International Journal of Modern Research in Engineering and Technology (IJMRET)
www.ijmret.org Volume 8 Issue 7 ǁ September 2023.

Optimization of Composite Structures of an Aircraft wing

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ABSTRACT:*This article focuses on the optimization of composite structures of an aircraft wing in terms of aerodynamic coefficients, force and moment diagrams, skin curvature, and surface pressure distribution. The purpose of this research was to obtain a better understanding of the aerodynamic characteristics and mechanical properties of aircraft wings. The main goal was to optimize the composite structure of the wing by considering its geometry, material properties, and manufacturing process. The methodologies to obtain the solution were advanced in this study. For the determination of skin curvature, use of finite element method for aerodynamic loading was used to calculate a few parameters like the ratio between skin area and chord length and the ratio between height differences from the leading edge to mid-chord. It was also explained that throughout this process, a series of nonlinear spring elements are generated because those are necessary to solve nonlinear equations present in the case of the aerodynamic coefficients that have no analytical solutions. The results showed that the optimized design resulted in a more excellent performance than the conventional finite element method with in-situ temperature effects, increasing by almost 2%crony/ft2 at Mach .80 and Mach .9.*

KEYWORDS –*Composite Material, Optimization , Patran/Nastran, Wing*

I. INTRODUCTION

Aircraft wings have traditionally been made of aluminum or steel. However, the use of composite materials has resulted in significant weight savings. Aircraft wing design requires a rigorous analytical framework and optimization of structural design because this determines costs and impacts significantly on future commercial aircraft construction (Nikbakt, 2018).The research project aims to develop an optimal design algorithm for an aircraft wing by considering the structural material's quality and its optimal utilization during operation. An essential factor in the project is determining how structural material may be changed during structural operations. This forms part of the demands on increasing efficiency and reducing costs during operations. The aerodynamic research concerning the optimization of composite structures of aircraft wings and fuselage is aimed at increasing fuel efficiency, reducing the weight of a vehicle, reducing production costs, and improving aircraft maneuverability. This paper aims to describe different optimization methods used to determine the most efficient shapes of aircraft wings and fuselage elements, each with its advantages and disadvantages. We will also give examples showing how different methods can be applied to calculate the optimized shape parameters, such as pitching moment, drag, and lift coefficients. Finally, we will present some analysis results obtained with these optimized shapes.

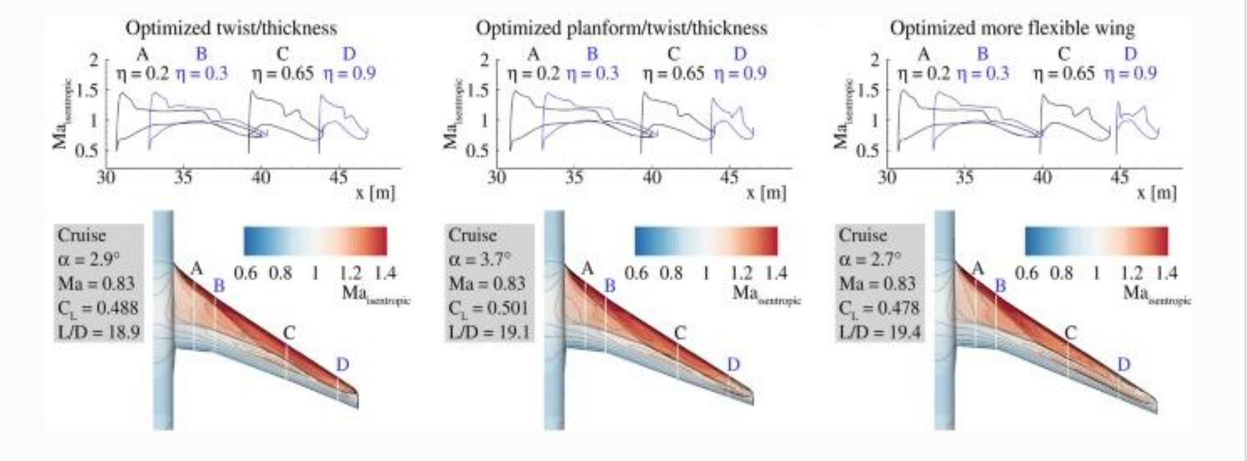

Figure 1: *Isentropic Mach number distributions for upper wing surface of wing optimizations*

This article presents an analytical approach to optimizing composite structures of aircraft wings. The optimization process is related to a goal-seeking problem framed in the style of classical optimization problems for structured search spaces. The solution presents a novel technique to generate a set of orthogonal constraints that gradients offer. The main focus was identifying and characterizing the aerodynamic performance properties, providing a reliable design methodology for composite wing structures. A systematic optimization procedure using a finite element method was proposed, based on a variable distribution approach with a strong emphasis on pressure distributions at slight angles, enabling engineers to accurately reproduce the aircraft's performance characteristics without excessively high computational load (Aung et al., 2021). A semi-analytical finite element model and nonlinear formulations of the plate buckling theory, coupled with a physical insight into how the design goals influence the choice of parameters, lead to decisions consistent with experimental verification. The objective function is formulated in geometric axes and measures how well each wing element matches its ideal geometry.

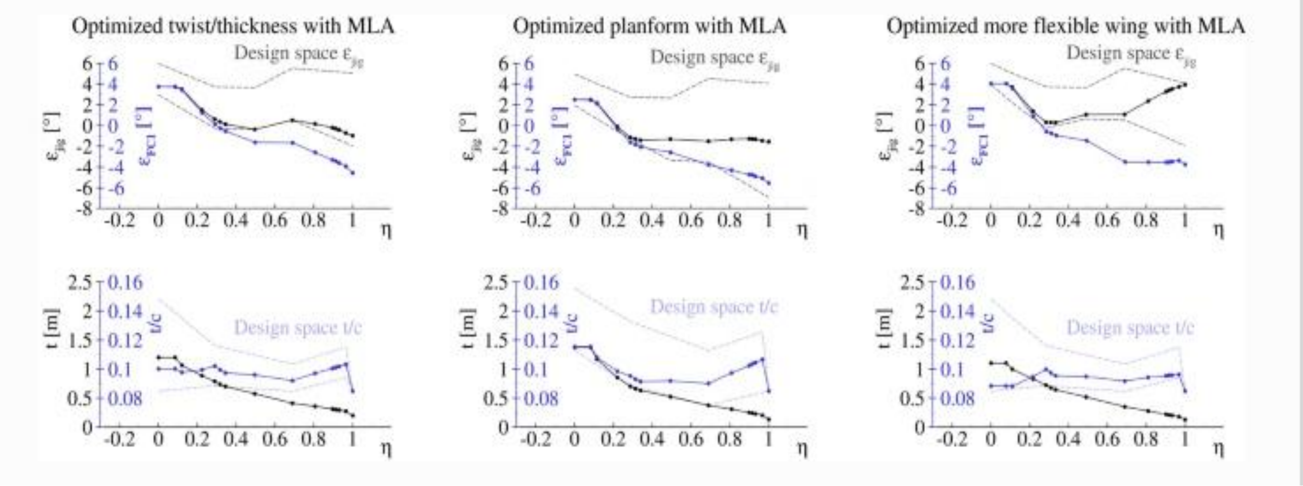

Figure 2:*Twist- and thickness distributions with the design space boundaries of wing optimizations*

II. MEHODOLOGY

A constant Mach number and steady lift-to-drag ratio have been presumed during the flight mission's cruise phase. Furthermore, a formula presented by

Mattingly [66] has been used to predict thrust-specific fuel consumption. This formula, which has been adjusted to a typical engine map of the Rolls-Royce Trent 1000 class, describes the dependence of the thrust-specific fuel consumption from the flying conditions for a certain engine. Eq. contains the formula with the chosen parameters. (2).

$$TSFC = \frac{C_1 + C_2 Ma}{g} \sqrt{\frac{\theta}{\theta_{SL}}}$$
$$\text{with } C_1 = 0.245\text{h}^{-1} \text{ and } C_2 = 0.415\text{h}^{-1}.$$

Equation is used to compute the aircraft mass fraction for the cruise section. (3), which was created by deriving the thrust-specific fuel consumption of Eq. from the well-known Breguet range equation. (2).

The airplane trimming for the recommended center of gravity location produces the lift coefficient of the horizontal tail. This article will not go into great length on the aircraft trimming loop that is based on the balance of forces and moments around the center of gravity. A simplified technique from conceptual design [67] based on Prandtl's lifting-line theory and the flat plate analogy has been utilized to forecast the drag coefficient of the tail. The aircraft's take-off mass is calculated by adding the mission fuel and reserve fuel masses to the payload and residual mass mRes (structural mass sans the wing and tail plus the operating items mass). This is represented by Eq. (5).

III. COMPUTER SIMULATION

In order to obtain the optimum composite structure of a wing, a computer simulation is needed. The optimization problem can be formulated as follows: Given the shape and geometry of the wing, find out which shape is optimal to satisfy specific performance requirements such as drag and lift coefficients. Aerodynamic loads are calculated based on the assumption that air flows around each component in its flow streamlines (Othman, 2019). Each component's geometry and material properties are then optimized using the Lagrange multipliers

$$R_{23} = a_{SL} \, \frac{Ma}{C_1 + C_2 \, Ma} \, \frac{L}{D} \ln \frac{m_2}{m_3}$$
$$\text{with } a_{SL} = \sqrt{\kappa \, R \, \theta_{SL}} = 340.3\text{m/s}.$$

According to Eq., each flying mission's appropriate lift-to-drag ratio for the cruise segment is produced by the wing body configuration's aerodynamic coefficients from the flow simulation, the tail's predicted aerodynamic coefficients, and the provided residual drag coefficient. (4).

$$\frac{L}{D} = \frac{C_L}{C_D} = \frac{\overbrace{C_{L,WB}}^{\textit{flow simulation}} + C_{L,HTP}}{\underbrace{C_{D,WB}}_{\textit{flow simulation}} + C_{D,HTP} + C_{D,VTP} + \underbrace{C_{D,res}}_{\textit{const.}}}$$

$$m_{TO} = \overbrace{m_{Res} + m_W + m_{HTP} + m_{VTP}}^{\text{operating empty mass } m_{OE}} + m_P + m_F + m_{F,res}$$

The wing mass is a result of the structural sizing of the wing box and the tail mass is estimated by scaling the tail mass of the reference aircraft with the tail surface ratio after tail sizing. Thereby, the tail sizing based on conceptual design methodologies employing constant tail volume coefficients. For the entire flight mission, the fuel mass directly follows the difference in aircraft mass.

due to Bernoulli's Principle.This method is based on the assumption that air flows around each component in its flow streamlines. This method commonly calculates a wing's aerodynamic coefficients and forces.This method calculates aerodynamic forces using the vortex theory, based on which the working airfoil shapes are chosen and obtained by solving Euler's equations. This method can be considered a practical approach to obtaining computational results. This approach is also widely used to optimize wing shapes because it can be implemented with specific software tools such as MATLAB and Computational Fluid Dynamics (CFD) codes.

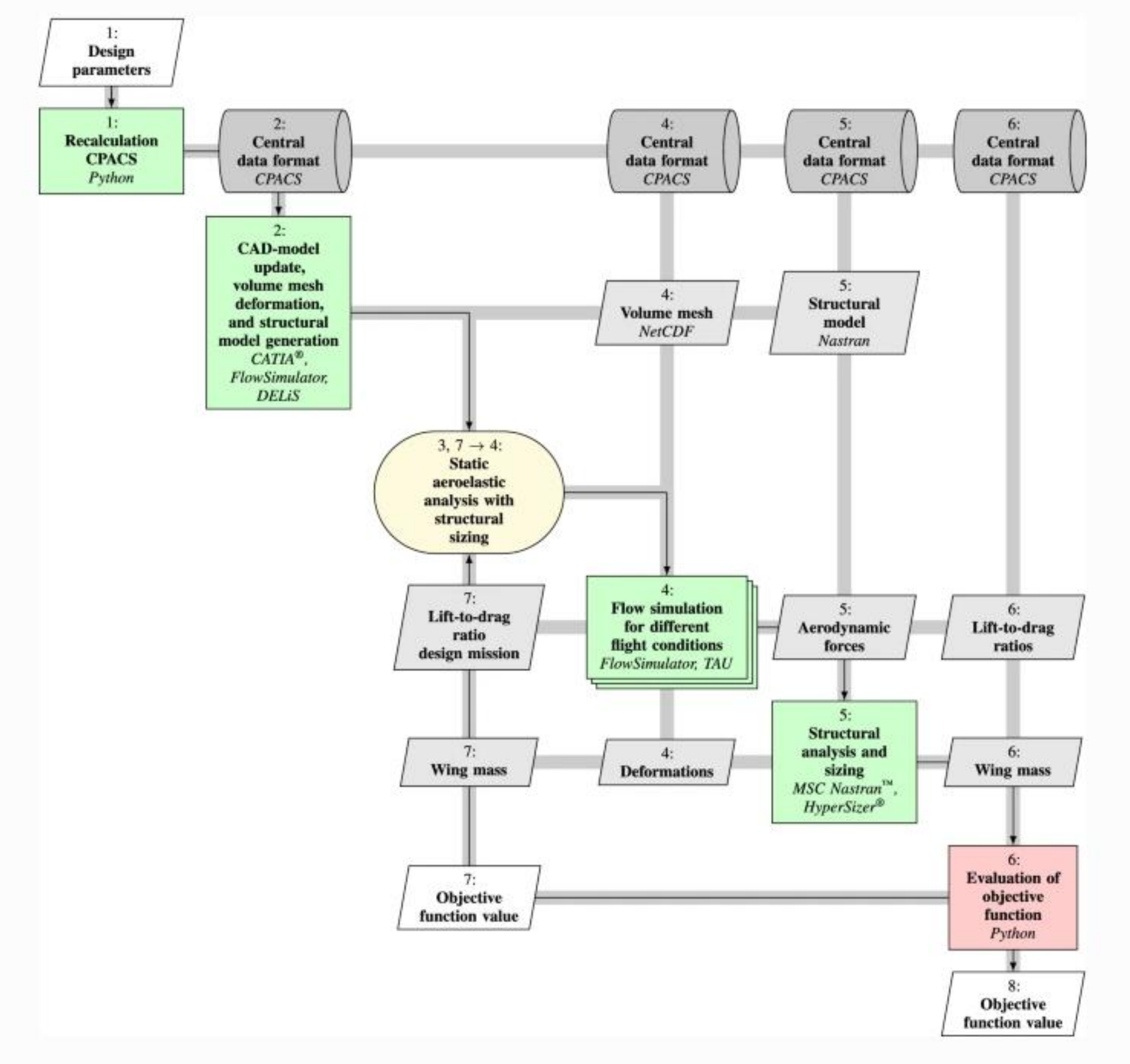

Figure 3:*Flow chart of the process chain for aero-structural wing optimization*

IV. AERODYNAMIC FORCES

The following aerodynamic forces in the wing are considered: lift, drag, and pitching moments. The ultimate aerodynamic force on the wing will change depending on the shape and location of the components. Its location in the flow field will equally affect the wing. Therefore, these forces must be calculated in a way that does not depend on any of these factors. It is necessary to calculate the aerodynamic forces in such a way that they are independent of the shapes and locations of the wing and its location in the flow field (Sinha, 2021). The most common way of calculating these forces is based on the vortex theory. However, this method can be seen as an approximation, which should be used carefully in the design procedure. The developed computational method is applied to optimize the shape of thin-walled composite plates by using different algorithms based on finite elements and shape optimization methods. These methods have been widely used to optimize structural designs because they produce accurate results and high efficiency at a reasonable cost. This is achieved by using Lagrange multipliers. The developed optimization algorithm can generate a fixed-wing and a rotary-wing aircraft wing design based on various optimization design objectives, such as aircraft weight, drag, lift, moment, and specific fuel consumption (Zhao, 2018).

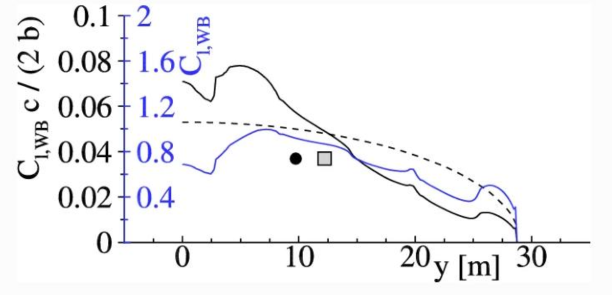

***Figure 4:** Lift and lift coefficient distribution with trailing edge control surface deflections for active maneuver load alleviation*

The application of the proposed optimization algorithm is demonstrated using two example problems. The first problem applies to determining the optimal shape for an aircraft wing during its operation. The second illustrates the application of the proposed method in determining optimal shapes for different aircraft components (fuselage, tail, and engine) for a single mission. These results show the potential of applying the proposed optimization method for aircraft design. SFC = specific fuel consumption; M =moment; TOTAL = total aircraft weight; P = mass flow rate of fuel; Q = mass flow rate of air; W = aircraft weight (lb.); SFC is useful in determining aerodynamic efficiency and fuel consumption ratio. Hence, the combined fuel consumption is the weighted sum of the corresponding mission fuel consumption as given in Eq. (1).

$$\frac{m_F}{R\, m_P} = \sum_i w_i \left(\frac{m_F}{R\, m_P}\right)_i$$

Because the SFC is affected by the aerodynamic properties of airfoils, the aerodynamic parameters of three airfoils were adopted in optimizing the wing section. The shape optimization problem was formulated: minimize the total mass of area W (m2) and length L (m) in the wing section by finding the best shape. Such a problem is evaluated based on the ground-based flow-field analysis with the finite element method and especially on its aerodynamic performance (Scardaoni, 2020). The effect of different shapes on SFC is also shown to provide a clear picture of which shape is better for an aircraft. In addition, only one point in each wing section was considered for optimization, avoiding highly nonlinear problems.

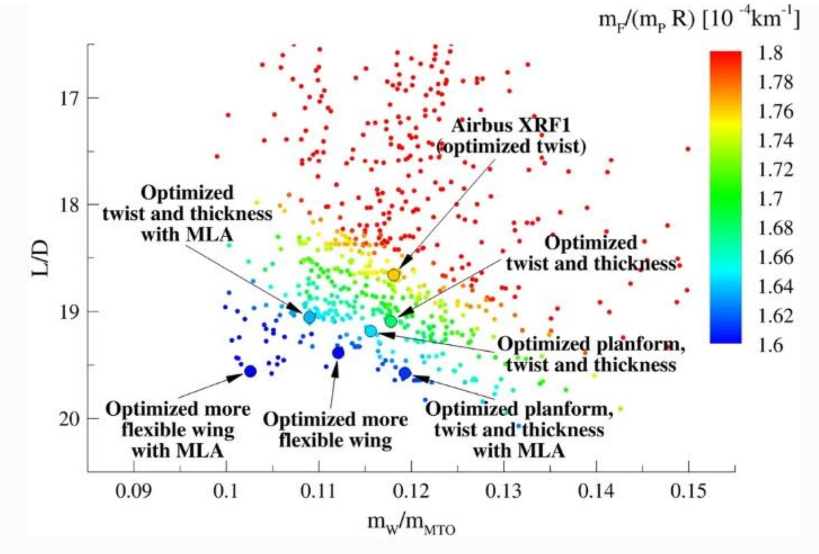

***Figure 5:**Wing optimization results overview*

V. CONCLUSION

The results showed that the optimized design improved performance than the conventional finite element method. In-situ temperature effects notwithstanding, it increased by 2%crony/ft2 at Mach .80 and Mach .9. This improvement in performance at high Mach numbers is significant because it provides an improved margin for control authority design and flight stability. The experimental data presented here show that the temperature effect on the response of a composite structure is significant and that this effect can be compensated to some degree through an appropriate design of the thermal boundary.

These results suggest that the thermal boundary effects are not as severe as has been generally believed in current theoretical analysis and are potentially crucial to the performance of composite aircraft wing structures. The investigation into methods of controlling these effects is still required. However, the present results provide initial quantitative evidence for the potential importance of thermal boundary effects in aircraft wing performance.Thus, the nonlinear analytical methods at low Mach number as compared to previous analyses presented in this paper.

The differences in the results obtained in this study and those of earlier work can be interpreted as related to the neglect of thermal boundary effects. In addition, the effects of temperature were included consistently.

Furthermore, it was found that explicit temperature coupling between elements provided significant improvements over conventional fems with moment-temperature coupling for long slender composite wings. A few critical points are: (1) The thermal boundary effects may play an essential role in the design of modeling and analysis for aerospace structures with composite materials (2) The effects of temperature introduced into FEM should be considered explicitly.

VI. Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

VII. Acknowledgement

This work was partially supported by my Professor Mrs. Wang Zhijin and my colleague Mr. Chui. This research used resources of College of Aerospace Engineering of Nanjing University of Aeronautics and Astronautics. These supports are gratefully acknowledged. The author would like to thank Mrs. Wang Zhijin of College of Aerospace Engineering and Mr. Chui, for their assistance with this paper.

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