ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24FEB447

Designing a Morphing Wing for Fixed-Wing UAVs

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Abstract:- This project report details the original conceptualization, design, and analysis of a morphing wing structure for fixed-wing Unmanned Aerial Vehicles (UAVs). Our approach incorporates an octahedron cell structure coupled with the application of shape memory alloys(SMAs) to facilitate controlled wing morphing. The primary goal is to augment the UAVs aerodynamic efficiency and adaptability to various flight conditions.

The octahedron cell structure is employed as the foundational framework, providing a balance between structural integrity andflexibility for shape adjustments. The integration of shape memory alloys, known for their reversible phase transformations, enables precise and efficient control over the morphing process. Through this combination, we aim to optimize the UAVs flight characteristics, including improved efficiency, stability, and maneuver ability.

To validate the feasibility and performance of the morphing wing design, Finite Element Analysis (FEA) has been conducted. This computational approach allows for a comprehensive evaluation of the structural integrity and aerodynamic behavior of the morphing wing under diverse loading conditions. The FEA results offer crucial insights into the structural response, stress distribution, and deformation patterns, guiding the iterative refinement of the design for optimal functionality.

This project represents a unique contribution to UAV technology, presenting an original perspective on morphing wing design that harnesses the benefits of octahedron cell structure and shape memory alloys. The insights gained from the FEA analysis provide valuable guidance for the ongoing development and implementation of morphing wing structures in fixed-wing UAVs. This work sets the stage for improved adaptability and performance in a range of operational scenarios, without reliance on external sources or existing research

I. INTRODUCTION

The landscape of Unmanned Aerial Vehicles (UAVs) is evolving rapidly, driven by the imperative for heightened adaptability and enhanced performance. This project is a response to this imperative, focusing on the conceptualization and development of a morphing wing structure tailored for fixed-wing UAVs. At the heart of our innovative approach lies a unique amalgamation of octahedron cell structure and Shape Memory Alloys (SMAs).

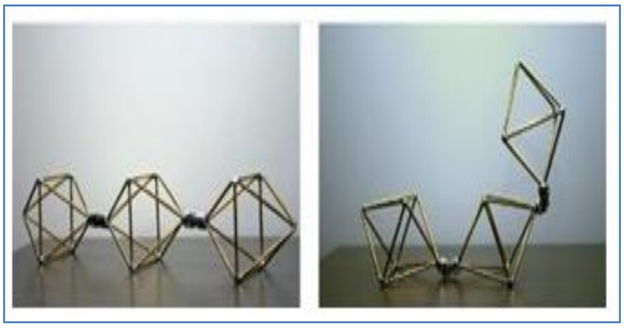

Fig. 1: Representation of Morphing Structure using Octahedron Cells

II. LITERATURE REVIEW

A. Review of literature

M. Di Luca , S. Mintchev , G. Heitz , F.Noca and D. In the course of this investigation, a hybrid wing configuration was meticulously devised, integrating elements of both a conventional wing and a foldable bird's wing. The incorporation of the foldable mechanism facilitates a notable reduction in wing area by 41%, consequently resulting in a substantial decrease in the drag coefficient by an impressive 40%. Upon deployment, the wing unfolds to augment the overall surface area, yielding a commendable increase in the lift coefficient by 32%. This strategic manipulation not only achieves drag reduction but also holds the potential to significantly enhance the top speed of the vehicle Haipeng Gu, Huajie HongThis paper provides a comprehensive exploration of the concept of linear variable wingspan aircraft—a cutting-edge amalgamation characterized by a sophisticated combination of a rigid skin and an integrated aileron design. The research findings conclusively indicate that the implementation of the variable wingspan design yields notable advantages, particularly in terms of reducing the minimum takeoff speed. Furthermore, this innovative design configuration showcases the potential to enhance the overall load-carrying capacity of the aircraft, underscoring its significance in the realm of aeronautical engineering Eun Jung Chae, Amin Moosavian, Alexander M. Pankonien ,Daniel J. broadening its applicability in demanding operational environments.

Vasile Prisacariu, Mircea Boscoianu , Ionica Circiu.This paper critically delves into the intricate development of a linear variable wingspan aircraft, undertaking a comprehensive analysis of potential technical routes for its realization. The exploration encompasses a theoretical examination of various technical pathways, emphasizing the versatility of the proposed variable wingspan. The conceptualization presented in this paper not only offers a theoretical framework but also underscores the

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aircraft's adaptability to diverse task requirements across a spectrum of speeds, thereby accentuating its potential in addressing multifacetedoperational demands.

Peter L. Bishay * , James S. Kok, Luis J. Ferrusquilla, Brian M. Espinoza.Thisresearch paper distinctly showcases an unconventional UAV design that distinguishes itself by the absence of discrete flight control surfaces, such as elevators, rudders, or ailerons.

B. Summary of the Literature

➢ *Introduction of Linear Variable Wingspan Aircraft:*

- Introduction to the study focusing on linear variable wingspan aircraft.
- Description of the integration of a rigid skin and aileron built-in design.

➢ *Research Findings on Take-off Speed and Load Capacity:*

- Discovery that the variable wingspan design reduces the minimum take-off speed.
- Notable reduction in drag coefficient by 40% during wing folding.
- Emphasis on the increase in lift coefficient by 32% upon wingdeployment.
- Recognition of the potentialimprovement in the aircraft's load- carrying capacity.

➢ *Hybrid Wing Configuration and its Advantages:*

- Detailed discussion on the hybrid wing configuration combining a conventional and foldable bird's wing.
- Examination of the advantages of wing folding, including a 41% decrease in wing area and the ensuing drag reduction.

➢ *Morphing Wing Performance Comparison:*

- Evaluation of a UAV wing configuration incorporating span- wise camber variation.
- Adjustment of spatial frequency and phase shift for a comparative study.
- Analysis using CFD software indicating superior performance of the morphing wing with a liftcoefficient (CL) exceeding 0.8 in the near-stall region.

➢ *Adaptive Octahedron Cell Concept:*

- Introduction to the Adaptive Octahedron Cell concept.
- Focus on its unique design with a minimal weight penalty, facilitatingextensive shape changes.
- Validation of functionality and adaptability through the construction and operation of a prototype.

➢ *Revolutionary Shape-Adaptive Wing Configuration (RSAWC):*

- Introduction of the RSAWC wing as an unconventional UAV design.
- Significance highlighted through direct comparisons between traditional and morphing wingconfigurations.
- Recognition of testing under various conditions as a notableachievement in aviation.

➢ *Linear Variable Wingspan Aircraft Development and Technical Exploration:*

- Examination of the development of linear variable wingspan aircraft.
- Analysis of potential technicalroutes for implementation.
- Theoretical exploration of diversetechnical pathways for achieving variable wingspan.

➢ *Innovative UAV Design with SlidingSkin Concept:*

- Presentation of a UAV design lacking discrete flight controlsurfaces.
- Introduction of the sliding skin concept, allowing the use of rigidskin without structural complications.
- A transformative approach to flight control systems and structural engineering in UAVs.

C. Identification of Gaps/Scopes of Work

➢ *Integration of Multiple MorphingTechnologies:*

Although several innovative morphing wing concepts have been explored individually, there is a research gap in integrating multiple morphing technologies (such as those seen in the Adaptive Octahedron Cell and RSAWC wing) into a unified design. This could lead to UAV wings that combine the benefits of different morphing mechanisms for enhanced adaptability and performance.

➢ *Material Innovation for MorphingWings:*

Developing new materials tailored to the specific needs of morphing wings is a crucial research avenue. Exploring lightweight yet robust materials that can withstand repeated folding and deployment, as well as variable aerodynamic forces, is essential for the longevity and safety of these designs.

➢ *Scaling Up for Larger UAVs:*

While many findings are based on smaller UAVs, the scalability of these morphing wing designs for larger UAVs, such as cargo drones or military applications, remains uncertain. Research should investigate the structural challenges and solutions for implementing morphing wings on alarger scale.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24FEB447

D. Problem Statement

The current structural frameworks for UAVs inadequately harness thepotential of morphing wing designs, impeding optimal aerodynamic performance. This project aims to rectify this deficiency by specificallydeveloping an efficient and robust structural framework conducive to realizing the full benefits of morphing wings in UAV applications.

E. Objectives

- To create an efficient and structurally sound framework that allows for seamless wing shape changes while maintaining the structural integrity necessary for safe and reliable UAV operations.
- To formulate a comprehensive conceptual framework for morphing wings in UAVs, emphasizing the integration of the octahedron cell structure to enhance adaptability and aerodynamic efficiency.
- To Increase the endurance for longduration operations of fixed-wing UAVs.

III. METHODOLOGY

A. Conceptualisation UAV Selection:

The conceptualization of the morphing wing design began with the selection of the TAPAS BH-201 UAV as the primary platform. The TAPAS BH- 201, renowned for its versatility and adaptability, provided a suitable foundation for integrating innovative technologies. The choice of this UAV was driven by its established performance metrics and compatibilitywith experimental modifications.

The considered UAV has the followingspecifications:

Capacity: 350 kg (772 lb) payload

Length: 9.5[31] m (31 ft 2 in)

Wingspan: 20.6 m (67 ft 7 in)

Empty weight: 1,800 kg (3,968 lb)

Powerplant: 2 × NPO-Saturn 36T engines wing-mounted turboprop, 74.57 kW (100.00 hp) each (Prototype)

Powerplant: 2 × VRDE indigenous, 160 kW (220 hp) each (Production)

Propellers: 3-bladed constant-speedpropeller

B. Performance

Maximum speed: 224 km/h (139 mph, 121 kn)

Ferry range: 1,000 km (620 mi, 540nmi)

Endurance: 24 hours+[34][35][36][37]

Service ceiling: 9,144[34] m (30,000ft)

C. Aerodynamic Profile:

The aerodynamic profile formed apivotal aspect of the conceptualization, with the NACA 6412 airfoil selected asthe baseline. The NACA 6412, characterized by its balanced lift and drag characteristics, served as the starting point for the morphing wing design. This airfoil's well-documented performance under various conditions provided a reliable foundation for subsequent modifications.

Table 1: Specifications of Airfoil NACA 6412

LENGTH[m]	**9.5**
WINGSPAN [m]	20.6
ASPECTRATIO	8
AIRFOIL	NACA 6412
WEIGHT [kg]	1800
SPEED	224 km/hr
CHORD LENGTH	1.5 meters

D. Morphing Wing Parameters:

Conceptualization involved definingkey parameters for the morphing wing design. The octahedron cell structure was identified as a central element, offering a unique combination of structural integrity and morphological adaptability. Parameters such as wing geometry, span-wise camber variations, and the integration of the octahedron cell structure were meticulously defined to achieve optimal aerodynamicefficiency.

E. Adaptive Mechanism:

In the conceptualization phase, attention was directed towards developing an adaptive mechanism thataligned with the octahedron cell structure. Mechanisms allowing controlled variations in wing shape and surface area were explored, emphasizing responsiveness to dynamic flight conditions. The goal was to achieve seamless integration between the UAV's operational requirements and the morphing wing's adaptive features.

F. CAD Design

The CAD design incorporated the adaptive mechanisms essential for wingmorphing. Actuators, hinges, or selected mechanisms were intricately woven into the model, allowing for controlled variations in wing shape. The dynamic interaction between the octahedron cell structure and the morphing mechanisms was visualized and refined within the CAD environment.

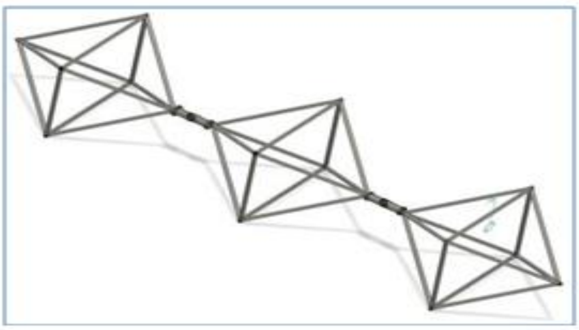

Fig. 2: 3D CAD Model of Octahedron Cells Joined Using Links

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24FEB447

Fig. 3: A 3D CAD Model of Links Used

G. Load and Structural Testing

The phase dedicated to load and structural testing is designed to thoroughly assess the performance of the octahedron cell structure, a pivotal element in the groundbreaking morphing wing design for the TAPAS BH-201 UAV. The primary aim of this testing phase is to authenticate the structural integrity and load-bearing capabilities of the octahedron cell under simulated operational conditions. This involves subjecting the octahedron cell to meticulously controlled loads, mimicking the dynamic forces encountered during UAV flight, and employing real-time monitoring to capture essential data on structural response, stress distributions, and potential failure points.

The testing protocol encompasses a comprehensive evaluation of the octahedron cell's load-bearing capacity, featuring incremental loading to discern its structural limits. Additionally, fatigue testing is conducted to replicate extended operational scenarios and gauge the structure's resilience to cyclic loading. In the occurrence of structural setbacks, an in-depth analysis of failuremodes is undertaken, guiding subsequent iterative optimization. This iterative optimization process entails fine-tuning parameters like geometry, material properties, and reinforcements to elevate the overall performance and resilience of the octahedron cell. The insights derived from this rigorous testing phase not only contribute to refining the morphing wing design but also serve as a crucial foundation for ensuring its effectiveness and durability in practical UAV applications.This topic is explained in chapter 4 of this paper.

An ideal elliptical lift distribution was used in the analysis. All calculations include a factor of 3.8 G. TAPAS BH201 UAV has a mass of 2150 kg, with a wing span of 20.6 meters. As such, the maximum loading on the wing will be as a result of the wings lifting the 1800 kg of the fuselage and theauxiliary components inside thefuselage. As a result, each wing would have to carry a load of **10,535N**.

Considering all things octahedron concept was selected as the primarymorphing technology, as explained earlier this is possible with the help of octahedron cells,in this section meshing of the cells is done subsequently to facilitate a finely tuned mesh for subsequent load testing.

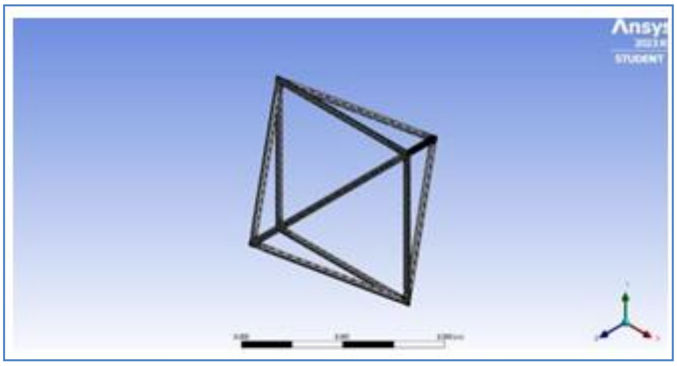

Fig. 4: Figure Represents a Successfull mesh of an Octahedron Cell

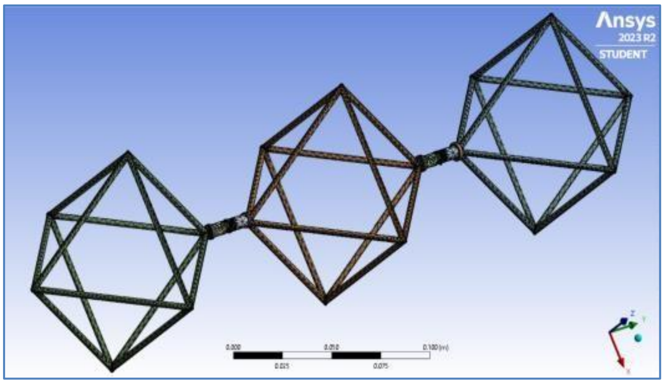

Fig. 5: Meshing of the Octahedral Structure done on ANSYS.

The extensive load and compression testing on this octahedron cell is further presented in chapter 4.

IV. SOFTWARE ANALYSIS

A. Methodology

➢ *Meshing*

Informed by the unique characteristics of octahedron cells, the mesh refinement strategy prioritizes areas of stress concentration identified during experimental testing. This approach ensures that the mesh is finer around critical points, such as joints and high-stress regions, allowing for a more precise representation of the structuralresponse.

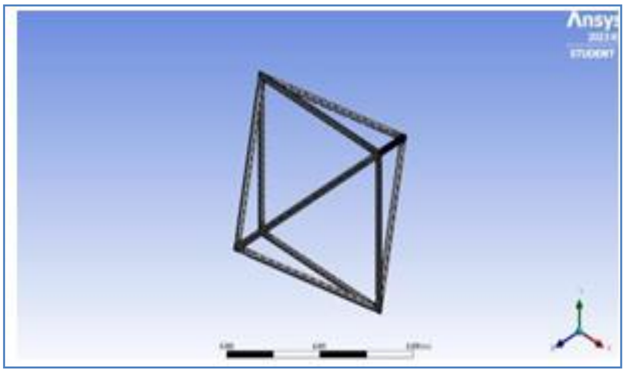

Fig. 6: Meshing of an Octahedroncell

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24FEB447

- *Equivalent Stress Testing*

The evaluation of equivalent stress is a pivotal aspect of understanding the structural integrity of the octahedron cells under varied loading conditions. Leveraging data obtained from extensive load and compression testing, the equivalent stress analysis serves as a crucial tool to quantify the combined effect of multiple stress components acting on the structure. Utilizing information derived from fatigue testing, which provides insights into thematerial's endurance under cyclic loading, this analysis aims to predict critical stress points within the octahedron cells.

Force applied is normal to the x- axis,and the magnitude is 10000N.

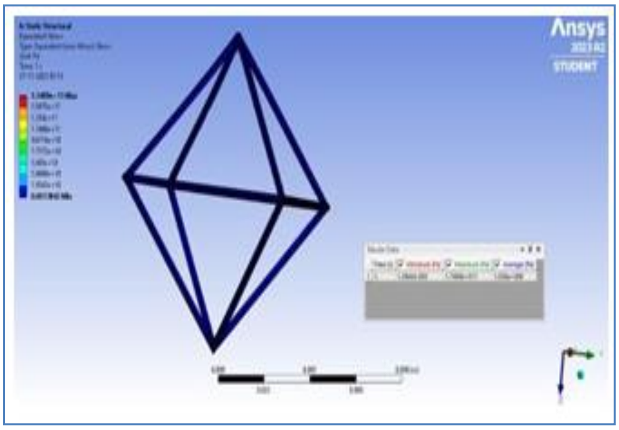

Fig. 7: Static Structural Analysis done for Equivalent Stress on the Cell

The analytical data resulting from the stress test unveils a broad spectrum of stress values within the octahedron cells. The minimum stress recorded is 1.3842e-003, indicating areas where the structural components experience relatively low stress levels. Conversely, the maximum stress is recorded at an elevated level of 1.7409e+011, suggesting zones within the octahedron cells that are subjected to significant mechanical loads.

- *Equivalent Elastic Strain Testing*

The Equivalent Elastic Strain testing conducted on the octahedron cells offers a nuanced perspective on their deformations and structural response under diverse loading scenarios. This testing methodology provides a comprehensive analysis of the elastic strain distribution within the octahedron geometry, shedding light on areas prone to deformation and stress accumulation.

Leveraging data obtained from rigorous load and compression testing, the Equivalent Elastic Strain analysis aims to quantify the elastic deformation experienced by the octahedron cells. This includes assessing how the structure deforms under applied loads, offering insights into potential areas of concern related to material resilience and structural integrity.

Force applied is normal to the x- axis,and the magnitude is 10000N.

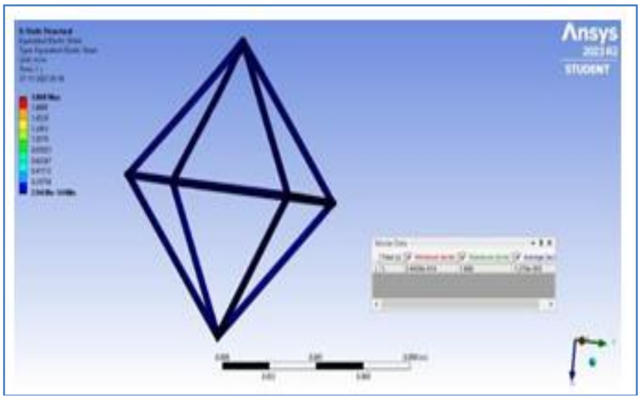

Fig. 8: Static Structural Analysis Done for Equivalent Strain on the Cell

The recorded maximum strain of 1.868[m/m] indicates areas of the structure that underwent significant elastic deformation, possibly in regions subjected to higher mechanical stresses. On the other hand, the minimum strain recorded at 2.9438e-014 suggests areas with minimal or negligible elastic deformation, potentially representing regions where the structural response was less pronounced.

- *Tensile Test*

This testing methodology involves applying axial loads to the cells, simulating conditions akin to stretching, and evaluating their response in terms of total deformation.

The total deformation recorded during tensile testing provides a comprehensive measure of how the octahedron cells elongate under tension. This data is invaluable for characterizing the material's behavior, identifying the elastic and plastic deformation thresholds, and assessing the overall structural integrity under tensile loading conditions.

Force applied is normal to the negative z-axis, and the magnitude is 10000N.

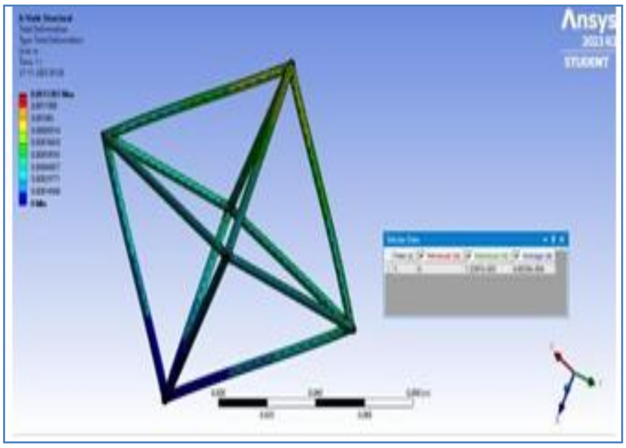

Fig. 9: Static Structural Analysis Done for Total Deformation Under Tensile Stress on the Cell

The recorded minimum deformation of 0 m indicates that certain areas of the structure experienced no measurable elongation, possibly reflecting regions where the material exhibited minimal response to the tensile loading.

Conversely, the maximum deformation recorded at 1.3397e-003 m signifies areas within the octahedron cells that underwent notable stretching or elongation under the tensile forces. This discrepancy between the minimum and maximum deformation values highlights the non-uniform response of the structure to tensile loading, providing insights into areas that are more susceptible to deformation andstress concentration.

➢ *Buckling Test*

This method involves systematically applying axial loads to the cells until a critical point is reached, revealing insights into the cells' propensity forbuckling – an essential considerationfor structural integrity.

The primary goals of the buckling test include determining the critical load at which buckling initiates, characterizingthe mode of buckling, and assessing theoverall stability of octahedron cells. By subjecting the cells to compressive forces, this test aids in identifying potential failure modes and providesessential data for refining design parameters to prevent buckling and enhance overall structural robustness.

Force applied is normal to the negativez-axis, and the magnitude is 10000N.

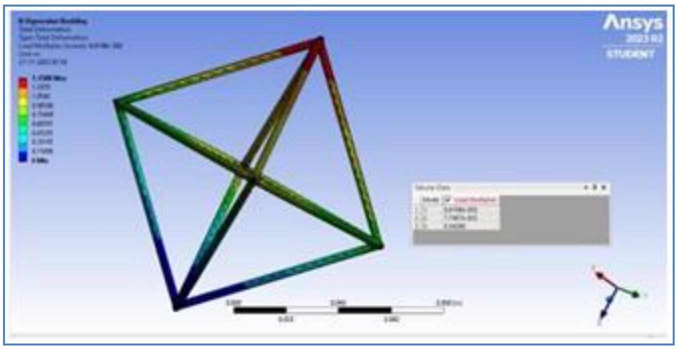

Fig. 10: Static Structural Analysis Done for Total Deformation Under Buckling Effect on the Cell

The recorded maximum deformation of 1.3588 m indicates areas within the structure that underwent significantdeflection or instability during the test, reaching a critical buckling point. Conversely, the minimum deformation recorded at 0 m suggests regions where the structure maintained stability without undergoing measurable lateral deflection.

This disparity between the maximum and minimum deformation valuesunderscores the non-uniform response of the octahedron cells to compressive loads. The recorded maximum deformation provides insights into the critical points and potential failuremodes associated with buckling.

➢ *Safety Factor*

The safety factor is a critical parameterin the structural analysis of octahedron cells, serving as a measure of the structure's robustness and its ability to withstand applied loads withoutcompromising integrity.

The safety factor integrates material properties, such as ultimate tensile or compressive strength, to assess the octahedron cell's resilience under different loading scenarios. It ensures that the structure can withstand forces without surpassing its material limits.

This factor is calculated by dividing the material's ultimate strength by the applied stress, providing a margin of safety against failure.

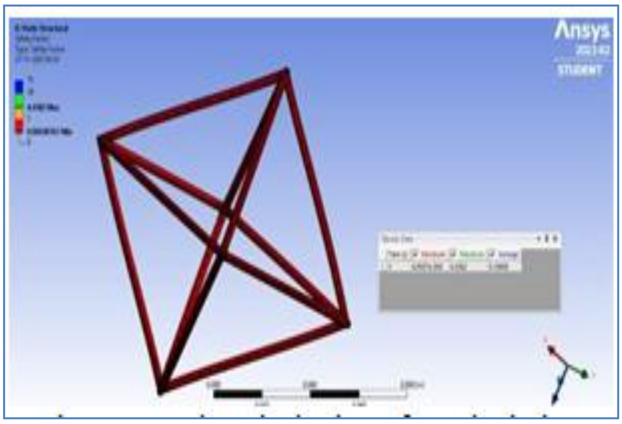

Fig. 11: Static Structural Analysis Done for Calculating Safety Factor for the Cell

The recorded minimum safety factor of 4.9507e-004 indicates regions within the structure where the safety margin is extremely low, potentially raising concerns about the structural integrity under specific conditions. On the other hand, the recorded maximum safety factor of 4.4382 suggests areas where the structure exhibits a more substantial safety margin, demonstrating resilience and stability against applied load.

V. RESULTS AND DISCUSSIONS

A. Introduction

This section serves as the nexus between our theoretical expectations and the empirical data derived from simulations and tests. Our aim is tounravel the intricacies of how these unique structures respond under various mechanical forces and delve into the implications of these findings.

B. Key Points in Results and Discussion

- **Structural Behaviour:** Understanding the structural behaviour of octahedron cells under various loading conditions, including stress distribution, deformation characteristics, and stability considerations.
- **Performance Metrics:** Analyzing critical performance metrics such as buckling, compression behavior, tensile strength, and safety factors to evaluate the structural integrity and resilience ofoctahedron cells.
- **Insights for Future Research**: Providing insights that inform the direction for future research, contributing to the broader understanding of morphing wing structures and similar applications.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24FEB447

C. *Compression Test:*

- Evaluate how octahedron cells respond to axial compressive loads.
- Examine the critical load at which buckling initiates, providing insights into structural stability.
- Assess the mode of buckling to understand the specific deformation patterns.

D. *Load Test:*

- Investigate the octahedron cells' response to applied loads, encompassing various loadingscenarios.
- Analyze the load-bearing capacity and stress distribution to identifycritical points in the structure.
- Explore the directional deformationunder different loads to understand how forces are distributed withinthe cells.

E. *Tensile Testing:*

- Assess the tensile strength and deformation characteristics of octahedron cells under axial forces.
- Determine the maximum load that the cells can withstand before failure.
- Explore the material's ability to stretch and deform, providing insights into ductility and overall structural integrity.

VI. FUTURE SCOPE AND CONCLUSION

A. *Future Scope*

➢ *Empirical Validation:*

The ongoing prototyping phase aims to provide empirical validation, generating valuable data for further refinement and addressing unforeseen challenges to ensure practical viability.

➢ *Optimization Opportunities:*

Opportunities for further optimization lie in refining the octahedron cell structure, materials, and morphing mechanisms, focusing on fine-tuning performance characteristics for optimalaerodynamic efficiency.

➢ *Real-World Testing:*

Real-world testing in diverse environmental conditions will be essential for evaluating the operational feasibility of the morphing wing, providing insights into its adaptability in varying scenarios.

➢ *Scalability and Integration:*

Considerations for scalability, manufacturability, and integration with other UAV systems will be explored to ensure practical applicability and versatility of the morphing wing technology.

➢ *Comparative Studies:*

The project sets the stage for comparative studies with traditional fixed-wing configurations, contributinginsights to the ongoing discourse on the efficacy and advantages of morphing wing technologies.

B. *Conclusion*

➢ *Methodological foundation:*

The research systematically progressed through conceptualization, CAD design, and rigorous load and structural testing, establishing a robust methodological foundation formorphing wing development.

➢ *Aerodynamic Advancements:*

The integration of the NACA 6412 airfoil and the octahedron cell structure represents a significant advancement, promising to enhance aerodynamic efficiency and adaptability in UAVs.

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