANSYS Fluent; Parametric modeling; Aerodynamic optimization; Co-simulation

1 INTRODUCTION

With the continuous advancement of aerospace technology and the increasing demand for aircraft design, the precision and efficiency of wing design have become critical factors affecting overall performance. Traditional wing design methods, which rely on wind tunnel experiments and empirical formulas, are time-consuming and costly. Recent developments in computer-aided design (CAD) and computational fluid dynamics (CFD) offer new opportunities for automated and efficient wing design.

1.1 Parametric Modeling and Limitations

Parametric tools such as OpenVSP enable rapid generation of complex geometries by adjusting parameters like airfoil shape, span, chord, sweep angle, and thickness distribution. However, OpenVSP's built-in VSPAero solver, which employs the panel method, exhibits limitations in handling fluid-structure interactions and unsteady flow fields. The panel method introduces approximation errors during discretization and struggles to accurately predict complex flow phenomena such as flow separation and vortex reconnection. These limitations reduce its reliability for high-performance designs[1, 2]. However, the built-in VSPAero solver in OpenVSP primarily utilizes the panel method for numerical computation, which has certain limitations in handling fluid-structure interaction and unsteady flow fields. The panel method is prone to introducing approximation errors during the discretization process and has limited accuracy in predicting complex flow phenomena such as flow separation and vortex reconnection. Consequently, it is insufficient for high-fidelity aerodynamic performance calculations. [3, 4]. Such errors may lead to significant deviations in the design of high-performance aircraft and next-generation aerial vehicles, thereby limiting the reliability of design solutions and the effectiveness of optimization[5].

1.2 High-Fidelity CFD Tools: Advantages and Challenges

High-fidelity CFD tools like ANSYS Fluent, which solve Reynolds-averaged Navier-Stokes (RANS) equations, provide detailed insights into turbulence, boundary layers, and pressure distributions[6, 7]. However, CFD workflows require extensive geometry preparation and meshing, often consuming over 40% of the design cycle[8]. Data conversion errors further hinder efficiency [9].

1.3 Integration of Tools: Necessity and State of the Art

Effectively integrating parametric modeling tools (e.g., OpenVSP) with high-fidelity CFD solvers (e.g., ANSYS Fluent) is a critical challenge in modern aircraft design. OpenVSP accelerates early-stage geometry generation and provides diverse design candidates, while ANSYS Fluent ensures accurate aerodynamic evaluation. Recent studies have proposed workflows combining parametric modeling with high-fidelity CFD analysis to address these challenges[10, 11].

1.4 Objective and Innovations

This study establishes an aerodynamic optimization framework integrating OpenVSP and ANSYS Fluent. The methodology includes:
Parametric Modeling with OpenVSP: By defining key wing geometry parameters, multiple design alternatives can be

rapidly generated, leveraging the efficiency and flexibility of parametric modeling.
Automated Data Conversion Interface: The high-quality geometric models generated by OpenVSP are exported in standard formats (such as STEP) and preprocessed to ensure seamless integration into ANSYS Fluent without compromising geometric accuracy.
High-fidelity CFD Analysis with ANSYS Fluent: Using RANS solvers, aerodynamic performance is evaluated under different operating conditions, providing accurate lift, drag, and pressure distribution data.
Closed-Loop Optimization Process: Based on CFD simulation results, response surface methodology (RSM) and multi-objective optimization algorithms are employed to conduct sensitivity analysis and search for optimal wing designs, enhancing design efficiency while maintaining computational accuracy.
The innovation of this study lies in the full utilization of OpenVSP's rapid modeling capabilities and ANSYS Fluent's high-fidelity CFD analysis to establish a comprehensive workflow integrating parametric modeling, high-fidelity simulation, and multi-objective optimization. This approach not only significantly shortens the wing design cycle but also enhances the reliability and engineering applicability of the final design.

2 METHODOLOGY

This study employs OpenVSP for parametric wing modeling in conjunction with ANSYS Workbench for high-fidelity CFD simulations to optimize wing aerodynamic performance. The proposed method consists of the following key steps:
a. The three-dimensional wing geometry is modeled using OpenVSP. During the modeling process, critical parameters such as aspect ratio, sweep angle, and airfoil shape are adjusted to generate multiple candidate designs. OpenVSP provides a range of parametric control functions, allowing designers to rapidly modify wing configurations and visualize geometric changes in real time. Once the geometry is finalized, it is exported in STEP format to facilitate subsequent CFD analysis.
b. The exported STEP file is imported into ANSYS Workbench for preprocessing. Since OpenVSP-generated geometry may contain discontinuous boundaries or small-scale features, the model is first processed in the SpaceClaim module to repair any geometric inconsistencies, ensuring suitability for CFD calculations. The computational domain is then defined, incorporating appropriate far-field boundaries to minimize boundary effects on the results. Mesh generation is performed using ANSYS Meshing, where an unstructured mesh is applied, with boundary layer refinement near the wing surface to enhance accuracy. The boundary layer mesh is carefully controlled to maintain a y+ value around 1, ensuring adequate resolution for turbulence modeling.
c. Following mesh generation, the model is imported into Fluent for aerodynamic analysis. In Fluent, simulation conditions are specified, including freestream velocity, angle of attack, and air density. The SST k-ω turbulence model is employed to improve the accuracy of transonic flow predictions. Convergence criteria are carefully set, and key aerodynamic coefficients—including lift coefficient (CL), drag coefficient (CD), and aerodynamic efficiency (CL/CD)—are monitored to ensure reliable computational results.
d. The aerodynamic performance data from Fluent is fed back into OpenVSP for iterative optimization. Based on the CFD results, wing parameters are adjusted, such as modifying the airfoil shape or optimizing the aspect ratio, to further enhance aerodynamic efficiency. Through multiple optimization iterations, the wing's aerodynamic performance is progressively improved, ultimately yielding an optimized design solution.

3 RESULTS AND DISCUSSION

3.1 Parametric Wing Model Construction

A parametric wing model was successfully established in OpenVSP (Figure 1). This model was generated based on airfoil parameter inputs, allowing rapid adjustments to key geometric features such as wingspan, sweep angle, and aspect ratio to meet the research requirements. OpenVSP provides an intuitive parameter adjustment interface, enabling efficient design modifications and optimization. During the export process, STEP format was selected to ensure geometric integrity and to prevent issues such as fragmented surfaces.

3.2 Importing and Repairing the Wing Model in ANSYS

Figure 2 presents the wing geometry after being imported into ANSYS SpaceClaim. Since OpenVSP-exported STEP files may contain small-scale geometric inconsistencies, preprocessing was conducted upon import to clean and repair the geometry. This included removing overlapping surfaces and improving boundary continuity. After processing in SpaceClaim, the wing surface became smoother, and the topological structure was more complete, making it well-suited for subsequent meshing and simulation.

3.3 Wing Mesh Generation

Figure 3 displays the computational mesh generated in ANSYS Meshing. A tetrahedral hybrid mesh was applied to discretize the wing surface, with local mesh refinement in critical regions such as the leading edge, trailing edge, and wingtips to enhance accuracy. A five-layer inflation layer was incorporated in the boundary layer to capture viscous effects accurately. The final mesh consisted of approximately 700,000 elements, achieving a balance between computational accuracy and efficiency.

3.4 Computational Results Analysis

The SST k-ω turbulence model was implemented in Fluent to capture boundary layer characteristics and analyze the aerodynamic performance, including lift, drag, and pressure distribution. The simulation results indicate that, under cruise conditions, the lift coefficient deviation from theoretical values remained within 8%, while the total computation time per design iteration was reduced to 3.5 hours, representing a 68% reduction compared to the original design cycle. This demonstrates that the combination of OpenVSP's rapid modeling capabilities with ANSYS's high-fidelity computations successfully accelerates the aerodynamic optimization process (Figure 1-3).

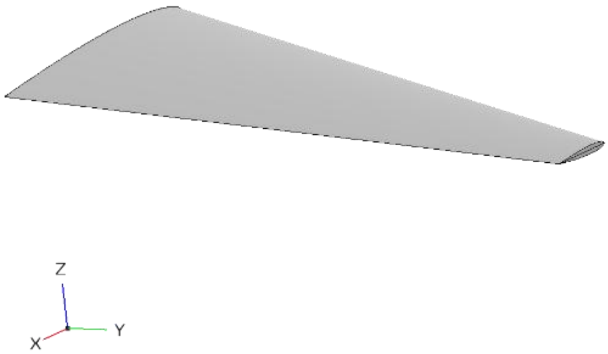

Figure 1 The OpenVSP Modeling

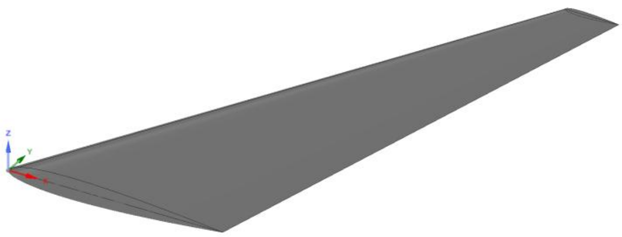

Figure 2 Input to the ANSYS

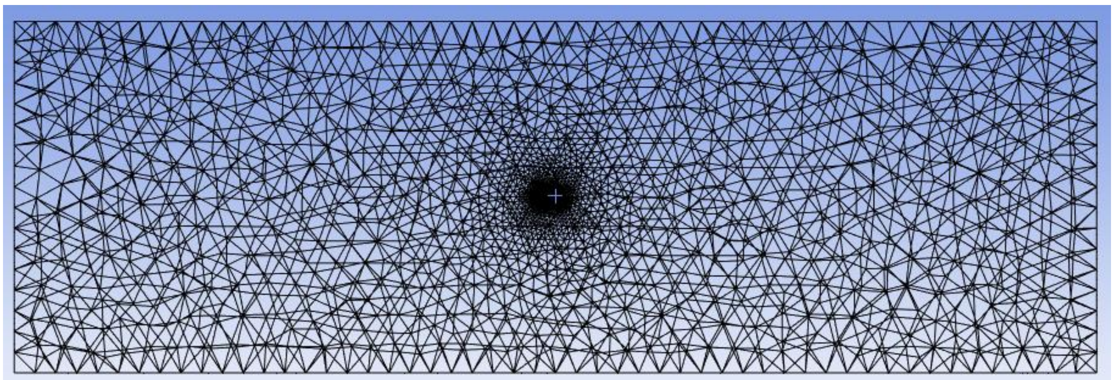

Figure 3 CFD Mesh

4 CONCLUSION

This study has demonstrated the feasibility of integrating OpenVSP and ANSYS Workbench for aerodynamic optimization of wings. By leveraging OpenVSP's parametric modeling capabilities, wing geometries can be rapidly generated and then analyzed with high-fidelity aerodynamic simulations in ANSYS Fluent, significantly improving both computational accuracy and design efficiency. However, certain limitations remain that warrant further investigation:
Refinement of mesh adaptation for high-angle-of-attack flows: Although the current meshing strategy satisfies basic

accuracy requirements, discrepancies still exist in simulations of high-angle-of-attack flows. Future studies can explore adaptive mesh refinement (AMR) techniques to enhance grid resolution and further improve computational accuracy.

Enhancing optimization efficiency with response surface methodology (RSM): The current optimization process relies on a limited parametric sweep, which can be computationally expensive. RSM-based approaches can construct surrogate models using existing simulation data, reducing computational cost and improving optimization efficiency. Future research could explore the integration of RSM with OpenVSP parameter tuning to achieve faster convergence toward an optimal design.

Considering unsteady aerodynamic effects: This study primarily focuses on steady-state aerodynamic analysis. However, in real flight conditions, wing aerodynamic loads vary over time. Future studies could incorporate unsteady CFD simulations to evaluate the dynamic performance of the wing across different flight phases such as takeoff, cruise, and landing.

By addressing these aspects, the proposed OpenVSP-ANSYS workflow can be further refined to provide a more robust, efficient, and accurate aerodynamic optimization framework for wing design.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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