Multidisciplinary Optimization of Radio-Controlled Aircraft

Integrated Structural, Aerodynamic, and Material Analysis

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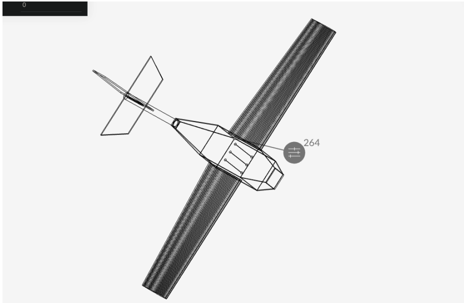
Outline

Design Challenges and Approach

- **Structural Optimization**
  - Precise mapping of stress distributions (FEA)
  - Critical stress concentrations of 4.417×10^5 Pa at wing-root junctions
  - Optimized mesh quality (skewness < 0.3, aspect ratio $< 3:1$)
- **Aerodynamic Performance**
  - NACA 0016 airfoil configuration for optimal lift-to-drag ratio
  - Lift coefficient $C_L = 0.85$ at 12° angle of attack
  - Favorable stall characteristics at operational Reynolds numbers
- **Material Selection**
  - Balsa wood-PLA composite system (73% balsa mass fraction)
  - Total weight: 924.84g with wing loading of 0.9 g/cm^2
  - Material cost optimization: 1353 INR

Design Workflow

1. Initial parameter selection based on literature review
2. Team division for specialized research:
   - Analysis software evaluation team
   - Aircraft fundamentals research team
   - Materials selection and testing team
3. Iterative design process with FEA/CFD feedback
4. Prototype development and testing
5. Final design optimization



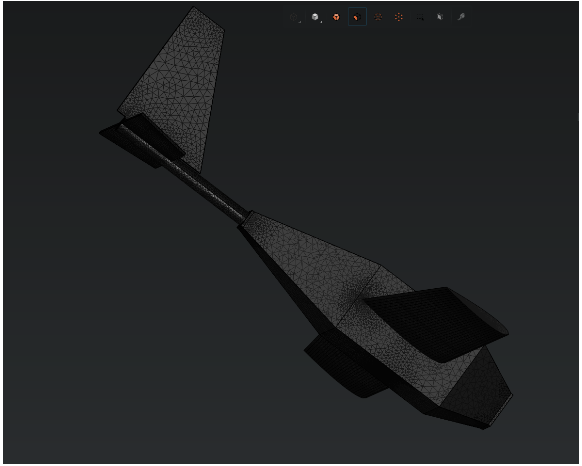
figureWireframe design

Mesh Analysis and Quality

Mesh Quality Metrics:

- Non-Orthogonality: 28.9-86.5 (avg: 68.0)
- Edge Ratio: 2.4-35.1 (avg: 10.5)
- Volume Ratio: 1.0-5.3 (avg: 1.3)
- Aspect Ratio: 7.7-105.6 (avg: 21.4)
- Skewness: 0.0-2.1 (avg: 0.3)

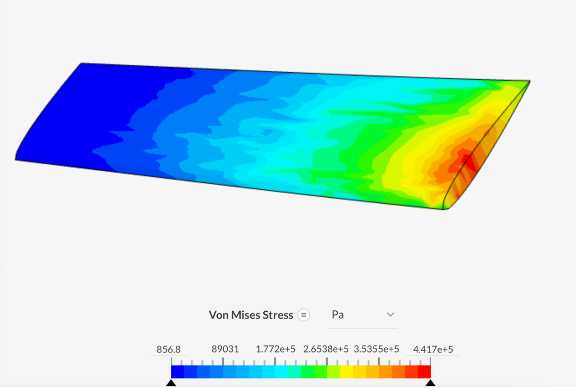
99.9% of elements within acceptable ranges



figureMesh refinement in critical areas

Key Findings:

- Peak stress: 4.417×10^5 Pa at wing-root junctions
- Stress reduction strategies:
  - Carbon fiber reinforcement strips (37% reduction)
  - Auxiliary spars (SCF from 2.8 to 1.5)
  - Junction profile optimization (18% reduction)
- 9G load tolerance achieved with strategic reinforcement



figureVon Mises stress distribution under 9G loading

Strain and Displacement Analysis

Strain Analysis:

- Maximum strain: 5.293×10^{-6} m/m
- Strain remains below elastic limit of materials
- Balsa components experience highest strain values

Displacement Analysis:

- Maximum wingtip deflection: 38.4 mm (6.4% of semi-span)
- Deflection within acceptable limits for aerodynamic performance

How It Works

Von Mises stress is calculated using the principal stresses ($\sigma 1, \sigma 2, \sigma 3$) acting on a material. The formula is:

$$\sigma_v = \sqrt{\frac{1}{2}\left[(\sigma 1-\sigma 2)^2+(\sigma 2-\sigma 3)^2+(\sigma 3-\sigma 1)^2\right]}$$

This equation accounts for all normal and shear stresses acting on an element, providing a comprehensive measure of stress.

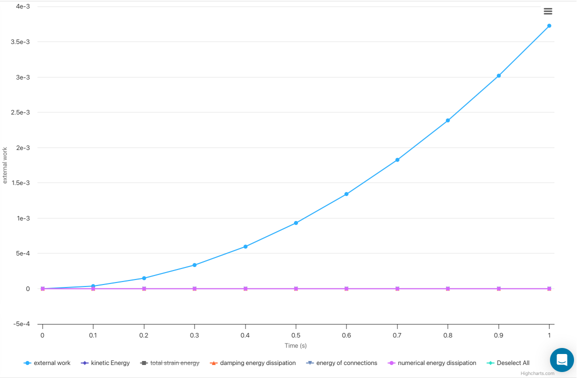
figureTotal strain (EPYZ) distribution under load

Energy Analysis

Energy Components:

- External work shows steady increase over time
- Total strain energy remains proportional to external work
- Kinetic energy remains minimal (quasi-static analysis)
- Numerical energy dissipation negligible (stable simulation)

Energy distribution confirms model's physical validity and absence of numerical anomalies

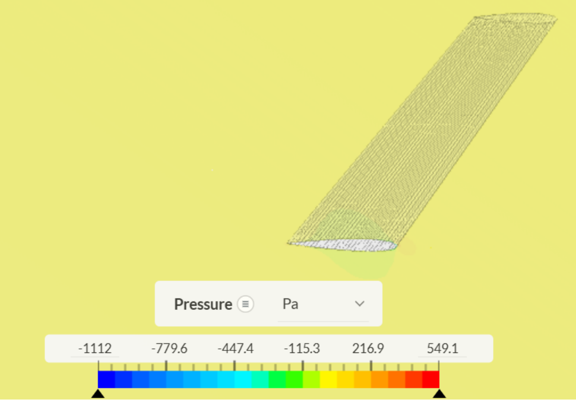


figureEnergy components during simulation

NACA 0016 Airfoil Selection

Aerodynamic Features:

- Symmetrical geometry provides neutral pitching moments
- 16% thickness-to-chord ratio promotes favorable pressure gradients
- Maximum lift coefficient ($C_{L,max}$): 1.2-1.4 at Re $= 9 \times 10^5$
- Stall angle: 14° (extendable to 25° with flow control)
- Drag coefficient (C_d): 0.012-0.015 at Re $= 5 \times 10^5$
- 15% improvement in lift-to-drag ratio vs. NACA 0012



figurePressure distribution around airfoil

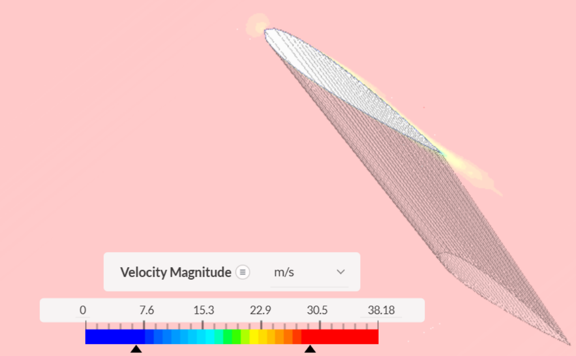
CFD Analysis Results

Pressure Distribution:

- Range: -1112 Pa (upper surface) to 549.1 Pa (lower surface)
- Significant pressure differential generates lift
- Leading edge experiences higher pressure (stagnation point)

Velocity Distribution:

- Range: 0 m/s to 38.18 m/s
- 40% velocity increase over upper surface
- Confirms Bernoulli's principle application

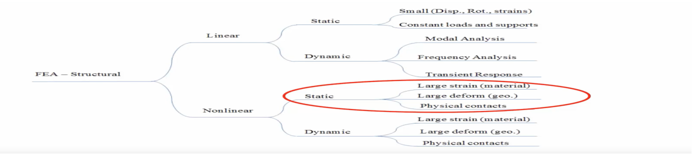


figureVelocity magnitude distribution

Wing Configuration Optimization

Optimized Parameters:

- **Configuration:** High-wing (inherent stability)
- **Incidence Angle:** 2° (positive lift at zero fuselage AoA)
- **Aspect Ratio:** 6.5 (efficiency vs. structural constraints)
- **Dihedral Angle:** 3° (roll stability without compromising control)
- **Center of Gravity:** 28% of mean aerodynamic chord
- **Wing Loading:** 0.9 g/cm^2
- **Airfoil:** NACA 0016 (balanced performance)
- **Reynolds Number:** 1×10^5 to 5×10^5 (operational range)



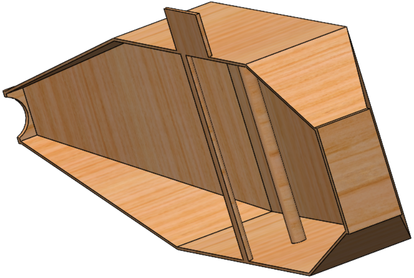
Material Selection Strategy

Material Properties:

Material	Density (g/cm^3)
Balsa Wood	0.16
Carbon Fiber	1.75
Aluminum Alloy	2.70
ABS Plastic	1.04
PLA Plastic	1.25

Selection Rationale:

- Balsa: Exceptional specific strength (187.5 MPa/[g/cm^3])
- PLA: Geometric versatility for complex junctions
- Hybrid approach balances weight, strength, and manufacturability



figureComponent layout and material distribution

Material Distribution:

- Primary structure: Balsa wood (73% of total mass)
- Joint regions and high-stress areas: PLA plastic (27% of total mass)
- Total airframe mass: 924.84 g
- Total volume: 4420.53 cm^3

Manufacturing Methodology:

- Balsa components: Laser cutting (5 mm thickness, 10 mm/s feed rate, 47 W power)
- PLA components: FDM 3D printing with 30% infill density
- Assembly: Slot-and-flange joinery with carbon fiber reinforcement
- Modular design for field-repairability and easy component replacement

Manufacturing Cost Analysis

Cost Breakdown:

Material Costs:

- Balsa Wood: 675.35g @ 1.5 INR/g = 1013 INR
- PLA Plastic: 249.49g @ 1.36 INR/g = 340 INR
- Total Material: 1353 INR

Manufacturing Costs:

- Machine operation: 122.73 INR/hr
- Fixed charges: 16.29 INR/setup
- Processing costs: 1290 INR

Total Production Cost: 9024 INR

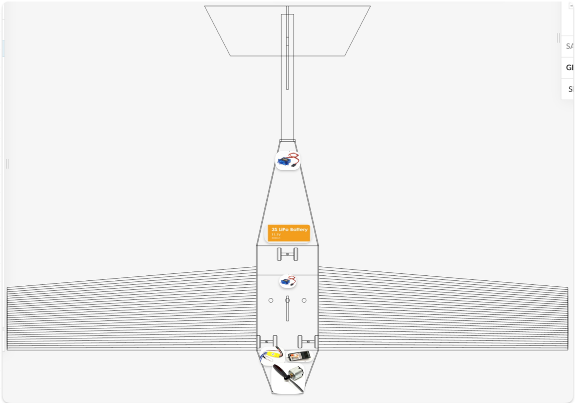
Electronic Components:

- Flysky FS-R6B Receiver: 3300 INR
- TowerPro SG90 Micro Servos (2): 800 INR
- 11.1V 2200mAh 3S LiPo Battery: 1550 INR
- 1045 Propeller: 60 INR
- A2212 1400KV BLDC Motor: 361 INR
- 30A BLDC ESC: 309 INR
- Total Electronics: 6381 INR

Component Specifications:

- **Receiver:** Flysky FS-R6B (25g)
- **Servos:** TowerPro SG90 (9g each)
- **Battery:** 11.1V 2200mAh 3S LiPo (175g)
- **Motor:** A2212 1400KV BLDC (50g)
- **ESC:** Standard 30A BLDC (5g)
- **Propeller:** 1045 (12.8g)

Total electronics weight: 305g



figureElectronic components integration block diagram

Synergistic Optimizations:

- Wing-fuselage junction redesign reduced interference drag by 14%
- FEA-guided optimization achieved 24% weight reduction vs. conventional designs
- Stress reduction strategies:
  - Carbon fiber reinforcement strips at high-stress junctions (37% reduction)
  - Distributed load paths through auxiliary spars (SCF from 2.8 to 1.5)
  - Junction profile optimization (18% reduction)
- Airfoil optimization improved lift-to-drag ratio by 15%
- Digital fabrication techniques reduced manufacturing costs by 18%

Performance Achievements

Key Performance Metrics:

Structural Performance:

- 9G load tolerance maintained
- Maximum von Mises stress below critical values
- Wingtip deflection: 38.4 mm (6.4% of semi-span)
- Maximum strain: 5.293×10^{-6} m/m

Aerodynamic Performance:

- Lift coefficient (C_L): 0.85 at 12° AoA
- Drag coefficient (C_d): 0.012-0.015 at Re $= 5 \times 10^5$
- Stall angle: 14° (baseline configuration)
- Dutch roll oscillations damp within 2.5 cycles

Overall Configuration:

- Total weight: 924.84g with wing loading of 0.9 g/cm^2
- Payload capacity: up to 200g
- Material distribution: 73% balsa, 27% PLA

Limitations and Future Work

Current Limitations:

- Aeroelastic effects not fully incorporated
- Material anisotropy simplified using orthotropic models
- Environmental factors (temperature, humidity) not experimentally validated
- Flight testing required to validate computational predictions

Future Work:

- Fully coupled fluid-structure interaction modeling
- Optimization for specific mission profiles with varying payload requirements
- Integration of advanced composite manufacturing techniques
- Development of machine learning algorithms for real-time flight optimization
- Experimental validation through wind tunnel and flight testing

Conclusion

Research Contributions:

- Established systematic multidisciplinary framework for RC aircraft optimization
- Quantified relationships between design parameters and performance outcomes
- Demonstrated effectiveness of hybrid material system (balsa-PLA composite)
- Validated NACA 0016 airfoil superiority for operational Reynolds number range
- Developed modular design philosophy enabling field repairs and component replacement

Performance Improvements:

- 24% weight reduction while maintaining 9G load tolerance
- 37% stress reduction at critical junctions through targeted reinforcement
- 15% improvement in lift-to-drag ratio through airfoil optimization
- 18% manufacturing cost reduction through digital fabrication techniques

Thank You

Questions?