Journal of Engineering and Technology

ISSN 2180-3811 eISSN 2289-814X https://jet.utem.edu.my/jet/index

DEVELOPMENT OF UAV FUSELAGE USING BIOMIMETIC CONCEPTS BASED ON DRAGONFLY WING PATTERN: ENHANCING STRUCTURAL EFFICIENCY AND LIGHTWEIGHT DESIGN

A.I. Sufian*[1] and Z. Sahwee[2]

[1] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[2] Unmanned Aerial System Research Cluster, Universiti Kuala Lumpur Malaysian Institute of Aviation Technology, 43800, Dengkil, Malaysia.

corresponding: fqhzzt@gmail.com

Article history:
Received Date:13 September 2024
Revised Date: 19 June 2024
Accepted Date: 3 July 2024

Keywords: Biomimetic Concept, Dragonfly Wings, Lightweight, UAV

Abstract— This research paper presents an invention that focuses on the application of biomimetic concepts based on the wing structure of dragonflies in the design and construction of UAV (Unmanned Aerial Vehicle) fuselages. The use of the structural and aerodynamic attributes exhibited by dragonfly wings structure into the design of UAV fuselage has the potential to enhance structural performance and yield a construction that is characterized by its low weight. This research encompasses a comprehensive analysis of the biological

(Unmanned Aerial Vehicle), Wing Structure	characteristics, structural composition, and aerodynamic properties of dragonfly wings. The effectiveness of the biomimetic-inspired UAV fuselage is determined through the utilization of SolidWorks and Ansys software. The results demonstrate the potential of incorporating biomimetic designs inspired by dragonfly wings into UAV technology, providing environmentally sustainable and lightweight alternatives for future aerial vehicles.

I. Introduction

Biomimetics, also referred to as biomimicry or bioinspiration, is an academic discipline that draws inspiration from the natural world to address human challenges and stimulate the creation of new methodologies [1]. The task involves conducting research and constructing models to analyze the patterns, processes, and mechanisms that exist within biological species and ecosystems. Biomimetics has emerged as a significant research and development framework during the last decade, primarily within technology-focused disciplines, but also with major benefits to society and the economy [2].

Researchers in the field of biomimetics aim to understand complex problem-solving mechanisms that have evolved in nature over millions of years, with the objective of applying these biological principles to many domains such as engineering, technology, and other related fields. The field has witnessed significant expansion in recent years due to its capacity to tackle sustainability and efficiency concerns while promoting sustainable development. These methodologies have yielded a range of promising designs and supplementary functionalities to get enhanced performance [3]. The dragonfly wing is a natural structure that has attracted the attention of numerous researchers due to its high-performance and lightweight characteristics. Its shape and performance have been extensively studied for potential applications in bioinspired design [4].

One potential path that can be explored is the field of biomimetics, which involves drawing inspiration from complicated structures and adaptations seen from the structural properties of dragonfly wings. This approach aims to enhance structural efficiency and achieve a lightweight design in the fuselages of UAVs. The following illustration, depicted in Figure 1, provides a detailed representation of the intricate structure of a dragonfly wing [5][6].

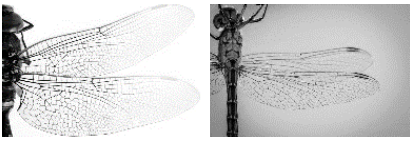


Figure 1: The Dragonfly Wing Patterns [5][6]

The application of dragonfly wing principles in the design of airplane wing has the potential to create aircraft that are lighter, more efficient, and require fewer materials. This might result in significant fuel and cost savings, as well as a notable reduction in the environmental impact of flying [6]. As a result, the concept is modified by including the design into the fuselage, so aiming to enhance its lightweight characteristics. Several researchers have been attracted to investigate the geometry and performance of a dragonfly wing, which is considered as one of numerous lightweight natural structures with high-performance characteristics.

The incorporation of the dragonfly design resulted in a notable increase of 25% in the out-of-plane stiffness, indicating the possibility of achieving a reduced weight [6]. Despite comprising less than 2% of the overall body mass of a dragonfly, its wings possess remarkable load-bearing capabilities, ensuring exceptional stability throughout various flying maneuvers such as flapping, gliding, and hovering. Furthermore, dragonflies have

ISSN: 2180-3811 Vol. XX No. X

the remarkable ability to initiate takeoff while carrying a payload exceeding three times their own body weight [7][8]. The main aim of this research is to reduce the weight of an existing fuselage [9] to enhance its performance.

There are several methods available to reduce the weight of a fuselage. The current research decided to evaluate other concepts beforehand selecting the dragonfly wing pattern as the primary design for the UAV fuselage. There will be five distinct models, each featuring a distinctive design approach for the purpose of scaling details. The utilization of SolidWorks will be employed for the development of the designs, in relation to the design software. The subsequent procedure will involve the calculation of the total deformation and equivalent (Von-mises) stress by Ansys analysis.

II. Biomimetic Inspiration

The wing patterns of dragonflies exhibit similarities akin to fingerprints. The intricate wing pattern arises from a complex structure of intersecting secondary veins, resulting in numerous small, yet uncomplicated, shapes [10]. The wings of the dragonfly possess a distinct structure that is characterized by discrete components, which collectively contribute to its remarkable flying capabilities [11]. The current research investigates several components of wings, such as the leading edge, trailing edge, and wing base, with a focus on their significance in maintaining stable flight and achieving aerodynamic balance. In contrast to high-frequency flapping insects such as fruit flies and bees, the wings in question were affixed to a flapping mechanism and exhibited varied wing beat frequencies. The normal frequency range of a dragonfly is seen to be between 120 and 170 Hz, whereas its wing beat frequency is measured at 30 Hz. The experimental apparatus employed in this investigation demonstrated the capability to achieve a peak wing beat frequency of 250 Hz [12]. According to the data presented in Figure 2, The comparative analysis of the wing pattern shown by dragonflies and other species of flying insects [8].

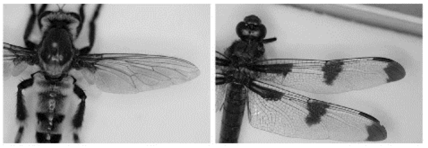


Figure 2: The Wing Design of a Robber Fly (left) and a Dragonfly (right) [8]

Dragonfly wings are composed of a thin cuticular membrane that is supported by a system of veins. The veins are hollow branching tubes that form the supporting framework, which often have cross-connections that form closed "cells" within the membrane. The membrane is formed by two layers of closely apposed integument. Together, the veins and membrane form a complex design within the wing that gives rise to whole-wing characteristics. The microstructure of dragonfly wings is complex. For example, wing corrugation has been found to be of great importance to the stability of the ultralight [13]. The wings possess a thin and layered structure akin to that of an aerogel, exhibiting remarkable strength and lightness [14]. The dragonfly's flight capability is significantly enhanced by the intricate network of veins that permeate its wings. The circulatory system of insects distributes hemolymph, which serves as the equivalent of blood in these organisms. This distribution is facilitated by a network of veins, which not only transport hemolymph but also contribute to the structural integrity of the insect's body. Furthermore, these devices enhance the aerodynamic efficiency of aircraft by producing vortices and reducing turbulence during flight. This work elucidates the potential of emulating dragonfly wing veins to enhance the aerodynamic properties of UAV fuselages and optimize the flow of air. At present, there are numerous research studies that explain the methodology for designing a UAV wing by emulating the structural characteristics of a dragonfly wing. However, a lack of literature exists pertaining to the process of achieving lightweight properties in the fuselage by similar means. This research is adopting an innovative approach by designing a lightweight fuselage based on the structural pattern observed in the wings of a dragonfly, thereby enhancing an existing design. The following part will provide a comprehensive discussion of the activities that will be undertaken to achieve the objective utilizing the SolidWorks and Ansys software.

III. Methodology

The current three-dimensional solid model of a UAV fuselage, as depicted in Figure 3, which was developed in a previous project, will undergo modifications in SolidWorks 2021 software to create four distinct design variations [15].

Figure 3: The Base Line Fuselage [9]

Once the fuselage was modelled using SolidWorks, it was subsequently transferred to Ansys software for additional study. There was a total of five distinct versions, each characterized by its own set of distinctive features and designs. The design of the fuselage was created using SolidWorks software. Subsequently, the file was exported to the Ansys computer to assess the total deformation and equivalent (Von-mises) stress.

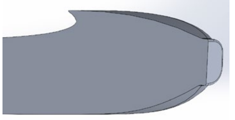
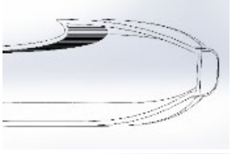
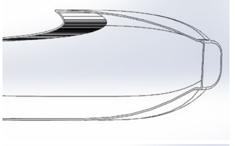
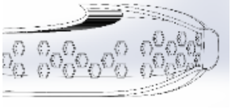
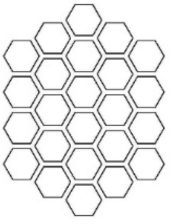
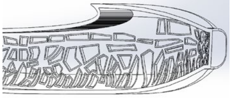
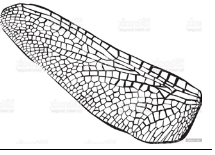
The utilization of the static structural analysis system has been employed. The mesh generation process was conducted before to commencing any analysis, followed by the application of boundary conditions. The boundary conditions imposed on the models consisted of a fixed position at the model's nose and a downward push exerted at the model's tail. The calculation of the overall deformation and equivalent stress for the structural outcome was performed. A comparison was conducted utilizing calculations for mass reduction, total deformation reductions, and stress equivalent (Von-mises) stress reduction.

ISSN: 2180-3811 Vol. XX No. X

A. Simulation Setup

Each of the five designs exhibited distinct features and design characteristics. Table 1 presented below offers a comprehensive elucidation of the characteristics. Several models in this study are derived from real-world objects, such as the honeycomb and dragonfly wing patterns.

Table 1: Models and the Characteristics

Models	Characteristics	SolidWorks	References
1	- Original - Solid body		
2	- Shell 4mm from model 1		
3	- Shell 2mm from model 1		
4	- Design a honeycomb pattern on model 2 - Shell 1.2mm		
5	- Design a dragonfly wing's pattern on model 2 - Shell 1.2mm		

B. Finite Element Analysis

The Finite Element Analysis (FEA) of this model was conducted using the Ansys software to determine the overall deformation and the equivalent (Von-mises) stress. The structure of the aircraft must ensure that it maintains of its structural integrity while maintaining its original dimensions and weight. In summary, the optimal airframe configuration for an UAV should possess characteristics of both lightweight construction and structural durability. The examination of the airframe provides researchers with valuable insights into the many forces acting upon it and the resulting stress experienced by the airframe. The determination of frame rigidity, maximum take-off weight, and suitable propulsion unit for the UAV are facilitated by this [16].

Static Structural Analysis

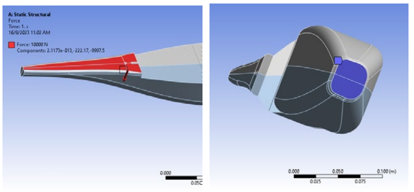
Static analysis refers to the examination of a structure's response under stable loading circumstances, disregarding the influence of inertia and damping effects resulting from time-varying loads. Static analysis is a computational method used to calculate the displacements, strains, stresses, and forces in structural components. It specifically focuses on loads that do not have a substantial impact on inertia and damping effects. The loading process and response behaviours are supposed to be steady, meaning that the loads and the reaction of structural components are assumed to change at a modest rate over time. The fundamental techniques employed in the analysis of structures encompass the flexibility and stiffness procedures [17].

Applying Mesh

The process of mesh generation involves the partitioning of the analytical continuously into a finite number of discrete sections or finite components. The higher the level of mesh refinement, the more optimal the outcomes, albeit at the expense of increased analysis duration. Hence, a trade-off is typically reached between the precision of results and the efficiency of problem-solving [18].

Boundary Conditions

The research is subject to specific boundary conditions, namely the application of force and the presence of a fixed support on each model, as depicted in Figure 4.



(a) (b)

Figure 4: (a) Force Applied at the End of the Tail Downwards, (b) Fixed Support Applied at the Nose of the Plane

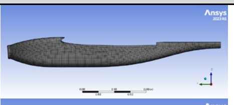
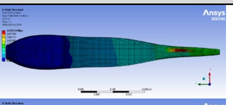
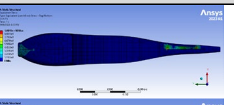
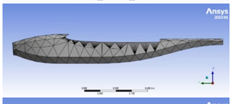
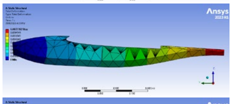
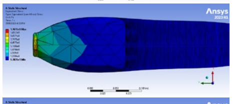
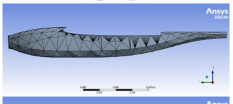
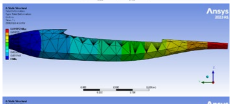
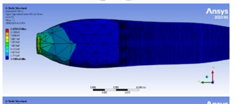
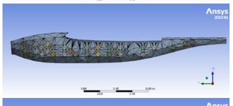
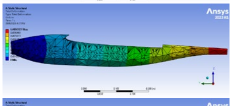
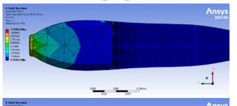
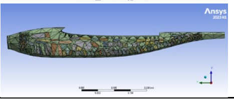
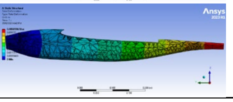
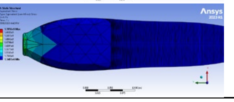
A downward force of 10,000 N is applied at the posterior end of the object. A fixed support is present for each geometric configuration located at the nose of the aircraft. The material employed for all geometric components is consistent, namely structural steel. The density of structural steel is 7850 kg/m3. The Young's modulus of structural steel is 200 gigapascals (GPa). The tensile yield strength is measured at 250 MPa, whereas the tensile ultimate strength is recorded at 460 MPa.

IV. Results and Discussion

FEA has been conducted on all five models using the Ansys software. The research on the analysis system chose for a static structure. It is essential to export the model from SolidWorks prior to commencing the meshing process. Once the boundary conditions for force and fixed support have been established, the computation of the equivalent (Von-mises) stress and total deformation is performed.

Table 2 presents the results of the meshing product outcome, along with the corresponding total deformation and equivalent (Von-mises) stress values obtained by the utilization of Ansys software. The meshing technique employed in model 1 involves the use of quadrilateral parts, whereas the meshing technique utilized in the other models is characterized by unstructured tetrahedron components. Red is used to represent the largest amount of total deformation seen at the tail of the plane, where the force was applied, across all five models. The nose of the aircraft exhibits a combination of green, yellow, and orange colors, which symbolize the Von-mises stress levels corresponding to each of the five models. The values for the equivalent (Von-mises) stress (GPa) and maximum total deformation (m) were derived using Ansys, while the mass (g) was acquired through the utilization of SolidWorks.

Table 2: The Ansys Result for Meshing, Total Deformation and Equivalent Stress

	Meshing	Total Deformation	Equivalent (Von-misses) Stress
1			
2			
3			
4			
5			

Once the design of the model is finalized, mass can be obtained. Upon implementing the boundary condition and conducting the meshing process, it becomes feasible to ascertain the total deformation and the equivalent (Von-mises) stress value. The results are presented in Table 3. According to the data provided, Model 1 exhibits the highest mass, measuring 2946.8g. Following Model 1, the subsequent models are ranked in descending order of mass as follows: Model 2, Model 4, Model 5, and Model 3, weighing 606.35g, 579.62g, 553.11g, and 190.92g, respectively. The models can be ranked in ascending order based on their total deformation as follows: Model 4, Model 2, Model 5, Model 1, and Model 3. The corresponding values for total deformation are 0.0092927m, 0.0072392m, 0.0068996m, 0.053374m, and 0.0092927m, respectively. In terms of the equivalent stress value, Model 1 exhibits the greatest value at 10.02GPa, followed by Model 3 at 2.43GPa, Model 5 at 1.59GPa, Model 2 at 1.16GPa, and Model 4 at 1.15GPa. The percentages of mass reduction, total deformation reduction, and equivalent (Von-mises) stress reduction were calculated based on the data obtained from SolidWorks and Ansys. Model 1 will function as the foundational basis or point of reference for the calculations.

Table 3: Data Of Mass, Total Deformation and Equivalent (Von-Misses) Stress of Each Model

	Mass (g)	Total Deformation (max) (m)	Equivalent (Von-misses) stress (GPa)
Model 1 (datum)	*2946.80*	*0.053374*	*10.02*
Model 2	606.35	0.0072392	1.16
Model 3	190.92	0.011852	2.43
Model 4	579.62	0.0092927	1.15
Model 5	553.11	0.0068996	1.59

Based on the calculations, while considering model 1 as the reference point, it is observed that model 3 exhibits the smallest deviation from the reference, with a mass reduction of 93.52%. Following closely, model 5 demonstrates a mass reduction of 81.23%. The model with the highest decrease in total deformation, closest to the datum, is model 5 at 87.07%. In terms of stress reduction, model 4 exhibits the greatest deviation from the datum at 88.52%, followed by model 2 at 88.42%, and model 5 at 84.13%. The results are stipulated in Table 4.

Table 4: The Percentage of Mass Reduction, Total Deformation Reduction and Stress Reduction

	Mass Reduction (%)	Total Deformation Reduction (%)	Equivalent (Von-misses) Stress Reduction (%)
Model 1 (datum)	*100*	*100*	*100*
Model 2	79.42	86.45	88.42
Model 3	93.52	77.79	75.75
Model 4	80.32	82.59	88.52
Model 5	81.23	87.07	84.13

ISSN: 2180-3811 Vol. XX No. X

The relationship between the mass of an object and its corresponding values of total deformation and equivalent (Von-mises) stress is such that when the mass decreases, the values of total deformation and equivalent stress increase. Model 3 exhibits the lowest weight among the five models and demonstrates the highest values of total deformation and equivalent (Von-mises) stress. Model 5 is the second lightest among the models considered. It also exhibits the second highest total deformation. However, it ranks third in terms of equivalent (Von-mises) stress, following model 4. The reason for the continuous increase in the Von-mises stress within the component can be attributed to the growth in the number of cutouts, as stated in reference [19]. Model 5 exhibits a greater number of cutouts in comparison to model 4. Figure 5 illustrates the cutouts corresponding to model 4 and model 5.

Aluminium alloys are frequently favoured materials in aerospace design and are mandated by engineering standards due to their corrosion-resistant qualities and impressive tensile capabilities. In comparison to steel, it exhibits a reduced weight, rendering it a favourable choice for a diverse array of aircraft components and applications within the aerospace industry [20]. The research employed steel in its investigation of the structure. This is the case as the analysis mostly consisted of the collection and computation of data for the goal of making comparisons. Due to its substantial mass, it will not possess practical utility in real-world applications.

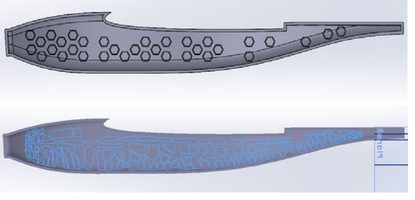


Figure 5: Model 4 (up) and Model 5 (down)

V. Conclusion

The findings of the previous study result in the values for total deformation and equivalent (Von-mises) stress. The objective is to reduce the weight of the current fuselage by

ISSN: 2180-3811 Vol. XX No. X

altering its internal design and dimensions, while preserving its original form and functionalities. Previous studies have explored the application of dragonfly wing patterns in the design of aeronautical wings. However, the present research aims to investigate the feasibility of incorporating the dragonfly wing pattern onto the fuselage.

The research starts by utilizing SolidWorks for the design process. Specifically, model 4 is developed based on the honeycomb structure, while model 5 draws inspiration from the biomimetic characteristics seen in the wing pattern of a dragonfly. Subsequently, the models in Ansys are subjected to analysis to derive accurate information on total deformation and equivalent stress (Von-mises) outcomes. Based on the calculations conducted, it is evident that model 5 has the potential to serve as the optimal design in fulfilling the research purpose as the model is the highest in percentage mass reduction and total deformation reduction which is 81.23% and 87.07% respectively. Although significant improvements have been achieved, the current research exhibits an intriguing shortcoming in design complexity.

One notable example of such complexity may be observed in model 5, which is characterized by a significant quantity of carefully constructed cuts. Although the previously mentioned design aspects may have been deliberately chosen to fulfill certain functional or aesthetic objectives, they inadvertently provide a potential drawback during the transition from the design stages to the manufacturing stage. The production process of several complicated cuts necessitates enhanced precision, hence increasing the potential for errors, misalignments, or unanticipated departures from the intended design. These potential outcomes might result in the prolongation of timelines, increased labor requirements, or compromised structural stability, so impeding the effective achievement of the ultimate deliverable.

Moreover, the intricate arrangement with diverse cuts could require the utilization of specialized fabrication techniques, tools, or machinery, hence potentially inflating costs and rendering the production process less economically viable or attainable in some circumstances. It is recommended to employ a strategic approach that entails a careful modification of the design to minimize any risks and challenges associated with the fabrication process. Opting to minimize the quantity of cuts in the current design is a proactive and forward-thinking decision aimed at safeguarding the production process against any faults and complications.

This approach aligns with a commitment to achieving excellence in both the design and production processes, resulting in a finished product that not only showcases an innovative concept but can also be effectively and cost-efficiently implemented. As a result, while research has mostly centered on the wing pattern of dragonflies, the potential utilization of avian, chiropteran, and other insect species, such as flies and butterflies, as models for the design of the internal fuselage, instigates a renewed phase of scholarly inquiry and inventive exploration. The wing structure offers a means to enhance flight dynamics and efficiency by virtue of its inherent flexibility and intricate performance characteristics. The utilization of wing patterns exemplifies the perpetual abundance of inspiration provided by the natural world, fostering a continuous drive to surpass practical limitations and attain superior quality.

VI. References

[1] M. S. Aziz, A. Y. El Sherif, “Biomimicry as an Approach for Bio-Inspired Structure with the Aid of Computation,” *Alexandria Eng Journal*, vol. 55, (1), pp. 707-714, 2016. doi:10.1016/j.aej.2015.10.015

[2] A. S. Jatsch, S. Jacob, K. Wommer, K. Wanieck, “Biomimetics for Sustainable Developments A Literature Overview of Trends,” *Biomimetics*, 2023. doi:10.3390/biomimetics8030304

[3] S. Tanaka, A. Asignacion, T. Nakata, S. Suzuki, H. Liu, “Review of Biomimetic Approaches for Drones,” *Drones*, 2022. doi:10.3390/drones6110320

[4] H. Zheng, M. Hablicsek, M. Akbarzadeh, “Lightweight Structures and the Geometric Equilibrium in Dragonfly Wings,” *Int Assoc of Shell and Spatial Struct*, 2021.

[5] Crane, L. (26 April 2018). *Superlight Aerogel Made by Mimicking a Baby Dragonfly's Wings. New Scientist.* Available: https://www.newscientist.com/article/2167410-superlight-aerogel-made-by-mimicking-a-baby-dragonflys-wings/#:~:text=To%20mimic%20the%20porous%20wings,so%20they%20don't%20collapse

[6] Magubane, N. (19 July 2023). *Natural Structures Can Give Rise to Stronger, Lighter Systems. Science & Tech.* Available: https://penntoday.upenn.edu/news/natural-structures-can-give-rise-stronger-lighter-systems#:~:text=Transforming%20theory%20into%20reality,structural%20efficiency%20of%20the%20wings.

[7] J. Sun, D. H. Chen, J. Tong, X. Li, C. Pan, M. Ling, “Biomimetic Structure Design of Dragonfly Wing Venation Using Topology Optimization Method,” *Journal of Mechs in Medicine and Biology*, vol.14, (4), 2014. doi:10.1142/S021951941450078X

[8] J. Chahl, N. Chitsaz, B. Mclvor, T. Ogunwa, J. M. Kok, T. McIntyre, E. Abdullah, “Biomimetic Drones Inspired by Dragonflies Will Require a Systems Based Approach and Insights from Biology,” *Drones*, 2021. doi:10.3390/drones5020024

[9] Z. Sahwee, N. L. M. Kamal, N. Norhashim, S. A. Shah, S. A. Hamid, “From Concept to Flight: Developing a Hybrid Solar-Powered UAV Prototype for Malaysian Skies,” *10th Int Conf on Recent Adv in Air and Space Tech*, 2023. doi:10.1109/RAST57548.2023.10198009

[10] *Dragonfly Wings*. Available: https://dragonflywebsite.com/dragonfly-wings.cfm.

[11] J. Han, Z. Hui, F. Tan, G. Chen, “Review on Bio-Inspired Flight Systems and Bionic Aerodynamics,” *Chinese Journal of Aeronautics*, vol. 34, (7), pp. 170-186, 2021. doi:10.1016/j.cja.2020.03.036

[12] P. N. Sivasankaran, T. A. Ward, E. Salami, R. Viyapuri, C. J. Fearday, M. R. Johan, “An Experimental Study of Elastic Properties of Dragonfly-Like Flapping Wings for Use in Biomimetic Micro Air Vehicles (BMAVs),” *Chinese Journal of Aeronautics*, vol. 30, (2), pp. 726-737, 2017.

[13] Han, X. (26 April 2018). *World's Oldest Insects Inspires a New Generation of Aerogels. Newcastle University.* Available: https://www.ncl.ac.uk/press/articles/archive/2018/04/dragonfly/.

[14] J. Sun, B. Bhushan, "The Structure and Mechanical Properties of Dragonfly Wings and Their Role on Flyability," *Comptes Rendus Mécanique*, vol. 340, (1-2), pp. 3-17, 2012.

[15] P. N. Sivasankaran, T. A. Ward, R. Viyapuri, M. R. Johan, "Static Strength Analysis of Dragonfly Inspired Wings for Biomimetic Micro Aerial Vehicles," *Chinese Journal of Aeronautics*, vol. 29, (2), pp. 411-423, 2016.

[16] A. Mishra, G. S. Malhi, S. Pal, P. Singh, "Structural Analysis of UAV Airframe by Using FEM Techniques: A Review," *Int Journal of Adv Sci and Tech*, Vol. 10, (Special Issue), pp. 195-204, 2020.

[17] R. U. Prakash, G. R. Kumar, R. Vijayanandh, M. S. Kumar, T. Ramganesh, "Structural Analysis of Aircraft Fuselage Splice Joint," *IOP Conf Series: Materials Sci and Eng*, Vol. 149, 2016. doi:10.1088/1757-899X/149/1/012127

[18] G. Raju, V. Suresh, T. Ramesh, V. Hathiram, "Modelling and Analysis of Fuselage," *Int Research Journal of Automotive Tech (IRJAT)*, vol. 1, (6), pp. 204-212, 2018.

[19] P. Dharmendra, K. J. Chaitanya, A. Sameera, K. Kavathiya, K. M. Monika, "Design and Analysis of An Aircraft Wing Rib for Different Configurations," *Int Research Journal of Eng and Tech (IRJET)*, vol. 7 (6), 2020.

[20] *Industrial Metal Supply, 2020.* Available: https://www.industrialmetalsupply.com/blog/aerospace-aluminum.