FEM Analysis of the 5% CHEETA UAV Wing Structure

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This report presents the finite element method (FEM) analysis of the 5% CHEETA UAV, a hydrogen-powered unmanned aerial vehicle (UAV). The primary objective of this study is to determine the location and magnitude of stress concentrations in the wings to optimize the internal wing structure for necessary reinforcement. The successful implementation of this scale model structure is a step toward validating the CHEETA concept and achieving emission reductions in the aviation sector.

I. Introduction

The Center for High-Efficiency Electric Transport for Aircraft (CHEETA) concept presents the potential to validate the advancement of electric propulsion technologies for aircraft by integrating hydrogen fuel cells to achieve sustainable, zero-emission flight. To validate the design concept of the full-scale CHEETA aircraft and understand stress distributions within the aircraft's structural components, it is necessary to adapt the full-scale CHEETA geometry to a smaller scale for testing purposes. This report outlines the process of conducting FEM analysis to motivate the design of the 5% scale CHEETA UAV's aircraft's structure. The successful implementation of this scale model structure is a step toward the validation of the CHEETA concept and emission reductions in the aviation sector.

II. Objective

The primary objective of this FEM analysis is to determine the location and magnitude of the stress concentration in the wings of the CHEETA UAV while in simulated flight conditions. This stress concentration data will help to suggest an optimal interior wing structure that provides the necessary support for the wing, by focusing on where to add more or less structural reinforcement. We hypothesize that the highest stress concentration will exist at the wing kink, where the two wing sections meet. This is a result of the changing

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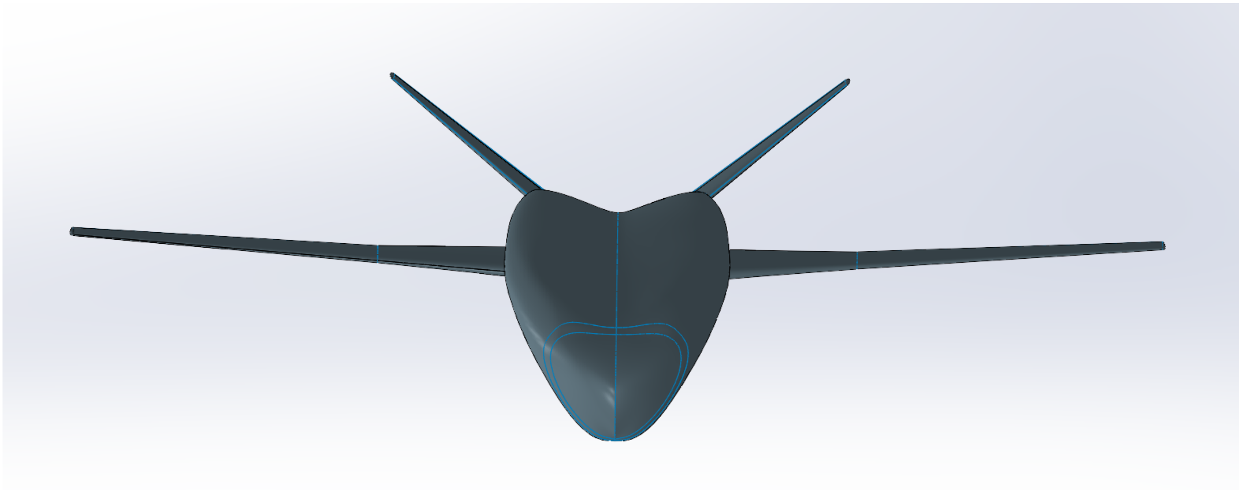

Fig. 1 5% CHEETA UAV Concept Airframe.

geometry at this location in addition to the high magnitude of lift force. Identifying this hotspot and confirming our hypothesis will guide the design of the internal wing structure.

The analysis will map the stress distribution over the wing to identify potential failure points and assess whether the UAV can withstand flight loads without structural failure. This will involve an assessment of material properties, boundary conditions, and load cases to simulate realistic flight conditions.

Fig. 2 5% CHEETA UAV Top-Down Wing Diagram.

III. Methodology

A. Modeling and Simulation

The FEM analysis was conducted using Abaqus CAE on a model created in SolidWorks. The outer shell of the wing was modeled as 1/8 inch thick balsa wood, with a Young's modulus $E = 3 \times 10^9$ Pa, Poisson's ratio $\nu = 0.38$, and density $\rho = 60\,\text{kg/m}^3$[1].

The UAV was modeled in SolidWorks with the specs provided by the CHEETA concept [2]. Next, the CHEETA UAV structure was converted into a .step file for the FEM analysis. The model was then imported into Abaqus where the properties were defined and the finite element mesh was created. Balsa wood properties were selected and defined as the shell of the model, as Balsa wood will be the predominant material in the assembly of the CHEETA UAV.

B. Boundary Conditions and Load Cases

The boundary conditions for this simulation were set to simulate straight flight conditions. The fuselage was restricted from moving in any direction or rotating on any axis to create the rigidly clamped case with the a cantilevered wing.

To determine the elliptical lift distribution of one wing given that the total lift of both wings is 50 N, we use the following equation for the lift per unit span $L(y)$:

$$L(y) = \frac{200}{\pi b}\sqrt{1 - \left(\frac{2y}{b}\right)^2}$$

where $L_0 = \frac{200}{\pi b}$ is the lift at the center of the wing, y is the distance from the wing root (center), and b is the wingspan of the wing. Therefore, the total lift for one wing integrates to 25 N over half the span (0 to $b/2$).

These simulated conditions replicate the stresses the UAV would experience during typical straight and level flight. By constraining the fuselage, we isolate the wing's response to lift forces and are then able to analyze the stress concentrations in a controlled environment.

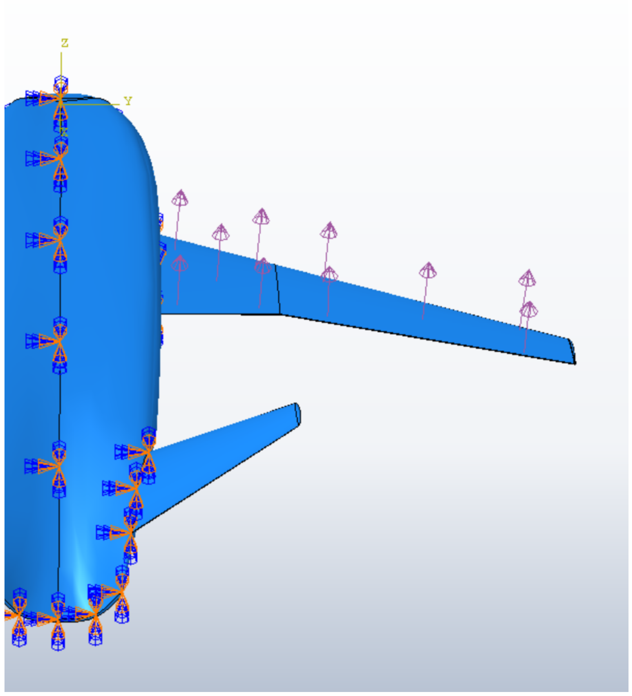

Fig. 3 Boundary conditions and load cases applied to the wing model.

C. Mesh and Element Selection

Tetrahedral elements were used due to the complex geometry of the aircraft, which was unsuitable for meshing with hexahedral or quadrilateral elements. The element size was set to 70 mm and then further reduced until a convergence of within 5% of the stress at the hotspot.

The mesh quality is critically important for the accuracy of the FEM analysis. Although tetrahedral elements more computationally intensive than hexahedral elements, they provide better flexibility for the more variable geometries of the UAV wing. The final element size chosen was 35 mm, at which point the stress results had converged satisfactorily.

IV. Results

The stress distribution analysis showed a stress hotspot at the wing kink as hypothesized. The results indicate that the wing kink, where the two wing sections converge, experiences the highest stress under the applied load conditions. The von Mises stress criteria identified the maximum stress concentration at this location, measuring 1.046×10^5 Pa. This area

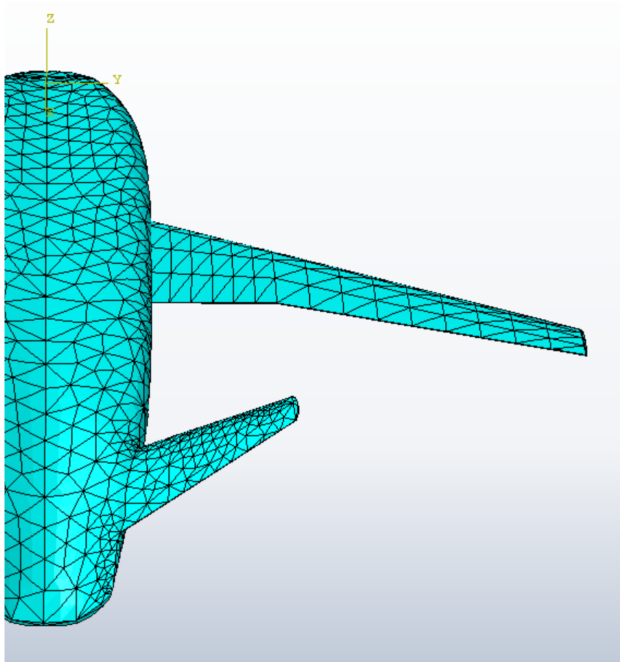

Fig. 4 Course mesh of the CHEETA UAV wing model.

requires significant reinforcement. The stress contours below provide a visualization of the location vulnerable to failure.

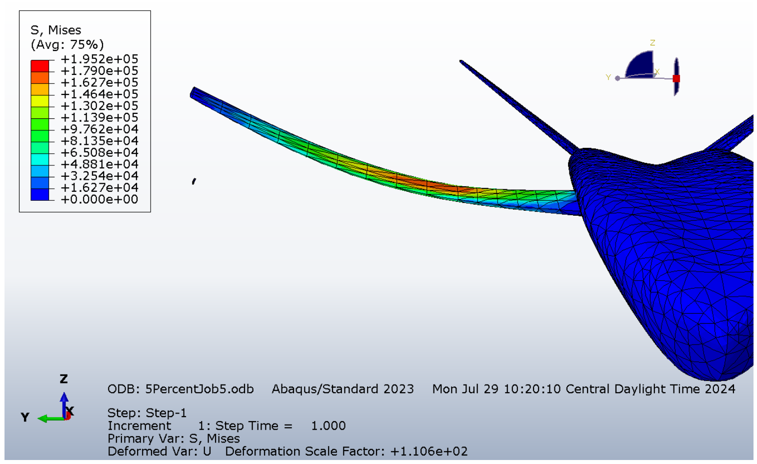

Fig. 5 CHEETA UAV Course Wing Stress Contours.

V. Design Improvement Recommendations

Based on the FEM results, the internal structure of the wing should feature at least two spars spanning the length of the wing, with additional spars within the high-stress region. Stringers should be placed along the leading and trailing edges, as well as on the top and

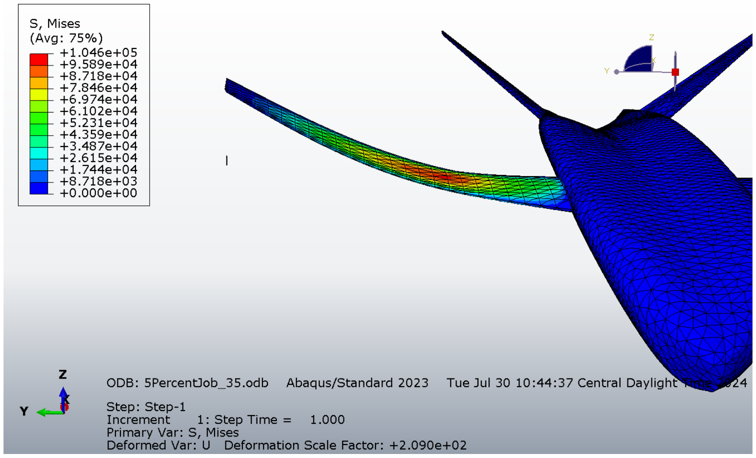

Fig. 6 CHEETA UAV Fine Wing Stress Contours.

bottom surfaces, to provide additional support. Further, double-wide reinforced ribs should be implemented in the areas surrounding the stress hotspot.

These reinforcements will distribute the loads more evenly and reduce the stress concentration at the wing kink. By adding multiple spars and double-wide ribs, the structural integrity of the wing will have a much higher likelihood of withstanding operational loads without failure.

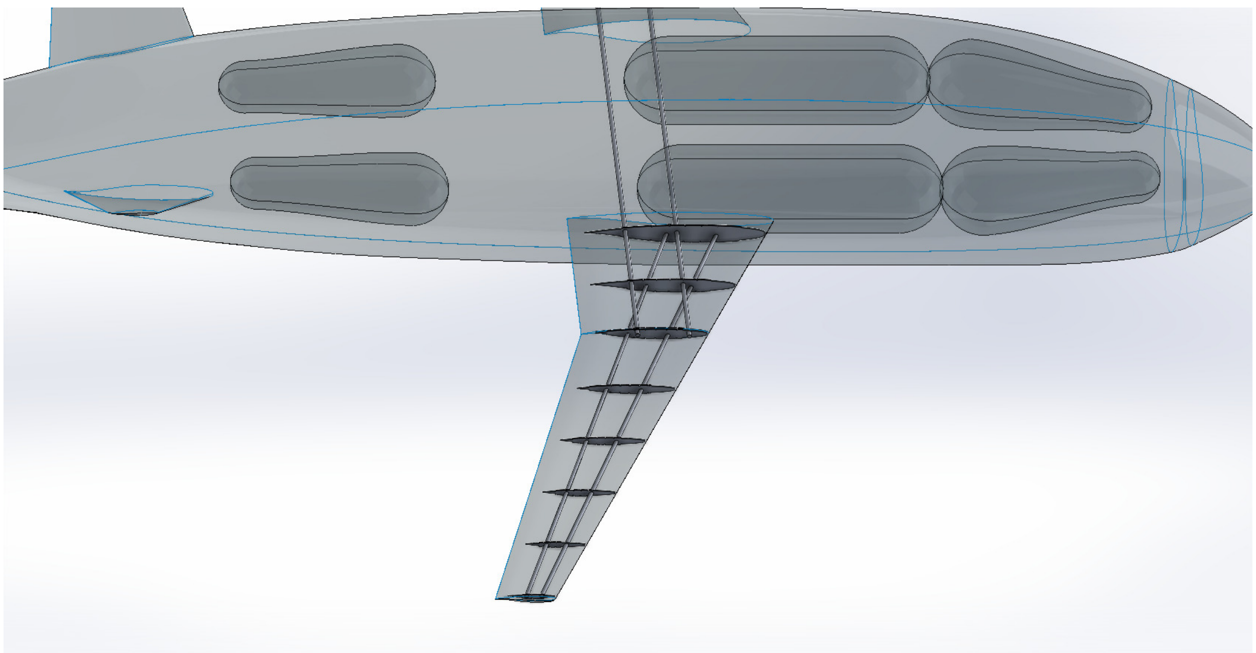

Fig. 7 Candidate Internal Wing Structure

VI. Conclusion

The FEM analysis of the 5% CHEETA UAV wing structure successfully identified the high-stress concentration areas, specifically at the wing kink. Reinforcing these areas with multiple spars and double-wide ribs is necessary to create an airworthy structure. These findings contribute to the ongoing design process of the 5% CHEETA UAV.

Further, this study demonstrates the importance of FEM analysis in the design of aircraft structures. By the ability to identify stress hotspots, FEM analysis provides critical data for an engineer and allows the design of well informed aircraft structure. Through FEM analysis, the structural integrity and performance of the UAV can be significantly improved.

Finally, this research supports the important goal of developing efficient aircraft in order to reduce the environmental impact of aviation.

References

[1] MakeItFrom.com, "Balsa," `https://www.makeitfrom.com/material-properties/Balsa`, 2024. Accessed: 2024-07-27.

[2] White, A., Waddington, E., Greitzer, E., Merret, J., Ansell, P., and Hall, D., "Trade-Space Assessment of Liquid Hydrogen Propulsion Systems for Electrified Aircraft," *AIAA*, 2023. https://doi.org/10.2514/6.2023-4345.