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Effect of Wing Attachment Bolts on the Drooping Phenomenon in CFRP Composite Aircraft Wing

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Abstract

- *Investigated the effect of wing attachment bolts on drooping in CFRP composite aircraft wings with a NACA 4412 airfoil design.*
- *Developed a FEM-based computational model to analyze deformation under stationary and flight conditions.*
- *Identified optimal configurations of bolts to minimize wing drooping and weight, thereby enhancing overall aircraft performance and fuel efficiency.*
- *Highlighted the advantages of using CFRP, such as superior strength-to-weight ratio, stiffness, fatigue resistance, and corrosion resistance.*

Presentation Outline

1. Introduction
2. Literature Review
3. Motivation
4. Work Methodology
5. Results and Discussion
6. Conclusion
7. References

Introduction

Fig 1: Wing Drooping Phenomena

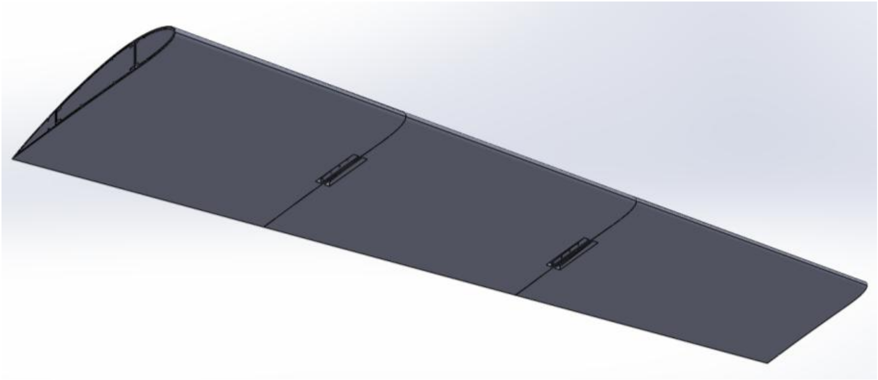

Fig 2: NACA 4412 Wing Profile

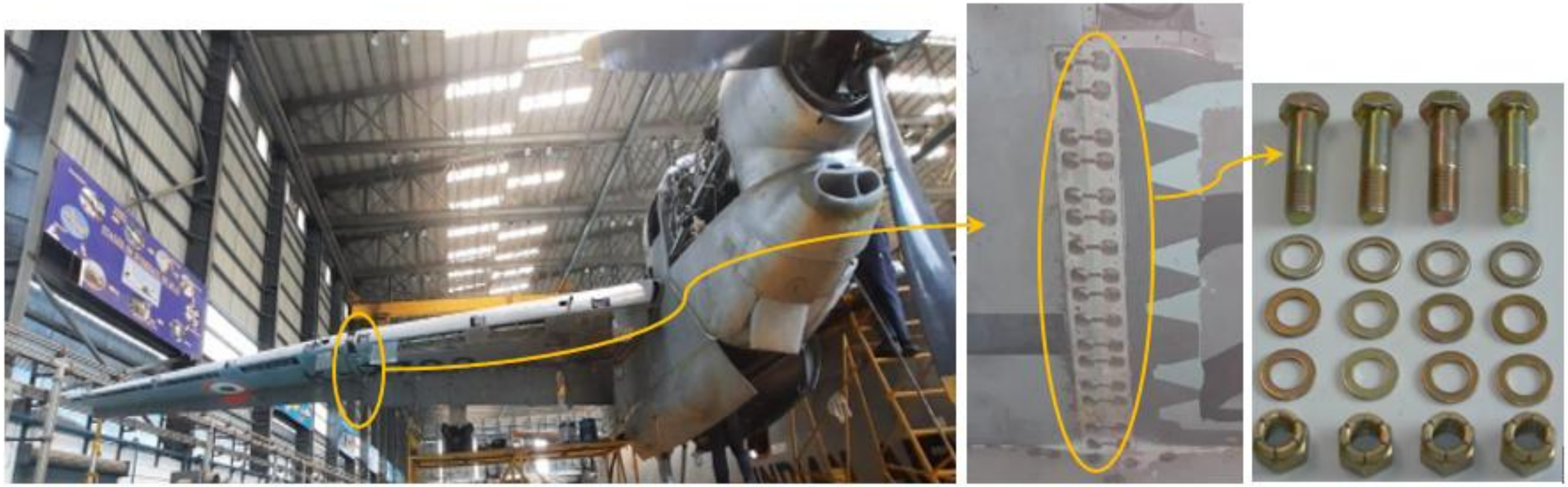

Fig 3: Wing span in aircraft, wing attachment, and used bolt as mechanical fasteners in the attachment.

Summary of Literature Review

S.No	Title	Author	Year	Observation
1	Analysis of General-Aviation Aircraft Wing Sections with Drooped Leading Edges	Syms, G.	2006	Analyzed the aerodynamic performance impacts of drooped leading edges on aircraft wings, providing foundational insights into wing drooping phenomena.
2	A Comparative Study of the Fatigue and Post-Fatigue Behavior of Carbon-Glass/Epoxy Hybrid RTM and Hand Lay-Up Composites	Cavatorta, M.P.	2007	Demonstrated how the fatigue and post-fatigue behavior of carbon-glass/epoxy composites impact wing structural integrity over time.
3	Structural Deformation and Stress Analysis of Aircraft Wing by Finite Element Method	Rabbey, M.F., Rumi, A.M., Nuri, F.H., Monerujjaman, H.M., & Hassan, M.M.	2014	Used FEM to model and analyze the deformation and stress distribution in aircraft wings, highlighting the effectiveness of composite materials in reducing deformation.
4	Design and Analysis of Wing of an Ultra-Light Aircraft	Yuvraj, S.R., & Subramanyam, P.	2015	Investigated the design and performance of ultra-light aircraft wings, emphasizing the importance of material choice and structural design in minimizing wing drooping.
5	Finite Element Analysis of Aircraft Wing Using Carbon Fiber Reinforced Polymer and Glass Fiber Reinforced Polymer	Das, S.K., & Roy, S.	2018	Provided a comparative analysis of CFRP and glass fiber reinforced polymers, demonstrating superior performance of CFRP in terms of structural stability and weight reduction.
6	Numerical Modelling of Aircraft Wing Deflection Under Different Loading Conditions	Adeyeye, K., & Odunfa, K.M.	2020	Conducted numerical modeling to study the deflection behavior of aircraft wings under various loading conditions, contributing to the understanding of wing stability.
7	Composite Wing Structure of Light Amphibious Airplane Design, Optimization, and Experimental Testing	Chinvorarat, S.	2021	Explored the optimization and experimental testing of composite wing structures, proving the benefits of using composite materials for improved performance and reduced wing drooping.

Motivation

- Investigate the benefits of using tapered bolts and nuts over ordinary bolts to improve wing performance and reduce drooping in both stationary and flight conditions.
- Assess the impact of CFRP composite material for wing skin compared to aluminum alloy to achieve reduced wing drooping.
- Identify the optimal bolt configuration to minimize the weight of fasteners while maintaining structural integrity.

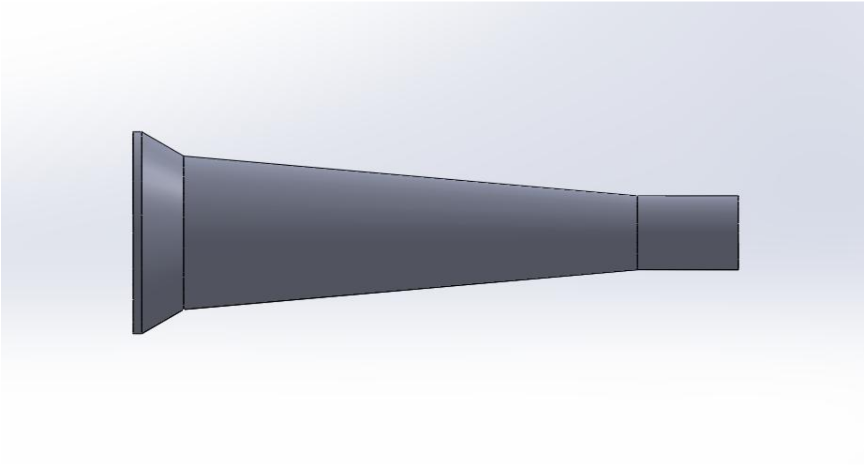

Fig 4: Tapered Bolt Attachment

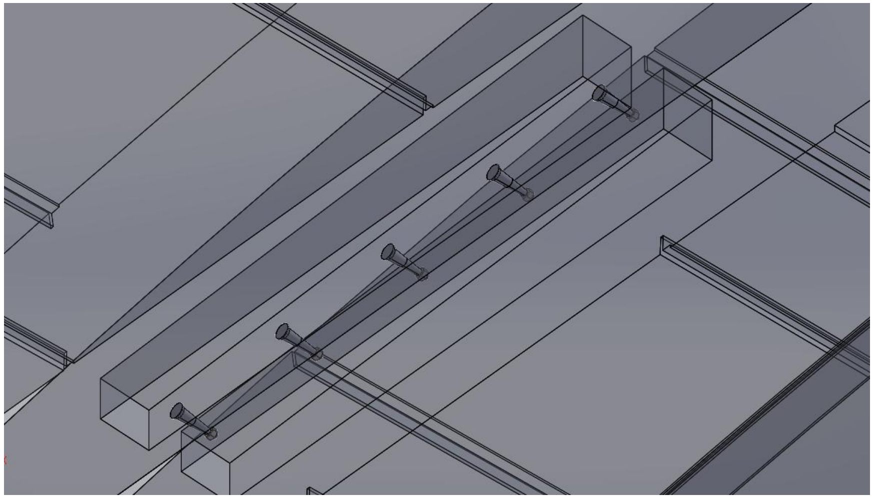

Fig 5: Wing Attachment between Sections

Work Methodology

FEM Analysis – Stationary Condition :

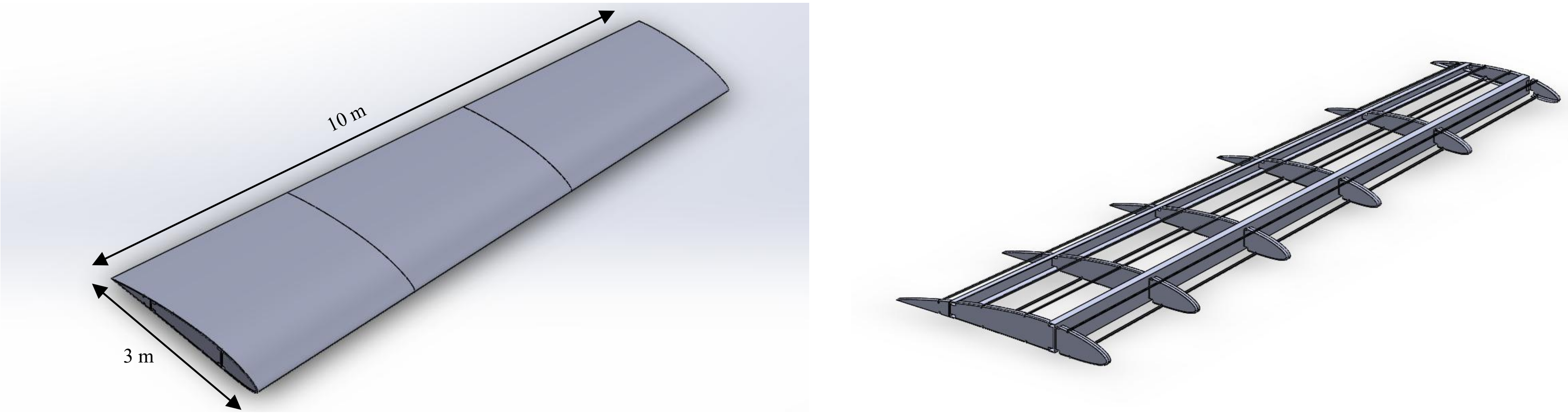

Fig 6: CAD Design of NACA 4412 with internal spar and ribs

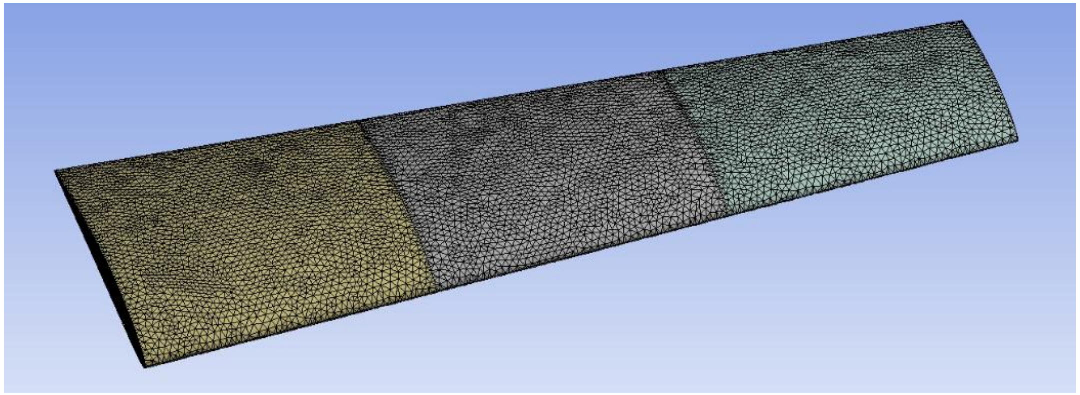

Fig 7: Mesh Selection (40 mm)

Work Methodology

FEM Analysis – Stationary Condition :

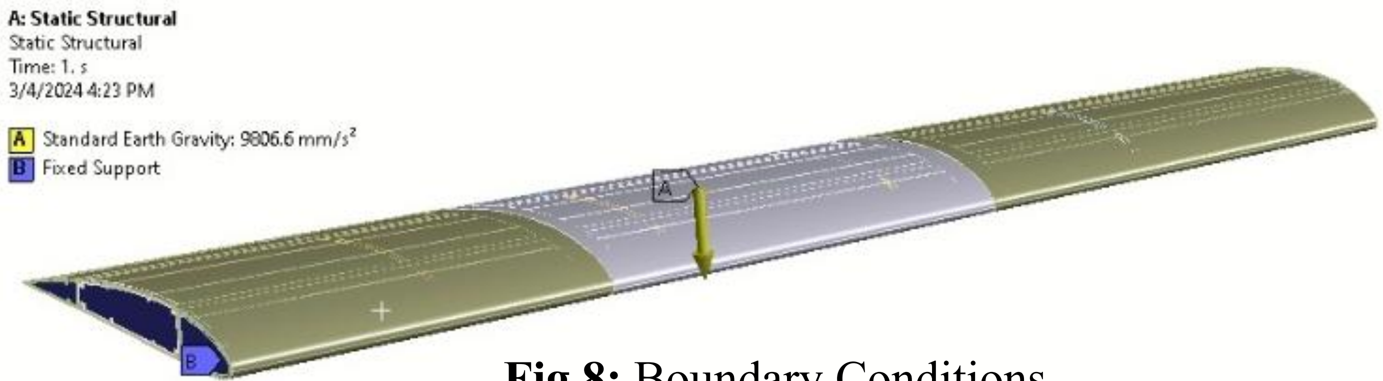

Fig 8: Boundary Conditions

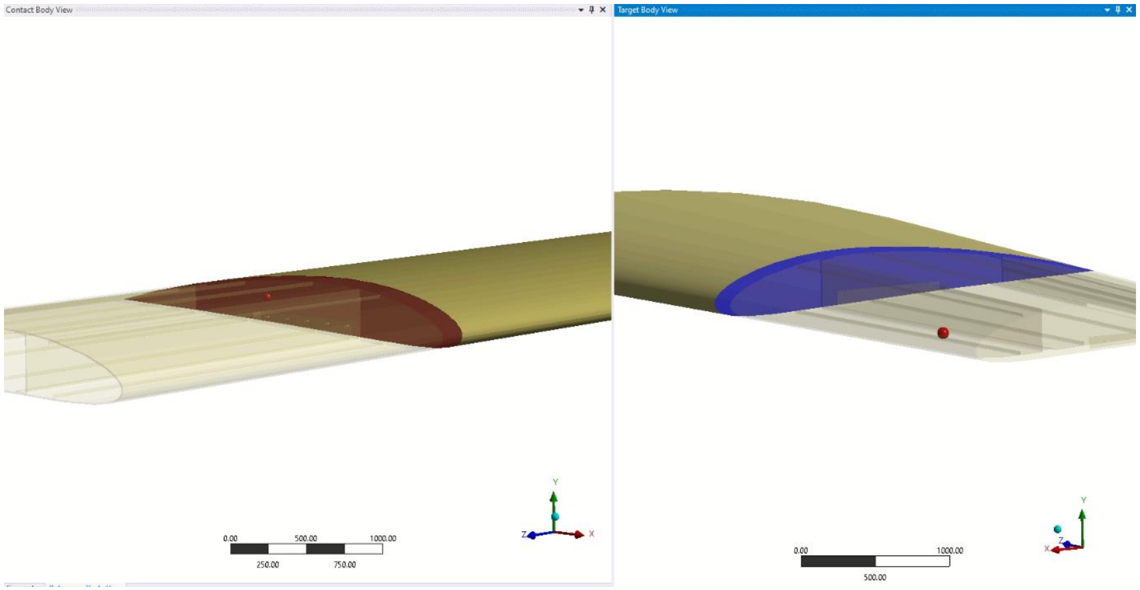

Fig 9: Frictional Contact Types

Numerical Results

ANSYS FEM Results:

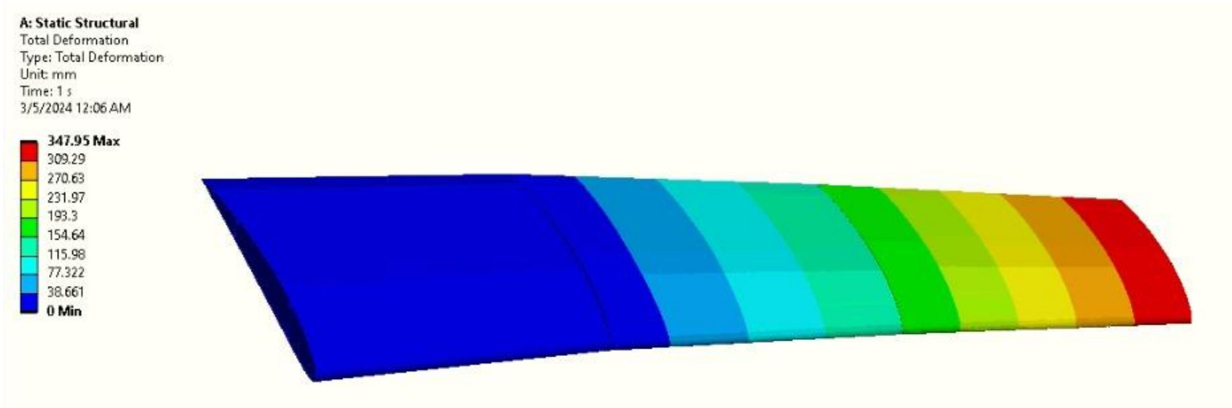

Fig 10: Deformation contour of optimal bolt configuration with 5° tapering angle bolts.

Tapering Angle (Degrees)	Total Deflection (mm)	Deflection Angle(Degrees)
1	335.01	1.919
3	344.48	1.973
4	333.42	1.909
5	347.95	1.993
6	376.98	2.159
7	362.03	2.073

Table 1: Deformation results obtained for varying tapering angles of bolts

Work Methodology

FEM Analysis – Flight Condition :

- Utilized CFRP Composite for the wing skin to minimize wing drooping.
- Imported pressure data from ANSYS Fluent, considering drag and lift forces, for static structural analysis
- Analyzed results for a bolt configuration featuring 10 bolts with a 5° tapering angle

Angle of Attack of Air on the wing (degrees)	Total Deformation (mm)
7	-1062.7
5	- 454.57
3	31.86
0	11.098
-3	291.42
-5	383.91
-7	471.45

Table 2: Effect of angle of attack on aircraft wing deformation

Conclusions

➢ *For Aluminum Alloy wings, bolt configurations were optimized with a 5-degree shank taper and 10 bolts, effectively reducing wing droop and deflection during stationary and flight phases.*

➢ *In the case of CFRP composite wings, the potential of CFRP materials in minimizing wing deformation and enhancing structural performance was demonstrated by our research, especially with a 5-degree shank taper and 10 bolts.*

No of Bolts	Total Deformation using CFRP Composite (mm)	Total Deformation using Al Alloy (mm)
6	175.64	474.23
10	132.53	347.95
12	120.68	335.01

Table 3: Comparison of deformation in composite wing and Al-alloy wing.

References

[1] Syms, G. (2006). Analysis of General-Aviation Aircraft Wing Sections with Drooped Leading Edges. Journal of Aircraft, 43(4), 1029–1035

[2] Salu Kumar Das and Sandipan Roy, Finite element analysis of aircraft wing using carbon fiber reinforced polymer and glass fiber reinforced polymer, IOP Conf. Ser.: Mater. Sci. Eng. 402 012077

[3] Sinchai Chinvorarat, Composite wing structure of light amphibious airplane design, optimization, and experimental testing, Heliyon, Volume 7, Issue 11, 2021, e08410, ISSN 2405-8440,

[4] Yuvraj S R and Subramanyam P 2015 Design and analysis of Wing of an ultra-light Aircraft International journal of innovative research in science, engineering and technology. 4,78-85

[5] Md. Fazlay Rabbey, Anik Mahmood Rumi, Farhan Hasan Nuri, Hafez Md. Monerujjaman, Md. Mehedi Hassan, Structural Deformation and Stress Analysis of Aircraft Wing by Finite Element Method. Advanced Materials Research, 906, 318–322

[6] Adeyeye, Kehinde, Odunfa, K. Moradeyo, Numerical Modelling of Aircraft Wing Deflection Under Different Loading Conditions, International Journal of Innovative Science and Research Technology, ISSN No:-2456-2165

[7] Cavatorta, M.P., 2007. A Comparative study of the fatigue and post-fatigue behavior of carbon-glass/epoxy hybrid RTM and hand lay-up composites. J. Mater. Sci. 42 (20), 8636–8644

[8] R.Rajappan, Pugazhenthi, Finite Element Analysis of Aircraft Wing using Composite Structure, The International Journal of Engineering And Science (IJES), ISSN: 2319 – 1813 ISBN: 2319 – 1805

[9] Fiorina A, Seman B, Castanie K M, Ali C, Schwob and L. Mezeix 2017 Spring-in prediction for carbon/epoxy aerospace composite structure, Composite Structures. 168,739–745.

[10] Nikhil A. Khadse, Modal Analysis of Aircraft Wing using Ansys Workbench Software Package, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181

[11] Study on the Tribological Behavior of Aluminum Alloy 6061 and Its Composites Reinforced with SiC Particles, Tribology - Materials, Surfaces & Interfaces" Volume 7, Issue 7 (2014)

[12] Buddi, S.C., Prasanthi, P.P., Srikanth, P., 2015. Mechanical properties of fiber reinforced composites using finite element method. Int. J. Mech. Eng. Robot. Res. 4 (1), 80–90

[13] A M H Abdul Jalil, W Kuntjoro and J Mahmud 2012 Wing structure static analysis using super Element, Procedia Engineering. 41, 1600 – 1606

THANK YOU