JJMIE

Volume 20, Number 3, September 2026
ISSN 1995-6665
Pages 339– 348
https://doi.org/10.59038/jjmie/200302
Editor-in-Chief: Prof. Faris M. AL-Oqla

Jordan Journal of Mechanical and Industrial Engineering

Design and Analysis of a Composite Wing for the Cessna 172 Aircraft with Additive Nano Silicon Oxide

Noor Al Huda Kareem Khalaf[*,1], Raed Naeem Hwayyin[2], and Ahlam Luaibi Shuraiji[3]

[1,2,3]*Electromechanical Engineering College, University of Technology, Baghdad, Iraq*

Received 31 Jan 2026 *Accepted 9 May 2026*

Abstract

The objective of this study is to analyze the overall deformation and stress distribution of a modified Cessna 172 wing design made of polyester reinforced with 0.6% weight-fraction carbon fiber and P-type silicon oxide (SiO_2) nanoparticles with porous and branched properties at different weight percentages of 0.1%, 0.2%, and 0.3%. This study explores the use of composite materials as an equivalent alternative to aluminum in aircraft wing structures. The aircraft design was constructed using the NACA 63-412 aerodynamic profile (airfoil), which is appropriate to this type of aircraft. Experimental tests contributed to determining the mechanical properties of the composite material, which were then used in numerical analysis using the finite element method for a three-dimensional model in Ansys software. The results showed an improvement in the overall wing deformation resistance, as well as a nonlinear stress distribution concentrated at the wing's support points and decreasing towards the wing tip and wing root. The results showed that increasing the weight percentage of SiO_2-type-P by different percentages (0.1%, 0.2%, and 0.3%) leads to a decrease in the overall wing deformation of 12.02%, 27.07%, and 46.56%, respectively, and a decrease in stress of 1.63%, 3.64%, and 6.24%, respectively.

Keywords: Cessna 172 wing, Carbon fiber, Silicon oxide, Composite materials, Aerodynamic profile.

1. Introduction

The importance of integrating composite and nanomaterial materials to reduce weight while maintaining performance efficiency is a key factor in the aviation industry. Reducing mass improves aerodynamic efficiency during flight, allowing for increased payload capacity, reduced fuel consumption, and consequently, lower aircraft emissions [1]. Glass fiber reinforced polymer (GFRP) or carbon fiber reinforced polymer (CFRP) composites have demonstrated exceptional properties, including high stress resistance and superior stiffness, making them ideal choices for modern aircraft wings [2]. Furthermore, incorporating nanoparticles into metallic composites enhances the strength of the composite material to meet diverse industrial requirements. Aluminum alloys from the 2xxx and 7xxx series are commonly used in the construction of light aircraft structures, such as the Cessna 172 [3]. The effect of adding silicon carbide nanomaterials at specific weight percentages to 7075 aluminum alloy on mechanical properties such as tensile strength and corrosion resistance has been investigated [4]. Enhancing mechanical properties through the addition of nanomaterials to the polymer matrix has been investigated. Adding silicon dioxide nanoparticles (SiO_2) or multi-walled carbon nanotubes (MWCNTs) improves these properties [5], and leads to enhancing fatigue life and increasing the material's failure resistance under alternating loads [6]. This study investigated the effect of time on the mechanical properties and creep behavior of polyester-glass fiber composites [7], while the effect of a salt environment on the mechanical properties of composite materials was investigated [8,9]. Advanced simulation tools, such as finite element analysis (FEA) using software like ANSYS and CATIA, contribute effectively to analyzing deformation behavior, stress distribution, shear stress, and fatigue life in the wing structure in operation [10,11-15]. These tools also provide information on vibration behavior analysis, thus ensuring design robustness [16]. With these capabilities, new design challenges emerge that require research attention, most notably aeroelasticity and the impact of manufacturing defects, such as voids and micro-cracks, on mechanical properties, which can reduce durability and lead to premature failure [17,18]. Optimization of component dimensions (such as shell thickness, number and position of ribs) and the study of repair techniques for damaged composite materials, such as core-shell rubber-reinforced patching (CSR), are also crucial for enhancing structural durability and extending service life [19,20]. Based on 3D printing of polylactic acid (PLA) material, the structural performance of a printed wing rib was investigated, as shown in Figure 1. Finite element analysis was employed to determine the stresses in the structure under load. The tensile strength increased by 61% as a result of combining sensor locations. The interaction between the load location

* Corresponding author e-mail: eme.23.126@grad.uotechnology.edu.iq.

and the speed of the testing machine head was also investigated, as load is a crucial factor in bending tests [21]. In this context, this study offers an applied contribution aimed at designing and analyzing the wing of a Cessna 172 aircraft using a carbon fiber/polyester composite material reinforced with silicon dioxide (SiO_2) nanoparticles. The research adopted a 3D model analysis of an aircraft wing using the finite element method based on ANSYS to analyze the stress distribution and total deformation. In doing so, this study helps bridge the gap between basic research on composite nanomaterials and their practical application in a vital aerospace component, thus supporting the development of lighter, more efficient, and more robust aircraft structures. The study aims to investigate the effect of applying advanced composite materials of polyester and carbon fibers with a weight fraction of 60%, reinforced with (SiO_2) type-P nanoparticles in different weight ratios with porous and branched morphological features in an innovative aircraft wing design for a Cessna 172 aircraft. It aims to analyze the overall strain and deformation under lifting load as to reduce the use of more expensive aluminum in its structure. Also, the study aims to investigate the effect of applying advanced composite materials of polyester and carbon fibers with a weight fraction of 60%, reinforced with (SiO_2) type-P nanoparticles in different weight ratios with porous and branched morphological features in an innovative aircraft wing design for a Cessna 172 aircraft, and to analyze the overall strain and deformation under lifting load, as well as reduce the use of more expensive aluminum in its structure.

2. Materials and Methods

2.1. Materials

This study used unsaturated polyester resin as the matrix for the composite material due to its lower cost compared to other types of resin, such as epoxy and vinyl ester. The composite material being investigated consisted of a polyester matrix reinforced with carbon fibers at varying weight percentages. P-type porous silicon dioxide (SiO_2) nanopowder, with dimensions ranging from 15 to 20 nm, was utilized. These nanoparticles are characterized by their branched shape and porosity, which range from 2 to 6 nm. The porosity of the nanoparticles increases adhesion to the other components of the composite, and their branching significantly improves the composite's cohesion. The nanoparticles are characterized by a high UV reflectance of 85%, as shown in Table 1. The additive of different weight ratios of nanoparticles, 0.1%, 0.2%, and 0.3%, was adopted in strengthening the composite material at a weight fraction of carbon fibers (wt%) of 60%. The mechanical and physical properties of the polyester composite components (matrix) are shown in Table 1, while Table 3 shows the properties of the carbon fibers (fibers) that work with the polyester to enhance the strength and stiffness of the composite material.

Table 1. Properties of Nano silicon oxide (SiO2) type-P

Code	Value
Purity	99.5+%
APS	15-20 nm-Porous particles
Color	White
Porous size	2-6 nm
Appearance	solid
Melting Temp.	1610 °C
Initial boiling Temp.	2230 °C
Flammability	solid, gas
Relative density	2.4 g/cm^3

Table 2. Mechanical characteristics of polyester

Value	characteristics
65 N/mm^2	Tensile strength
3.0 %	The elongation ratio
3600 N/mm^2	Elastic modulus
1268 kg/m^3	The density
70	Rockwell hardness scales

Table 3. Characteristics of the Carbon Fiber Mat

Characteristic	Value
The mass per area	200 (g/m^2)
Weave	Plain
The width's size	1000/2000 (mm)
The thickness's size	0.16 (mm)

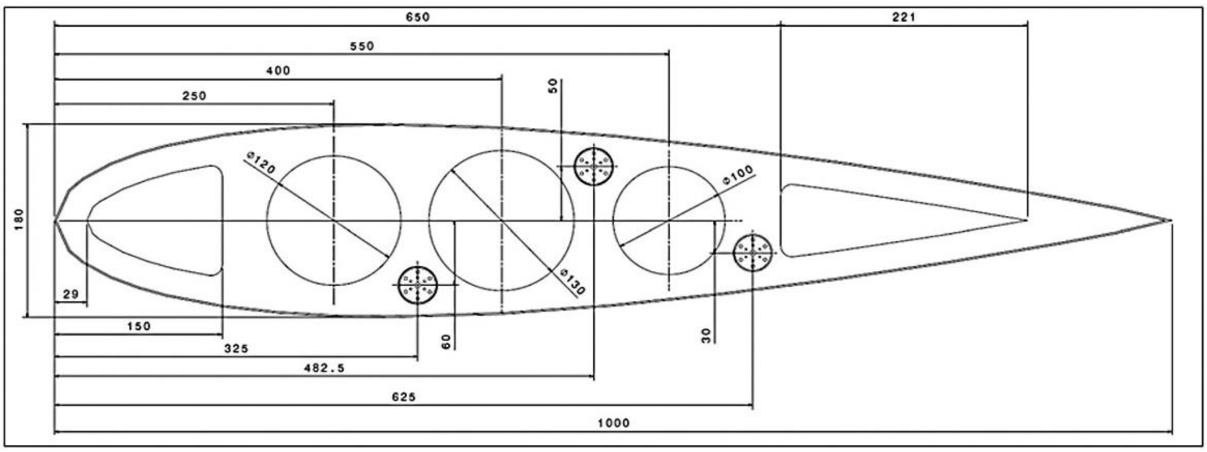

Figure 1. Wing rib dimensions (mm).

2.2. Methods

A system consisting of a vacuum compressor was fabricated to evacuate the air from the acrylic mold, as shown in Figure 2, resulting in high-quality composite samples free from air bubbles. Air bubbles in composite materials act as defects and points of stress, leading to failure. The weights of the composite material components were precisely measured using an analytical balance, as shown in Figure 3. To achieve optimal homogeneity of the silicon dioxide (SiO_2) nanoparticles, we added them to the polyester matrix supplied by İLKALEM Trade and Industry Joint Stock Company (Turkey) in weight ratios of 0%, 0.1%, 0.2%, and 0.3%, with a fiber weight fraction of 60%. The mixing process was conducted at 25°C using a probe mixer operating at 80% capacity. Ultrasonic curing was applied for 5 to 10 minutes, including alternating cycles (10 seconds on, followed by 5 seconds off), with cold water used to maintain the mixture temperature. The casting process was performed using a vacuum mold to prevent bubble formation during the pouring process. A series of mechanical tensile strength samples were prepared according to ASTM D3039, with varying dimensions and weight ratios of nanoparticles, as shown in Figures 4a and 4b. The SEM images (at 8000× magnification) show the dispersion of P-type nano-SiO_2 particles within the carbon fiber/polyester composites. At 0.1 wt.% SiO_2, particles are homogeneously distributed, enhancing mechanical properties. At 0.2% and 0.3% SiO_2, limited to higher agglomeration is observed due to the porous and branched morphology, yet mechanical performance continues to improve. The discussion confirms that the unique porous and branched structure of SiO_2 improves interfacial adhesion and fills microstructural gaps [22].

3. Wing Design of Cessna 172

Table 4 shows the specifications of the Cessna 172 aircraft wing. The study modified the type and shape of the spar used for reinforcing the wing root of the Cessna 172 aircraft.

Table 4. Wing dimensions of the Cessna 172 aircraft [23]

Parameter	Value
Wing Section	NACA 63-412
Wing Span (Length)	11 m
Wing Root Chord (Body Wing Width)	1.63 m
Wing Tip Chord (Wing Tip Width)	1.13 m
Dihedral Angle	1.7°
Aspect Ratio	7.5
Cruise Speed	63 m/s
Air Density	1.007 kg/m³
Kinematic Viscosity of Air	1.714×10^{-5} m²/s

Figure 5 shows the detailed dimensions of the wing root in millimeters (mm) and its internal cavities, which contribute to weight reduction while maintaining the strength of the rib used to reinforce the wing, based on the NACA 63-412 profile. Figure 6 shows the detailed dimensions of the wingtip. The wing skin thickness is 6 mm, and for reinforcement, 6 mm thick composite hollow tubes of the same thickness are used, extending between the wing root and wing tip.

Figure 2. Vacuum casting mould of composite Samples

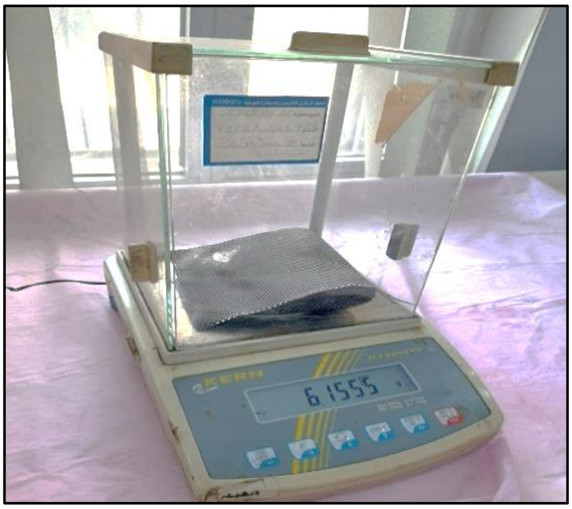

Figure 3. High precision weighing scale

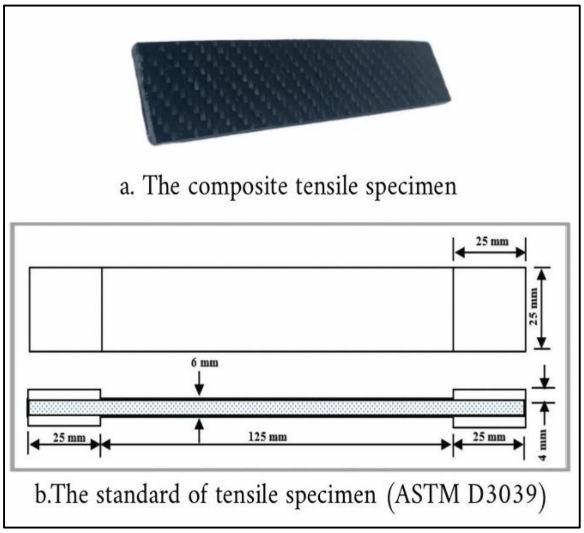

Figure 4a and b. The tensile test specimens

  - Volume 20, Number 3 (ISSN 1995-6665)

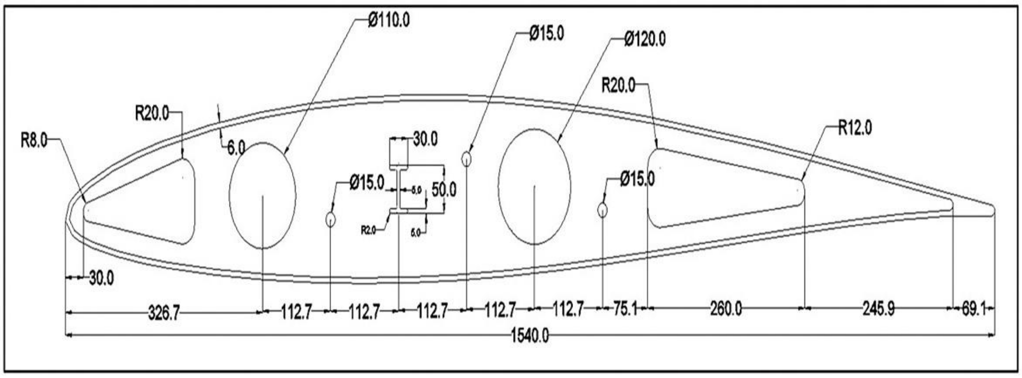

Figure 5. The dimensions of the wing root (all dimensions in mm)

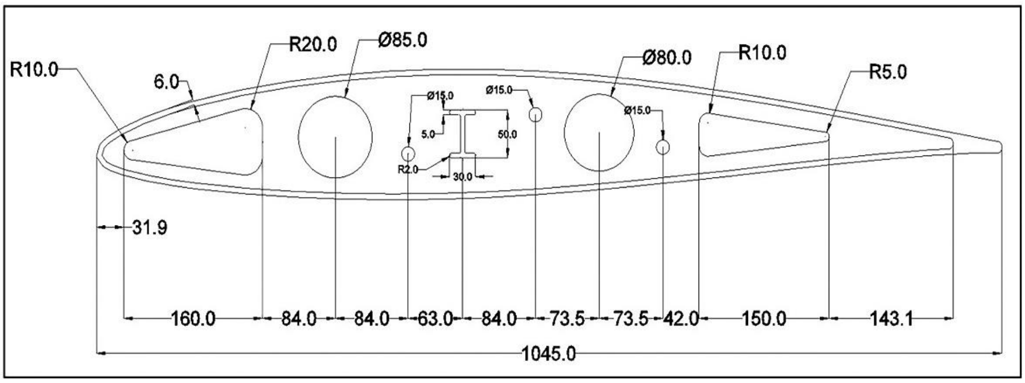

Figure 6. The dimensions of the wing tip (all dimensions in mm)

Figure 7 shows the components of the wing structure, which consist of Al-7075 bars to enhance the safety of the wing design, while Figure 8 illustrates the wing shape of the Cessna 172 aircraft. The spar structure shown in the two figures is made of nano-granule-reinforced composite material, except for section I, which is made of 7075 aluminum alloy to act as a support in order to meet the safety requirements of the aircraft wing. The Figure 7 illustrates the structural components of the composite wing, including the composite skin, ribs, spars, and stringers, all constructed from advanced composite materials such as fiber-reinforced polymers (FRP) and reinforced with lightweight nanoparticles. The design demonstrates optimal laminate lay-up to achieve high strength relative to density. The design demonstrates an optimal arrangement of composite panels to achieve high strength-to-density ratios. The wing's weight depends on the density of the composite material used in its construction. Table 5 shows the type of material used for the wing components, while Table 6 shows the standard wing specifications for aircraft, including the standard weight and the weight for each composite material configuration, which depends on the density and volume of each component in each configuration.

The lifting force can be determined using the following equation [24]:

$$\text{Lifting Force } (L) = \frac{1}{2} \cdot \rho . v^2 . S \cdot C_L \quad (1)$$

Where L is the lifting force (N); ρ: air density (kg/m³); v: velocity (m/s); S: the wing planform area (m²); and the Coefficient of Lift (CL) is equal to 1.5 (dimensionless).

Table 5. Illustrates the components of the wing structures

Part No.	Dimensions	Material
1	One bar with I cross-section length 5.5 m	AL-7075
2	All other structures	composite fiber carbon/polyester reinforced with Nano (SiO_2) type-P

Table 6. Details of the Cessna 172 wing

Details	The value	Unit
Total weight of wing of plane Cessna 172	About 150 to 200	kg
The total weight of the composite wing at carbon fiber is a weight fraction of 60%. At densities (kg/m³) of 1266.81, 1263.25, 1276.25, and 1292.56 at nano ratios of 0%, 0.1%, 0.2%, and 0.3%, respectively	150.25, 155.59, 157.11, and 159.02, respectively	kg

Table 7. The details of the components of the composite wing.

Part No.	Part name	Volume (m³)
1	Ribs	0.0059175
2	Spar Composite pipe-1	0.0109893
3	Spar Composite pipe-2	0.0085
4	I-Section (AL-7075)	0.00273
5	Three composite rods (ϕ15 mm)	0.0029157
6	Skin	0.08877

4. Modeling the wing

Figure 9 illustrates a detailed mesh model of a Cessna 172 wing, created in the ANSYS 2019 R3 simulation environment for accurate finite element analysis. This model consists of 1,861,094 nodes and 876,263 elements, demonstrating a high mesh density that enhances its capability to represent complex field gradients, including stress distribution and strain. The 15 mm element size was adopted for a 5500 mm wing to achieve high accuracy. Furthermore, the 1 mm defeaturing size contributes to improved network quality, maintaining numerical analysis efficiency and ensuring high reliability of the results.

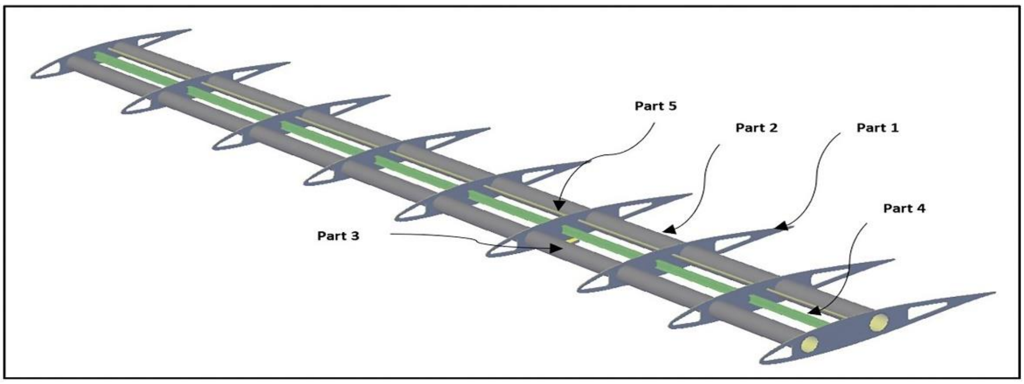

Figure 7. The composite components of wing structure

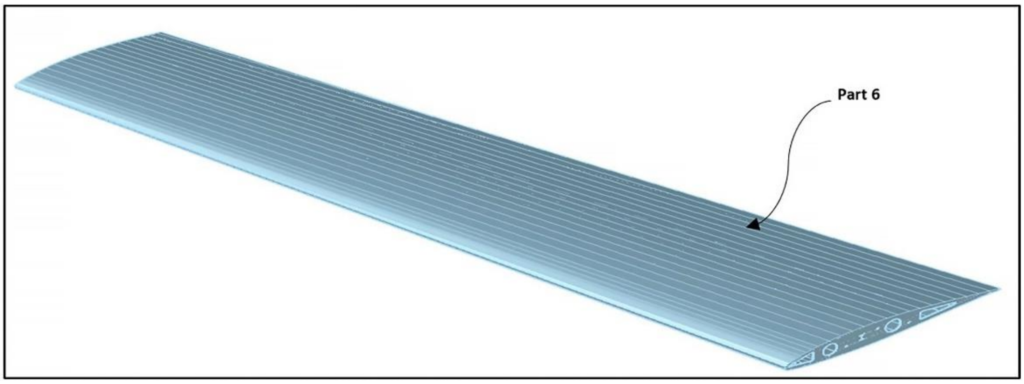

Figure 8. The wing shape of the Cessna 172 aircraft

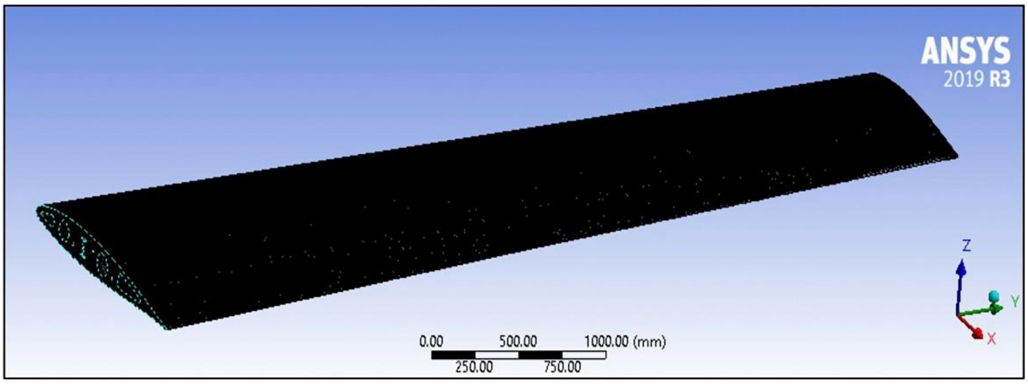

Figure 9. Aircraft wing model meshing

Figure 10 shows the load applied to the wing of a Cessna 172 aircraft, specifically the area where the lift force is applied, equivalent to the aircraft's weight, to achieve takeoff at the aircraft's design speed. The structure is designed with a bond between the composite parts and the T6-7075 aluminum I-section, which acts as a support column for the composite material to meet manufacturing safety requirements. A load of 1121.69 kg (11,000 N) is applied to each wing, while the total aircraft weight ranges from 998 to 1157 kg. The wing provides the capacity to bear twice the total airplane weight. The uniform distribution of the ribs ensures even stress distribution across the wing and, consequently, the entire structure.

The Cessna 172's design incorporates a wing support point positioned at one-third of the wing's length from the wing root, which is attached to the fuselage. This support point work for reinforce the wing and reduce the bending, but it also increases the stress at that point. Figure 11 illustrates the mounting points in the wing model, specifically at the wing root and the wing support point on the fuselage.

5. Results and discussions

Finite element modeling of wings for wing structure design demonstrated that one of the important factors in the accuracy of numerical analysis data is the appropriate grid element size, which contributes to increasing its accuracy [25]. The finite element analysis using Ansys simulated the overall deformation of an aircraft wing under lift, based on experimental results of the mechanical and physical properties of a polyester-carbon fiber composite reinforced with varying proportions of SiO_2-type-P nanoparticles. Figure 12 shows the total wing deformation in millimeters (mm) for a composite material containing 60% fractional weight carbon fibers without adding SiO_2-type-P nanoparticles. The analysis shows that the highest bending strain, 33.328 mm, was at the wingtip and decreased towards the wing's support point.

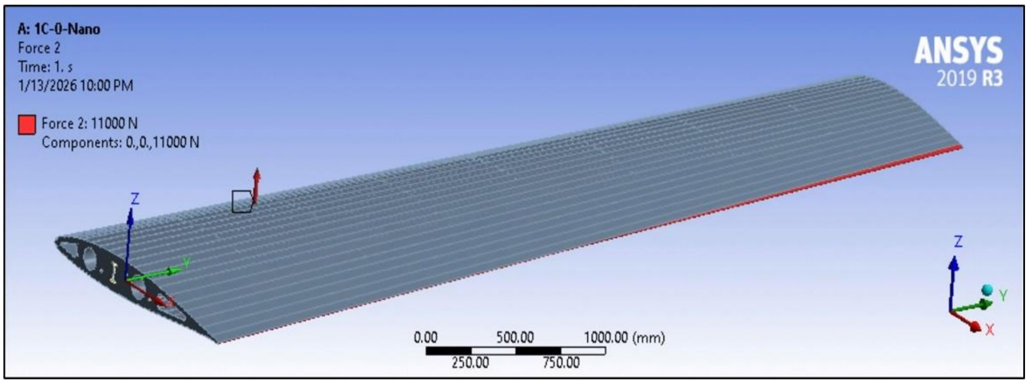

Figure 10. Loading conditions during lifting on the aircraft wing

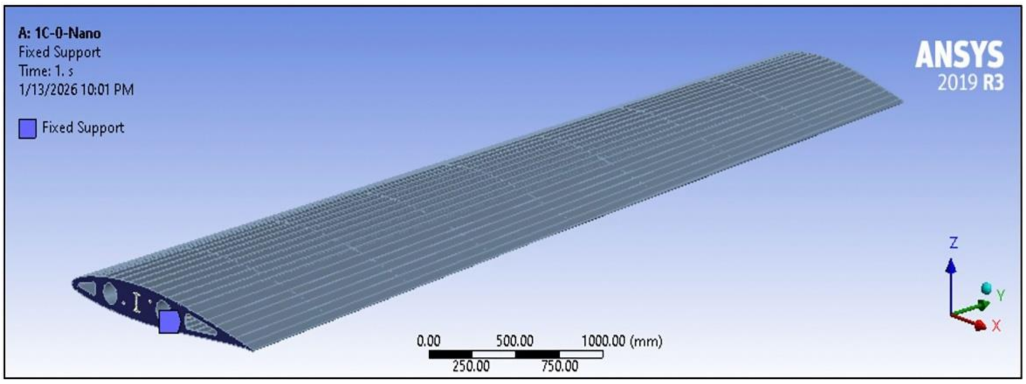

Figure 11. Fixing conditions for aircraft wing

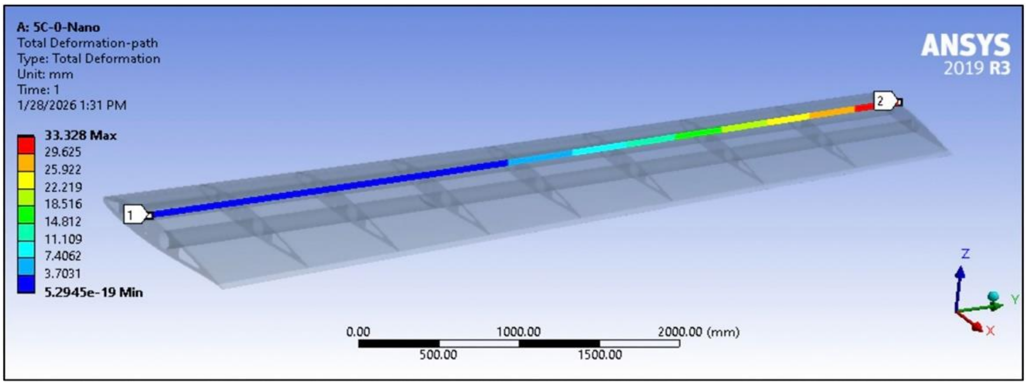

Figure 12. Total deformation of the wing model without Nano SiO_2-type-P at a wt% of 60%.

The total deformation in Figure 13 at a weight fraction of 60% with the additive of Nano SiO_2-type-P with a weight ratio of 0.1% is shown. The maximum deformation occurs at the wingtip during lift, reaching 29.32 mm, and decreases as the wing approaches the support structure. Increasing the nanoparticle content reduces the maximum total wing deformation by 12.02% when compared to that without nano. The nanoparticles enhance the composite material's strength by improving the cohesion of its microstructure, thanks to their unique morphological properties, including porosity and branching, which contribute to their resistance to deformation.

The total deformation of the Cessna 172 wing model made of the composite material shown in Figure 14 is at 60% wt% with an additive of 0.2% SiO_2-type-P particle. Numerical analysis of the model reveals that the greatest deformation occurs at the wingtip, reaching a maximum value of 24.306 mm, and decreases towards the support point. The maximum deformation of the wing is reduced by 27.07% compared to the wing without nanoparticles. Increasing the nanoparticle content increases stiffness but reduces the material's elongation, indicating increased brittleness.

Figure 15 shows the deformation distribution on an aircraft wing made of a 60% polyester-carbon fiber composite with the addition of 0.3% Nano SiO_2-type-P. Numerical analysis of the wing model reveals that the maximum overall deformation at the wingtip decreased with increasing nanoparticle content in the composite material, reaching a maximum deformation of 17.808 mm.

The maximum overall deformation at the wingtip decreased by 46.56% compared to the wing without nanoparticles. The addition of 0.3% nanoparticles at 60% carbon fiber yielded the maximum reduction in overall deformation due to the homogeneity of the composite material's composition and the increased stiffness resulting from the dispersion of internal stress concentrations under load.

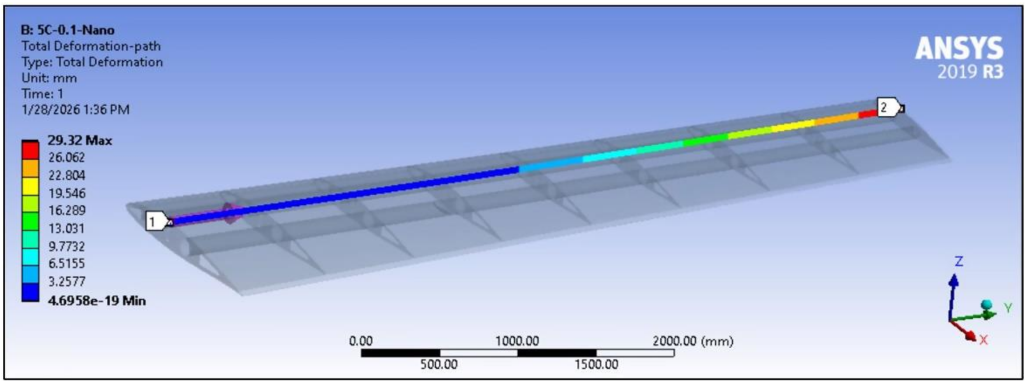

Figure 13. Total deformation of the wing model at ratios of Nano SiO_2-type-P of 0.1% at a wt% of 60%

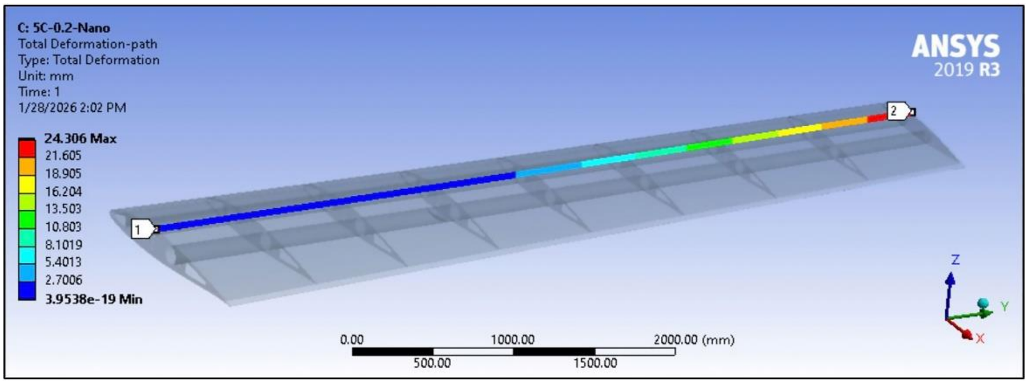

Figure 14. Total deformation of the wing model at ratios of Nano SiO_2-type-P of 0.2% at a wt% of 60%

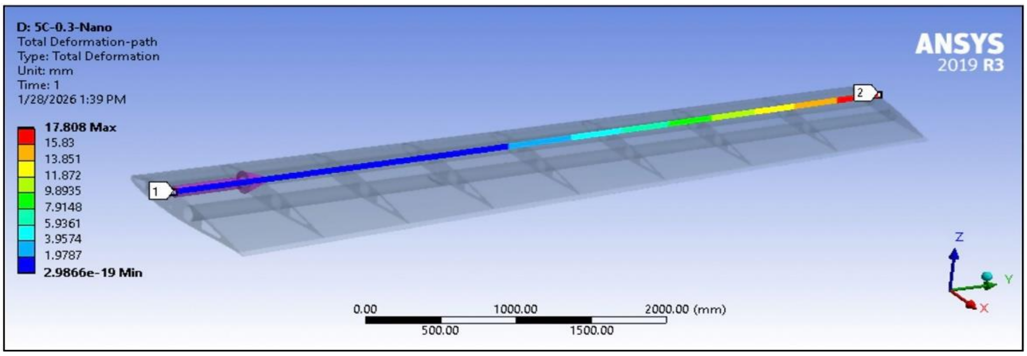

Figure 15. Total deformation of the wing model at ratios of Nano SiO_2-type-P of 0.3% at a wt% of 60%

The overall deformation comparison shown in Figure 16 is for a 5500 mm wing made of a polyester-carbon fiber composite with a 60% weight fraction and varying percentages of SiO_2-type-P additives (0.1%, 0.2%, and 0.3%). A T6-7075 aluminum I-section bar is used to enhance strength and safety during routine wing inspections. The distribution of overall deformation along the wing shows that the maximum deformation is concentrated at the free wingtips, as they are far from the support and mounting points in the aircraft structure. The results indicate that the greatest reduction in deformation was achieved with the addition of 0.3% SiO_2-type-P. The low deformation at 2000 mm is due to the wing's support of the fuselage, as per the aircraft design, which reduces overall deformation at this point. Deformation then increases with distance from the support area.

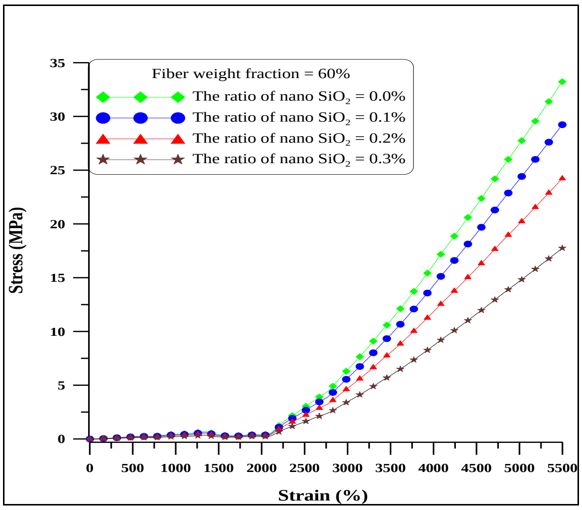

Figure 16. Compare the total deformation along the wing model at ratios of Nano SiO_2-type-P of 0%, 0.1%, 0.2%, and 0.3% at a wt% of 60%

The results in Figure 17 show the stress distribution analysis along the wing of a Cessna 172 aircraft made of composite material at a weight fracture of 60% of the total weight, reinforced with Nano SiO_2-type-P particles. This analysis highlights the crucial mechanical effect of incorporating nanoparticles and the critical regions of the structural design, which is based on finite element simulation. The nonlinear stress distribution pattern along the wing shows its maximum value at the wingtip, between 2000 and 2250 mm, and not at the free end or the wing root due to the wing's anchor point. The wing then decreases after the high stress concentration towards the wingtip and the wing root. Reinforcement with Nano SiO_2-type-P particles shows a gradual decrease in stress with increasing percentages of (0.1%, 0.2%, and 0.3%), resulting in stress reductions of 1.63%, 3.64%, and 6.24%, respectively. The increased weight ratio of nanoparticles improves load transfer in the polymer matrix to the fibers and then between the carbon fibers themselves, while also reducing the formation of stress concentrations in the composite's microstructure. Furthermore, nanoparticle reinforcement increases the stiffness of the composite material, thereby enhancing its resistance to higher loads.

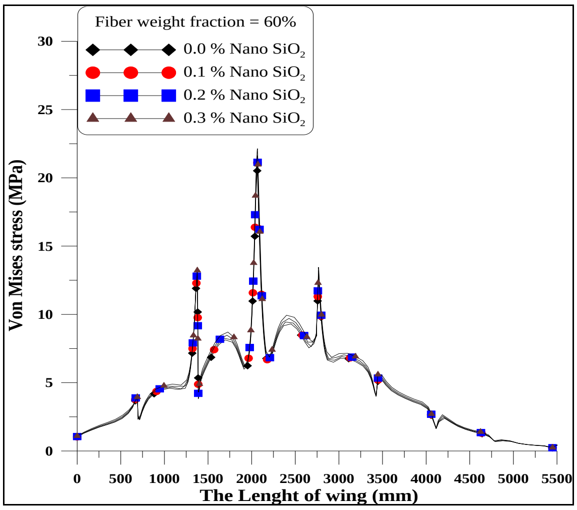

Figure 17. Compare the Von Mises stress distribution along the wing model at ratios of Nano SiO_2-type-P of 0%, 0.1%, 0.2%, and 0.3% at a wt% of 60%

The experimental tensile test results shown in Figure 18 at a 60% weight fracture of carbon fibers demonstrate the effect of increasing the weight percentage of SiO_2-type-P additives. The results show that increasing the nanoparticle content increases the stress with a limited decrease in strain. The addition of nanoparticles with a distinctive shape enhances the cohesion of the composite material by occupying the interstitial spaces in its microstructure, thus strengthening its structure. Furthermore, increasing the nanoparticle content disperses stresses under load and acts as a shield against crack growth and failure. Numerical analysis depends on the experimental results that determine the physical and mechanical properties of the composite material, helped to accurately define its behavior. The composite material has lower densities than aluminum alloys, which allows for more reinforcement by the composite material while keeping a suitable weight for the aircraft wing and improving its efficiency in the application.

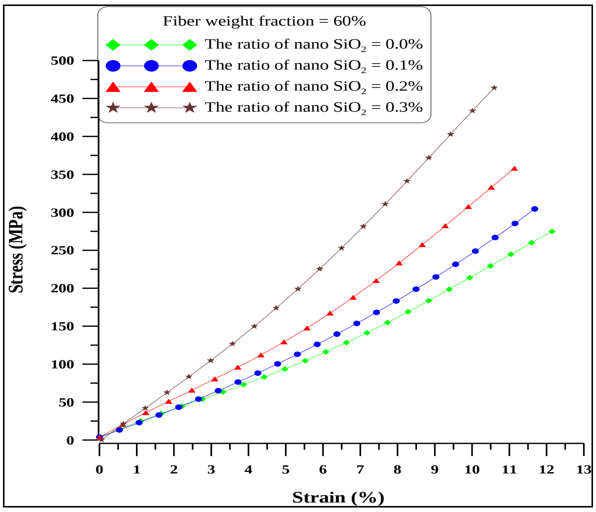

Figure 18: The composite's tensile strength has a weight fraction of carbon fiber (60%) and is reinforced with 0%, 0.1%, 0.2%, and 0.3% SiO_2-type-P

6. Conclusions

- Increasing the amount of SiO_2-type-P nanoparticles resulted in a good improvement in the overall deformation of the Cessna 172 wing by 12.02%, 27.07%, and 46.56% when the nanoparticle content was increased by 0.1%, 0.2%, and 0.3%, respectively.
- The composite material made of 60% carbon fibers with 0.3% additives showed the highest reduction in total deformation, at 46.56%.
- The increasing weight ratios of Nano SiO_2-type-P by 0.1%, 0.2%, and 0.3% lead to stress reduction along the wing stress of 1.63%, 3.64%, and 6.24%, respectively.
- The stress distribution is nonlinear along the wing, with the maximum stress value concentrated at the anchor point between 2000 and 2250 mm, while the stress decreases towards the wingtip and the wing root.
- Experimental results demonstrated improved mechanical properties due to the homogeneity of the composite material's structure and the addition of SiO_2-type-P nanoparticles, which enhanced the material's cohesion and increased its strength.
- The results demonstrated the efficiency of the Cessna 172 wing design, which can support twice the aircraft's weight, in addition to reducing the use of expensive aluminum compared to the composite material. The composite material's volume-to-weight ratio in the wing structure reached 89.7%, importantly reducing manufacturing costs.
- The importance of this research lies in analyzing the three-dimensional strain and stress distribution of the wing under lift during takeoff for a Cessna 172 wing structure made of polyester and carbon fiber composite material, as well as reducing manufacturing costs while maintaining its effectiveness and efficiency.

Acknowledgements

We are grateful to the University of Technology and the Electromechanical College for support in finalizing this study.

References

[1] Gibson, R. F., Principles of Composite Material Mechanics . 5th ed. CRC Press; 2021.

[2] J Sankeerthan, Dr. L Balasubramanyam, K R Yellu Kumar, N. Karthikeyan, "Comparative Study on the Static and Fatigue Life Analysis of Aircraft Wing Structures Using Lightweight Materials", Global Journal of Engineering Innovations & Interdisciplinary Research (GJEIIR), Vol 5 Issue 6, 2025, pp.1-6.

[3] Mouritz, A. P., Introduction to Aerospace Materials. 1st ed. Woodhead Publishing; 2021.

[4] Intethar Jameel Farhood, Raed Naeem Hwayyin, Iman Saleh Kareem, "Laser Power Effect on Mechanical Properties of AL-7075 With/Without Additive Nano Silica Carbide", Semarak Engineering Journal, Vol.11, Issue 1, 2025, pp. 207-219.

[5] Azhar Sabah Ameed, Raed Naeem Hwayyin, Abbas Khammas Hussien, "The Effect of Multi-Walled Carbon Nanotubes on the Mechanical Properties of Composite Material Carbon Fibers/Polyester Used in Ships Hulls", Jordan Journal of Mechanical and Industrial Engineering, Volume 17, No. 3, 2023, pp. 357-366, https://doi.org/10.59038/jjmie/170304.

[6] Raed Naeem Hwayyin, Ahmed Salman Hammood, Azhar Sabah Ameed, "Fatigue Analysis of Polyester Composite Plate Reinforced with Carbon Fiber and Nano Silicon Dioxide", Jordan Journal of Mechanical and Industrial Engineering, Vol.19, No. 3, 2025, pp.579-587 https://doi.org/10.59038 /jjmie/190310.

[7] Raed Naeem Hwayyin, Azhar Sabah Ameed, "The Time Dependent Poisson's Ratio of Nonlinear Thermoviscoelastic Behavior of Glass/Polyester Composite", Jordan Journal of Mechanical and Industrial Engineering, Vol.16, No. 4, 2022, pp. 515 – 528.

[8] Raed N. Hwayyin, Azhar S. Ameed, Ahmed S. Hamood, "The effects of salt concentration on the impact strength of composite material", *AIP Conf. Proc.2443,030052,* Baghdad, Iraq, 2022, https://doi.org/10.1063/5.0100587.

[9] V. Vinay, R. Chanakya, G. Manikanta, T. Lakshman Sai, Dr. G. Vijay Kumar, "Design and Analysis of Composite Wing", International Journal of Innovative Research in Science Engineering and Technology (IJIRSET), Vol. 14, Issue 4, 2025, pp.8731-8739, DOI: 10.15680/IJIRSET.2025.1404411.

[10] Shabeer KP , Murtaza M A, "Optimization of Aircraft Wing with Composite Material", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 6, 2013, pp. 2471- 2477.

[11] M. Dyuthi Priya, R. Vijaya Prakash, B. Purna Chandra Sekhar, "Modeling and Structural Analysis of Aircraft Wing with Different Materials using FEM", International Journal of Emerging Science and Engineering (IJESE), Vol.13 Issue 9, 2025, pp.1-8. http://doi.org/10.35940/ijese.A3790.13090825.

[12] Joyel K Joseph and Avinash Babu, "Design, Modal and Stress Analysis of Aircraft Composite Wing", International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 3, Issue 19, India, ICESMART-2015 Conference Proceedings.

[13] R.N. Hwayyin, "Finite element analysis of fire extinguisher for different types of composite materials", Eng. & Tech. Journal, Vol. 29, No. 13, 2011.

[14] R.N. Hwayyin, "Nonlinear thermoviscoelastic behavior of composite thin plates", Eng. & Tech. Journal, Vol. 33, Part (A), No. 8, 2015. https://doi.org/10.30684/etj.2015.108832.

[15] Hana M. Almagzob ,Tarik.H. Elssoni, and Abdulaziz Abdul Majid, "Structural Design and Analysis of a Light Aircraft Wing", The 1st Scientific Conference for Aerospace Researches & Applications Sudan (SCARA-1), Paper No: SCARA-1.8-11, (58), 2021, pp.1-7.

[16] Amin A. M. Fadlalla, Matza Gusto Andika, Kosim Abdurohman, Unggul Satrio Yudhotomo, "Aeroelastic Analysis and Design of Composite Wings: a Review", International Review of Aerospace Engineering (I.RE.AS.E), Vol. 17, N. 5, 2024, pp.175-189, doi.org/10.15866/irease. v17i5.25572.

[17] Kabasha Kizito, Semayat Fanta, "Analyzing the Influence of Defects on The Mechanical Properties of Microcomposite Aircraft Structures", GSJ: Volume 13, Issue 6, June 2025, pp.238-261.

[18] Mahadeva Prasad, Vijay Kumar S., Vikram Kedambadi Vasu, c, Praveena B. A., "Design, Optimization and Analysis of Aircraft Composite Wing for Aerospace Application", Journal of Propulsion Technology, Vol. 44 No. 4, 2023, pp. 8436-8441.

[19] Dionisis Semitekolos, Sofia Terzopoulou and CostasCharitidis, "Enhancing Carbon Fiber-Reinforced Polymers' Performance and Reparability Through Core–Shell Rubber Modification and Patch Repair Techniques", Polymers Vol. 17, No. 407, 2025, pp.1-23, https://doi.org/10.3390/ polym17030407.

[20] Dogea, R., Yan, X.T. & Millar, R., "Testing and evaluation of the structural performance of a 3D-printed polylactic acid aircraft wing rib", Discov Mechanical Engineering, **2**, 6 ,2023, pp.1-17. https://doi.org/10.1007/s44245-023-00013-8.

[21] Brundaban Patro, D. Shashidhar, B. Rajeshwer and Saroj Kumar Padhi, "Preparation and Testing of PAN Carbon/Epoxy Resin Composites", The Open Mechanical Engineering Journal, Vol.11, 14-24, 2017, pp.14-24., DOI:10.2174/1874155X01711010014.

[22] Noor Al-Huda Kareem Khalaf , Raed Naeem Hwayyin and Ahlam Luaibi Shuraiji, "Impact of Silicon Oxide Nanopowder on the Mechanical and Electrical Properties of Carbon Fiber/Polyester Composite Materials", AIMS Materials Science, Vol. 13, Issue 2, 2026, pp. 205–222. DOI: 10.3934/matersci.2026012.

[23] Hüdayim Başak, Anıl Akdemir, "Design Optimization of Cessna 172 Wing With Biomimetic Design Approach", International Journal of Pioneering Technology and Engineering, IJPTE Vol, 3, No. 1, 2024, pp.07-15, https://doi.org/10.56158/jpte.2024.66.3.01.

[24] E.L. Houghton and P.W. Carpenter, Aerodynamics for Engineering Students, Fifth Edition, Fifth edition published by Butterworth-Heinemann; 2003.

[25] Ruxandra Mihaela Botez, Teodor Lucian Grigorie, Oliviu Sugar-Gabor and Alejandro Murrieta-Mendoza, Aircraft Modeling and Simulation, Applied Sciences, MDPI, UK; 2022, https://doi.org/10.3390/books978-3-0365-3211-0