Multi-Domain Assessment of Boron Fiber–Carbon Nanotube Nanocomposites for Drone Engineering Applications

Laxana Sourirajan1, Rajkumar Rajapandi2, Arul Prakash Raji1, Balaji Ganesan3, Subhav Singh4,5,6, Deekshant Varshney7,8, Vijayanandh Raja1, a)

1Department of Aeronautical Engineering, Kumaraguru College of Technology, Coimbatore-641049, Tamil Nadu, India

2Department of Mathematics, Kumaraguru College of Technology, Coimbatore-641049, Tamil Nadu, India

3Department of Aerospace Engineering, Hindustan Institute of Technology and Science, Chennai-603103, Tamil Nadu, India

4Centre for Promotion of Research, Graphic Era (Deemed to be University), Uttarakhand, Dehradun, India

5Division of research and development, Lovely Professional University, Phagwara, Punjab, India

6Chitkara Centre for Research and Development, Chitkara University, Himachal Pradesh-174103, India

7Division of Research & innovation, Uttaranchal University, Dehradun, Uttarakhand, India

8Centre of Research Impact and Outcome, Chitkara University, Rajpura-140417, Punjab, India

Corresponding author: a)[vijayanandh.raja@gmail.com](mailto:vijayanandh.raja@gmail.com)

**Abstract.** Landing gear plays a vital role in ensuring stability, ground support, and impact absorption capabilities of unmanned aerial vehicles (UAVs), particularly during takeoff and landing phases. It must offer high structural integrity while remaining lightweight to enhance overall UAV performance. In addition to supporting the airframe, it provides critical protection for sensors and structural components especially in demanding environments encountered by small UAVs. This study focuses on the design and analysis of lightweight, high-performance landing gear using advanced nanocomposites and modern computational tools, including 3D EXPERIENCE platforms. Boron-epoxy composites, known for their excellent stiffness-to-weight ratio and compressive strength, serve as the base material. These composites are formed by embedding boron fibers into an epoxy resin matrix, offering superior thermal and mechanical stability compared to conventional materials. To further enhance performance, carbon nanotubes—both single-walled (SWCNTs) and multi-walled (MWCNTs) are incorporated into the boron-epoxy matrix. Structural simulations and analyses reveal that while both CNT types significantly improve mechanical properties, SWCNT-reinforced boron-epoxy composites demonstrate superior efficiency under applied load conditions. These findings highlight the potential of SWCNT-enhanced boron composites for high-stress UAV components such as landing gear.

# INTRODUCTION

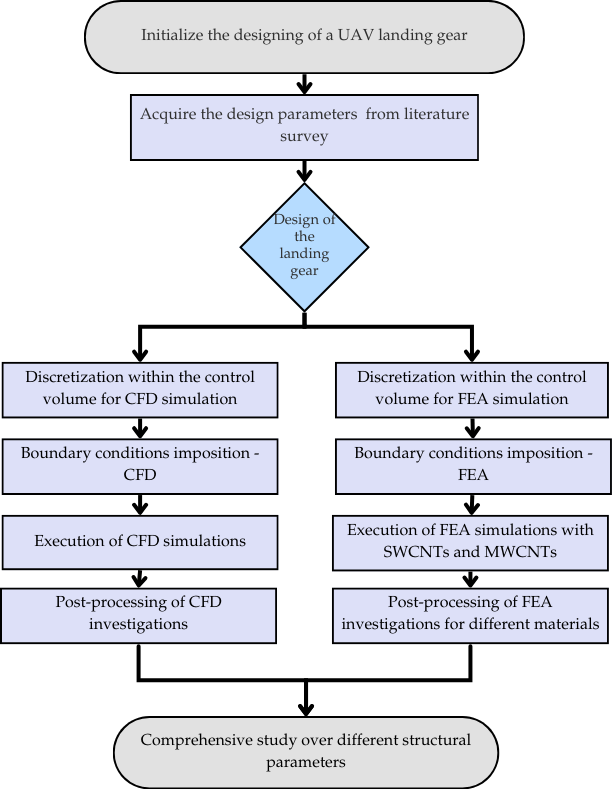
Nanotubes made of carbon with diameters on the scale are called carbon nanotubes. Prioritizing low-cost, high-strength, and lightweight materials is crucial when selecting engineering components. Complicated structures may experience structural issues as a result of rotor placement, unexpected loads, and environmental influences. Structural integrity and lifetime can be increased by using advanced materials including sandwich composites, metal matrix composites, and composites based on Single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs). The ideal material for the project will be determined with the use of computational and experimental testing. Boron-epoxy composites are used in applications where stiffness is a crucial design factor. These composites are created by combining boron fibers with an epoxy resin matrix, resulting in a structure that can withstand high compressive forces. The addition of boron improves the thermal stability of the epoxy composites. Due to their high specific tensile strength, high specific modulus, and excellent fatigue strength, boron-epoxy composites are commonly employed in the construction of aircraft landing gear. These composites offer significant advantages and serve as an alternative to conventional materials [1-6]. Florian H. Gojny (2005) conducted a comparative study on the fracture behavior of nanocomposites reinforced with various types of carbon nanotubes (CNTs). His findings served as a key reference for the current work, particularly in evaluating the tensile performance of SWCNT- and MWCNT-reinforced composites [1]. Robiul Islam Rubel (2019) explored the effects of CNT agglomeration in reinforced composites, providing valuable insights into the detrimental influence of poor dispersion on both the reinforcement and matrix properties [2].

A. K. Gupta (2014) performed finite element analysis (FEA) on polymer composites containing CNTs, offering foundational support for the current study’s modeling strategies, material property inputs, mesh configurations, and element selection [3]. Similarly, Kulmani Mehar (2017) focused on the bending behavior of nanocomposites, contributing essential theoretical knowledge, mechanical property data, and computational tools. While early applications of ANSYS posed challenges, its reliability has since made it a preferred platform. This work utilizes ANSYS Workbench 17.2 to analyze the tensile response of nanocomposites [4].

Mohammed Jawad Aubad (2020) investigated hybrid laminate composites composed of MWCNTs, epoxy resin, carbon fiber, and Kevlar fiber. His combined use of FEA and experimental validation provided valuable procedural and material insights relevant to the current study, particularly regarding the fabrication process, MWCNT characteristics, and FEA simulation techniques [5].

J.-H. Du (2007) delivered a comprehensive review on the growing significance of CNT-based polymer composites, highlighting their cross-disciplinary benefits such as superior thermal and electrical conductivity, enhanced tensile strength, and a high strength-to-weight ratio. His work addressed applications in thermal interface materials, optical and electronic devices, and electromagnetic shielding. Additionally, Du examined reinforcement mechanisms, processing challenges, and optimization parameters such as filler content, matrix selection, manufacturing methods, and environmental considerations offering a rich source of data for advanced nanocomposite development [6].

# IMPOSED METHODOLOGY – integrateD COMPUTATIONAL APPROACH



1. Methodology followed in this study

Computational structural analyses are carried out using FEA, a method that utilizes preloaded numerical codes. Depending on the type of test and the material's characteristics, ASTM standards offer common design parameters for researching fundamental features that make it simpler to create a numerical model [7-11]. This article analyses the flexural properties of composite materials from many fields [12-15]. In this study, the design criteria specified by ASTM D7264 such as 100 m span, 20 mm width, and 7 mm thickness are applied. Research on multidimensional composite fibers is allowed with up to ten layers [16-18]. To accurately mimic the original physical model, fine discretization is crucial [19-21]. Figure 1 delivers the steps followed in the methodology used in this study.

# Results And Discussions

In this discussion, the conventional Boron epoxy is tested under compression with the SWCNTs and MWCNTs.

## Computational analysis of Boron Epoxy composite associated with SWCNTs under compression test

Figures 2 to 7 presents the comprehensive structural analysis of Boron Epoxy associated with MWCNTs for a compression load. These figures allow one to understand about the distribution of load, concentration of stress and energy obtained through the strain [32-49].

|  |  |
| --- | --- |
|  |  |
| 1. Total Deformation of landing gear with SWCNT material | 1. Equivalent stress of landing gear with SWCNT material |
|  |  |
| 1. Equivalent elastic strain of landing gear with SWCNT material | 1. Strain energy of landing gear with SWCNT material |
|  |  |
| 1. Normal stress of landing gear with SWCNT material | 1. Shear stress of landing gear with SWCNT material |

## Computational analysis of Boron Epoxy associated with MWCNTs under compression test

Figure 8 to 13 presents the comprehensive structural analysis of Boron Epoxy associated with MWCNTs for a compression load.

|  |  |
| --- | --- |
|  |  |
| 1. Total deformation of landing gear with MWCNT material | 1. Equivalent stress of landing gear with MWCNT material |
|  |  |
| 1. Equivalent elastic strain of landing gear with MWCNT material | 1. Strain energy of landing gear with MWCNT material |
|  |  |
| 1. Normal stress of landing gear with MWCNT material | 1. Shear stress of landing gear with MWCNT material |

## Discussions

Figures 14 to 19 illustrate the graphical analysis of key structural parameters such as equivalent stress, total deformation, equivalent elastic strain, normal stress, strain energy, and shear stress for Boron Epoxy composites reinforced with SWCNTs and MWCNTs [22-26]. Understanding these structural characteristics is essential to ensuring the safety, durability, and performance efficiency of aircraft landing gear systems [50-60]. Total deformation analysis, in particular, plays a vital role by revealing how much the landing gear displaces under operational loads, such as impact during landing or stress encountered during taxiing. This insight helps engineers prevent excessive bending or buckling that could compromise structural integrity or disrupt associated systems like retraction mechanisms. Evaluating stress and strain behavior also allows for optimized material selection and structural design, contributing to more reliable and resilient aerospace components [27-31, 61-70].

1. Total deformation of Boron Epoxy with CNTs
2. Equivalent Stress of Boron epoxy with CNTs
3. Equivalent Elastic Strain of Boron epoxy with CNTs
4. Normal stress of Boron epoxy with SWCNTs and MWCNTs
5. Shear stress of Boron epoxy with CNTs
6. Strain Energy of Boron epoxy with SWCNTs and MWCNTs

Throughout the discussions it can be seen clearly that depending on the applications, the materials can be changed. It is essential to research structural factors such as stresses and strains in UAV (unmanned aerial vehicle) landing gears to guarantee their dependability and security while in use. While strain analysis sheds light on the landing gear's deformation behavior under various loading scenarios, stress analysis assists in locating regions of high stress concentration that are vulnerable to failure under impact loads [71].

# Conclusion

The foundational data required for this study including three-dimensional geometry, material mechanical properties, boundary conditions, and the selection of primary and secondary constituents of the nanocomposite—is obtained through a comprehensive literature review. This foundational knowledge facilitated the design of UAV landing gear systems capable of withstanding operational loads, absorbing impact energy, and ensuring safe landings by accurately analyzing stress and strain distributions.

Comparative analyses are conducted on Boron Epoxy composites reinforced with SWCNTs and MWCNTs. The results revealed that the SWCNT-reinforced boron epoxy composite exhibited the lowest values for total deformation, equivalent strain, shear stress, and normal stress. While other structural parameters are slightly lower for the MWCNT-reinforced variant, the higher strain energy observed in MWCNT composites suggests potential long-term degradation under repeated loading.

Despite this, MWCNT-infused composites still outperform conventional boron epoxy materials in several aspects, making them a viable alternative for structural applications where moderate performance and cost-efficiency are acceptable. Overall, SWCNT-reinforced boron epoxy emerged as the superior material for advanced UAV landing gear systems.

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