International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

LIGHT AIRCRAFT WING SECTION

[1] Mr. K. Srinivasa Rao, [2] K.Shiva Krishna, [3] CH.Rohith Raghava, [4] G.Sanjay, [5] S.Shiva krishna
[1]Assistant Professor, [2345]Students
Department of Mechanical Engineering
Siddhartha Institute of Technology & Sciences, Narapally
sreenivas@siddhartha.org.in, 25tq5a0306,@siddhartha.co.in, 25tq5a0307@siddhartha.co.in,
25tq5a0315@siddhartha.co.in, 24tq1a0310@siddhartha.co.in

ABSTRACT

This work presents the aerodynamic and structural analysis of the wing section of a two-seat light aircraft with a maximum take-off mass of 600 kg. The wing is rectangular in plan, with a span of 9.0 m, a chord of 1.4 m and an area of 12.6 square metres, giving a wing loading of 467 N per square metre. The study compares two common light-aircraft airfoils, NACA 2412 and NACA 4415, and then examines a wing box made of a front spar, a rear spar, ribs and skin under the lift load of a symmetric manoeuvre. The aim is to select an airfoil and a structural material that give low cruise drag, a safe stall margin, adequate stiffness and the least possible mass.

Two-dimensional airfoil analysis was carried out in ANSYS Fluent on a C-type structured mesh of about 210,000 cells with the k-omega SST turbulence model at a Reynolds number of 4.8 million, which corresponds to a cruise speed of 50 m/s. For NACA 2412 the computed maximum lift coefficient is 1.58 at a stall angle of 16 degrees, the minimum drag coefficient is 0.0068 and the best lift-to-drag ratio is 104 at 6 degrees. NACA 4415 reaches a higher maximum lift coefficient of 1.71 at 14 degrees, but at the cruise lift coefficient of 0.31 its drag coefficient is 0.0081 against 0.0069 for NACA 2412.

NACA 2412 was therefore selected, and the semi-span wing box was modelled in CATIA with a main spar at 25 percent chord, a rear spar at 65 percent chord, fifteen ribs and 1.0 mm skin. A static structural analysis in ANSYS Mechanical was performed at the limit load factor of 3.8, which gives a half-wing lift of 11,183 N distributed spanwise by the Schrenk method and a root bending moment of about 21.4 kN m. Three materials were compared: aluminium alloy 2024-T3, aluminium alloy 6061-T6 and a carbon fibre reinforced polymer with unidirectional spar caps and quasi-isotropic skins.

The aluminium 2024-T3 wing box shows a tip deflection of 112 mm, a peak von Mises stress of 214 MPa at the main spar root and a factor of safety of 1.61 on yield, with a half-wing box mass of 18.4 kg. The 6061-T6 box of the same geometry deflects 119 mm but its factor of safety falls to 1.29, which is below the required 1.5. The CFRP box deflects 96 mm, has a factor of safety of 2.24 against the allowable laminate stress and weighs 11.6 kg, which is 37 percent lighter than the 2024-T3 box.

I. INTRODUCTION

The wing is the main lifting surface of an aircraft, and its design decides much of the aircraft's take-off distance, climb rate, cruise speed, stall behaviour and fuel consumption. For a light aircraft the wing must give enough lift at low speed for safe take-off and landing on short runways, while keeping drag low at cruise. These two

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

needs pull the design in different directions, and the choice of airfoil section is one of the first decisions that settles the balance between them.

The wing must also carry the lift it produces back to the fuselage. In most light aircraft the lift is carried by a wing box made of one or two spars, a set of ribs that keep the airfoil shape, and a skin that resists torsion and carries part of the bending. During a pull-up or a gust the lift can rise to several times the aircraft weight, and the root of the main spar then experiences very high bending stress. The structure has to withstand these loads with a suitable factor of safety while remaining as light as possible, since every kilogram of structure reduces payload or fuel.

Conventionally, airfoils are chosen from published section catalogues and wind-tunnel data, and the wing structure is sized with hand calculations based on simple beam theory, followed by static load tests on a prototype wing. Such tests are expensive and are usually carried out late in the design, so any weakness found at that stage leads to costly changes. Computational fluid dynamics and the finite element method now allow both the aerodynamic and the structural behaviour of a wing to be studied in detail on a computer before anything is built.

In this work the wing section of a 600 kg two-seat light aircraft is studied using such tools. Two candidate airfoils, NACA 2412 and NACA 4415, are analysed in ANSYS Fluent to obtain lift, drag, the lift curve, the stall angle and the pressure distribution. The selected airfoil is then used to build a semi-span wing box in CATIA, which is analysed in ANSYS Mechanical under the limit manoeuvre load for aluminium 2024-T3, aluminium 6061-T6 and CFRP, and the results are compared in terms of deflection, stress, factor of safety and mass.

II. LITERATURE SURVEY

The systematic study of airfoil sections began with large wind-tunnel test programmes in which families of sections were built and tested under controlled conditions. The NACA four-digit series came out of this work, and its sections are defined by a simple equation that sets the maximum camber, the position of maximum camber and the thickness as a fraction of chord. Because the shape is defined by a few parameters, the series made it possible to study the effect of camber and thickness on lift, drag and pitching moment in an orderly way. Test reports from these programmes showed that moderate camber increases maximum lift and shifts the lift curve upward, while greater thickness improves stall behaviour but raises drag at high speed. Sections such as NACA 2412 and NACA 4415 have since become standard choices for light aircraft, and their measured characteristics are still widely used as reference data for validating computer predictions.

Computational methods for airfoil analysis have developed from inviscid panel methods to coupled viscous-inviscid codes and finally to full Reynolds-averaged Navier-Stokes solvers. Panel methods with boundary-layer coupling give good predictions of lift and drag in attached flow at low cost and are often used in early design. Studies using finite volume solvers have shown that the k-omega SST turbulence model predicts the lift curve, the drag polar and the onset of trailing-edge separation of four-digit sections reasonably well, provided the mesh resolves the

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

boundary layer with y plus near one and the far-field boundary is placed far enough from the airfoil. Comparisons reported in the literature typically show agreement with wind-tunnel lift data within a few percent in the linear range, while the maximum lift and post-stall behaviour are more sensitive to the turbulence model and to transition assumptions.

Research on wing structural layout has examined the number and position of spars, the spacing of ribs, and the thickness of skin needed for light aircraft. A two-spar arrangement with the main spar near the quarter-chord and a rear spar ahead of the flaps and ailerons is common, since it forms a closed torsion box and gives a convenient attachment for control surfaces. Classical analysis treats the wing as a cantilever beam with the spanwise lift distribution obtained from lifting-line theory or from the Schrenk approximation, which averages the planform shape and an elliptical distribution. Studies have shown that this approach gives root bending moments close to those from more detailed methods for straight wings, and it remains a standard basis for preliminary sizing of spar caps and webs in certification calculations.

Finite element analysis of wing boxes has been reported in many studies, using shell elements for skins, spar webs and ribs and beam or shell elements for spar caps and stringers. These studies show that peak stresses occur at the main spar root and around cut-outs, and that skin panels between ribs can buckle under compression on the upper surface well before material yield is reached. Modal analyses have also been reported, since the first bending and torsion frequencies of the wing influence flutter margins. Comparisons with static load tests on light aircraft wings indicate that well-built finite element models predict tip deflection within about five to ten percent, which is sufficient for design decisions when combined with an appropriate factor of safety.

Material studies for light aircraft wings have compared aluminium alloys and fibre reinforced composites. Aluminium 2024-T3 is widely used for its high strength and good fatigue behaviour, while 6061-T6 is easier to weld and cheaper but has lower strength. Carbon fibre reinforced polymers offer high specific stiffness and strength, and studies on composite wing boxes report mass savings of thirty to forty percent compared with aluminium, together with better corrosion resistance. Disadvantages reported include higher material and tooling cost, sensitivity to impact damage and more complex inspection. The literature therefore suggests that airfoil selection and structural material selection should be evaluated together, using aerodynamic loads from CFD as input to the structural model, which is the approach adopted in the present work.

III. SYSTEM ANALYSIS

The problem considered is the design of the wing section for a two-seat light aircraft with a maximum take-off mass of 600 kg, a rectangular wing of 9.0 m span and 1.4 m chord, and a cruise speed of 50 m/s at sea level. The cruise lift coefficient needed to support the weight is about 0.31, and the aircraft must stall at no more than about 80 km/h with flaps retracted, which requires a maximum section lift coefficient of at least 1.5. The airfoil should give low drag at the cruise lift coefficient, gentle stall behaviour and a small nose-down pitching moment so that tail loads remain modest. The wing structure must carry a limit load factor of 3.8, which corresponds to a half-

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

wing lift of 11,183 N, with a factor of safety of at least 1.5 on material yield or allowable stress. The tip deflection at limit load should not exceed about 3 percent of the semi-span of 4.5 m, and the wing box mass should be kept as low as possible.

Existing System

In conventional practice the designer of a light aircraft wing selects an airfoil from published catalogues of wind-tunnel data, often choosing a section that has been used successfully on similar aircraft. Lift and drag at the actual Reynolds number are estimated from charts by interpolation, and three-dimensional effects are added with empirical corrections. When a new or modified section is considered, wind-tunnel tests on a scale model are needed, which take time and suffer from Reynolds number differences between model and full scale. The structure is sized with hand calculations in which the wing is treated as a simple cantilever beam, and spar caps, webs and skins are given thicknesses that satisfy bending and shear stress limits with generous margins. The final check is a static load test of a complete prototype wing loaded with sandbags or hydraulic jacks to the ultimate load. Problems found at this stage, such as local buckling or excessive deflection, require redesign and another test article, which adds cost and delay.

Disadvantages of Existing System

- Airfoil data at the exact flight Reynolds number are often not available in catalogues.
- Scale-model wind-tunnel tests are costly and suffer from Reynolds number mismatch.
- The pressure distribution over the chord is not visible without a pressure-tapped model.
- Stall angle and post-stall behaviour are hard to predict from interpolated chart data.
- Hand calculations treat the wing box as a simple beam and ignore skin and rib interaction.
- Local stress concentrations at the spar root and rib joints are not identified.
- Skin buckling between ribs is often discovered only during the prototype load test.
- Comparing different structural materials needs several prototype wing boxes.
- Generous safety margins used to cover uncertainty make the structure heavier than needed.
- Design changes after a failed static test cause long delays and high cost.

Proposed System

The proposed approach uses a CAD and simulation workflow that studies the aerodynamic and structural behaviour of the wing in two parallel branches which then meet at a common design evaluation. In the aerodynamic branch, the NACA 2412 and NACA 4415 coordinates are generated, a C-type structured mesh of about 210,000 cells is built around each airfoil with y plus below one, and ANSYS Fluent with the k-omega SST model is run at a Reynolds number of 4.8 million for angles of attack from minus 4 to 18 degrees. Lift, drag and pitching moment coefficients, the lift curve,

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

the stall angle and the pressure coefficient distribution are extracted. In the structural branch, the selected airfoil is used to build a semi-span wing box in CATIA with two spars, fifteen ribs and skin, which is meshed with shell elements in ANSYS Mechanical. The Schrenk lift distribution at the limit load factor of 3.8 is applied, and deflection, von Mises stress, factor of safety, buckling load factor and mass are found for aluminium 2024-T3, aluminium 6061-T6 and CFRP.

Advantages of Proposed System

- Lift, drag and moment coefficients are obtained at the actual flight Reynolds number.
- The full lift curve, including the stall angle, is predicted before any model is built.
- Pressure coefficient and velocity fields show where the flow accelerates and separates.
- Two or more airfoils can be compared on equal terms in a short time.
- The wing box is modelled with real spars, ribs and skin rather than a simple beam.
- Peak stresses at the spar root and around rib joints are located precisely.
- Skin panel buckling can be checked with an eigenvalue analysis before testing.
- Several materials are compared on the same geometry and the same lift loading.
- Structural mass can be reduced because margins are based on calculated stresses.
- Only the final configuration needs a physical static load test.

IV. METHODOLOGY

The methodology begins with the definition of the aircraft data: a maximum take-off mass of 600 kg, a wing of 9.0 m span and 1.4 m chord, a cruise speed of 50 m/s and a limit load factor of 3.8. The coordinates of NACA 2412 and NACA 4415 are generated from the four-digit equations and imported into the meshing tool, where a C-type domain extending 20 chords from the airfoil is meshed with about 210,000 quadrilateral cells and a first cell height that gives y plus below one. ANSYS Fluent with the k-omega SST model and a velocity inlet of 50 m/s is solved for angles of attack from minus 4 to 18 degrees, and lift, drag, moment and pressure coefficients are recorded. The airfoil with the lower drag at the cruise lift coefficient and adequate maximum lift is selected. Its profile is used in CATIA to model the semi-span wing box, which is meshed in ANSYS Mechanical with shell elements, fixed at the root and loaded by the Schrenk distribution. Static structural, linear buckling and modal analyses are carried out for each material and the results are compared.

SYSTEM ARCHITECTURE

The workflow is arranged as two parallel branches that start from common aircraft data and meet at the design evaluation stage. The Aircraft Data block holds the mass, wing geometry, cruise speed and load factor. The aerodynamic branch begins with Airfoil Coordinates for NACA 2412 and NACA 4415, followed by C-Mesh Generation and the ANSYS Fluent k-omega SST solver, which produces the lift and

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

drag polar, the Cl versus alpha curve, the stall angle and the pressure distribution. The Airfoil Selection block compares the two sections at the cruise lift coefficient and passes the chosen profile to the structural branch. The structural branch starts with the CATIA Wing Box Model containing the main spar, rear spar, ribs and skin, followed by shell meshing in ANSYS Mechanical, application of the Schrenk lift load at a load factor of 3.8 and the root fixed support. Static structural, buckling and modal solutions give deflection, stress and frequency for aluminium 2024-T3, aluminium 6061-T6 and CFRP. The Design Evaluation block compares factor of safety, deflection and mass and gives the recommended airfoil and material.

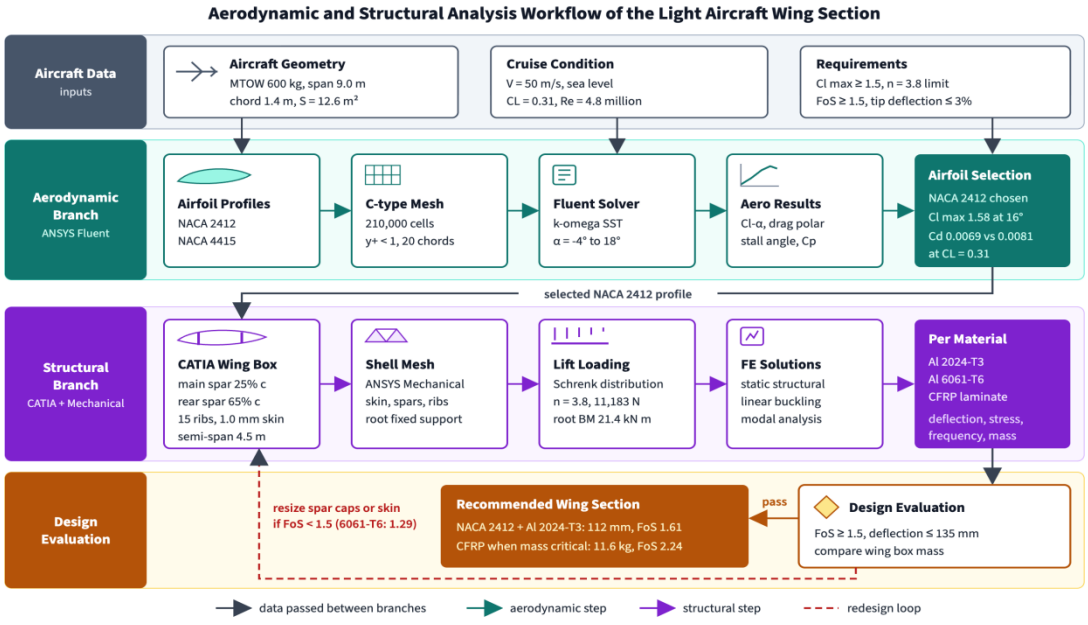


Fig. 1 System Architecture

V. RESULT AND OUTPUT

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

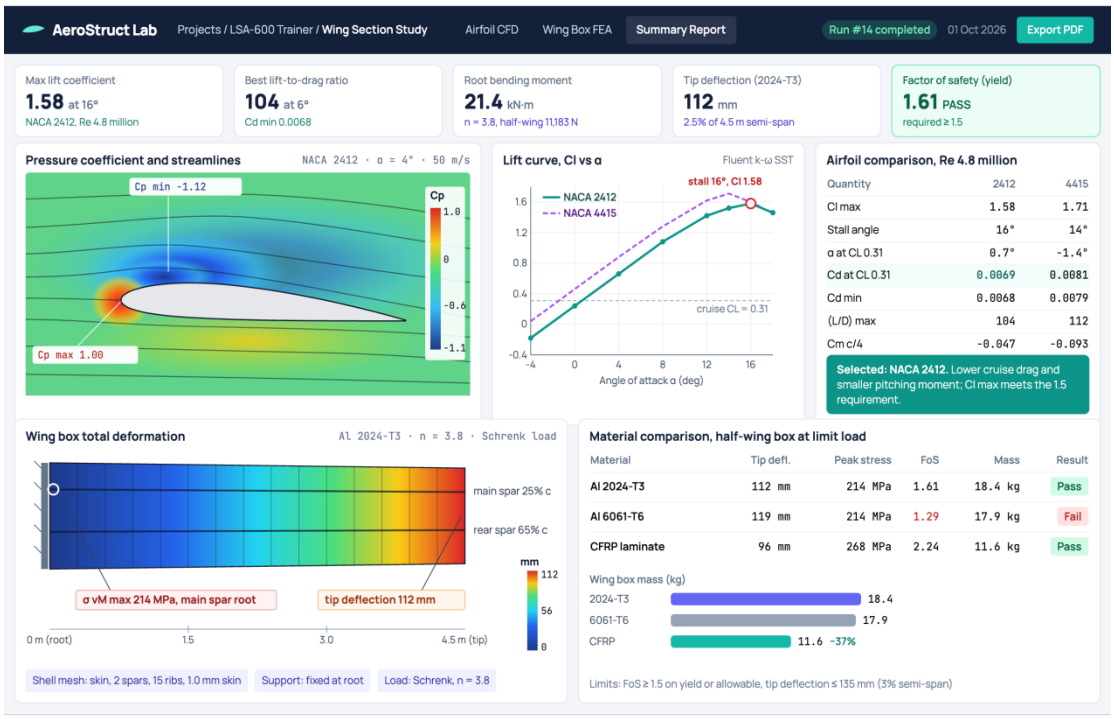


Fig. 2 Result and Output Screen

VI. CONCLUSION

The wing section of a 600 kg two-seat light aircraft has been studied through airfoil CFD in ANSYS Fluent and wing box structural analysis in ANSYS Mechanical, with the geometry modelled in CATIA. The combined workflow allowed both the aerodynamic section and the structural material to be chosen on the basis of calculated results rather than catalogue interpolation and prototype testing alone.

The CFD results at a Reynolds number of 4.8 million showed that NACA 2412 reaches a maximum lift coefficient of 1.58 at a stall angle of 16 degrees and a best lift-to-drag ratio of 104, while NACA 4415 gives a higher maximum lift of 1.71 but more drag at the cruise lift coefficient of 0.31 and a larger nose-down pitching moment. Since NACA 2412 meets the stall speed requirement with lower cruise drag, it was selected for the wing.

The structural results at the limit load factor of 3.8 showed that the aluminium 2024-T3 wing box has a tip deflection of 112 mm, a peak stress of 214 MPa and a factor of safety of 1.61, which satisfies the requirement of 1.5 with a half-wing box mass of 18.4 kg. The 6061-T6 box of the same geometry did not meet the requirement, with a factor of safety of 1.29. The CFRP box gave the lowest deflection of 96 mm, a factor of safety of 2.24 and a mass of 11.6 kg, a saving of 37 percent. Aluminium 2024-T3 is recommended for a training aircraft, with CFRP preferred when mass is critical.

Future work will include a three-dimensional CFD study of the complete wing with flaps and ailerons to capture tip vortex and spanwise flow effects, a flutter analysis that couples the wing modes with unsteady aerodynamics, optimisation of spar cap and skin thickness along the span, and a static load test of a wing box specimen to validate the predicted deflection and strain values.

International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

REFERENCES

[1] Kumar, R. D., Prudhviraj, G., Vijay, K., Kumar, P. S., & Plugmann, P. (2024). Exploring COVID-19 through intensive investigation with supervised machine learning algorithm. In Handbook of Artificial Intelligence and Wearables (pp. 145-158). CRC Press.
[2] Swathi, B., Vijay, K., Sushanth Babu, M., & Dinesh Kumar, R. (2024, November). Machine Learning Techniques in Cloud Based Intrusion Detection. In The International Conference on Artificial Intelligence and Smart Environment (pp. 557-564). Cham: Springer Nature Switzerland.
[3] Sv satyakrishna, shirisha rangu, bhargavi nalacheruve. (2024) Prospective investigation on colorectal cancer with SMOTE on machine learning Algorithm
[4] Dr.G.Vishnu Murthy, BhargaviNalacheruve 1Professor, Department of computer Science & engineering, Anurag University, TS, India. 2Student, Department of computer Science & engineering, Anurag University, TS, India.
[5] V. N. S. Manaswini, K. K, C. Nigam, S. S. Ali, R. Niranjana, and Suman, "Real-Time Object Detection in Drone Surveillance Using YOLOv5," in Proc. 2025 3rd Int. Conf. IoT, Communication and Automation Technology (ICICAT), Gorakhpur, India, 2025, pp. 1–6, doi: 10.1109/ICICAT68430.2025.11414670.
[6] B. Soundarya, V. N. S. Manaswini, M. Ayyakrishnan, R. D. Kumar, "Contextual Analysis of Big Data Analytics in Intelligent Transportation Frameworks," in Intersection of Artificial Intelligence, Data Science, and Cutting-Edge Technologies: From Concepts to Applications in Smart Environment, Lecture Notes in Networks and Systems, vol. 1353, Cham: Springer, 2025, doi: 10.1007/978-3-031-88304-0_79.
[7] R. D. Kumar, V. N. S. Manaswini, "Applications of blockchain in smart cities: detecting fake documents from land records using blockchain technology," in Blockchain for Smart Cities, Elsevier, 2021, pp. 105–117, doi: 10.1016/B978-0-12-824446-3.00017-X.
[8] Tejavath Veeramma, Badarla Anil, Guguloth Ravinder, "An advanced movie recommender using collaborative filtering and sentiment analysis," International Research Journal of Modernization in Engineering Technology and Science, vol. 7, no. 7, July 2025, doi: 10.56726/IRJMETS81618.
[9] Ravi Kumar Banoth, Ramana Murthy B V, "Automatic crop recommendation system using LightGBM and decision tree machine learning models," Journal of Machine and Computing, vol. 5, no. 1, pp. 343, Jan. 2025, doi: 10.53759/7669/jmc202505026.
[10] Ravi Kumar Banoth, Dr. B.V. Ramana Murthy, "Smart agriculture through IoT and machine learning for analyzing carbon footprints," in Proc. Int. Conf. Computer Science and Communication Engineering (ICCSCE), Apr. 2025.
[11] Ravi Kumar Banoth, B. V. Ramana Murthy, "Soil image classification using transfer learning approach: MobileNetV2 with CNN," SN Computer Science, vol. 5, art. no. 199, 2024, doi: 10.1007/s42979-023-02500-x.