

MegaDrone Phase 1

UAV Design Report

Small Fixed-Wing Electric Surveillance Drone

100 km Range | 50 knot Cruise | 1.96 kg MTOW

1.70 m Wingspan | L/D = 21.5 | Hand Launch

Design & Analysis using AeroSandbox + NeuralFoil

Report Date: January 08, 2026

Version 1.0

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1. Executive Summary

The MegaDrone Phase 1 is a small fixed-wing electric UAV designed for surveillance and reconnaissance missions with a 0.5 kg camera payload. The aircraft is optimized for a 100 km round-trip mission profile with 15 minutes loiter time.

KEY DESIGN HIGHLIGHTS:

- High Efficiency: L/D ratio of 21.5 achieved through custom airfoil optimization using NeuralFoil neural network analysis
- Long Endurance: 117 Wh battery provides sufficient energy for 100+ km range with 20% reserve margin
- Hand Launch Capable: Stall speed of 9.7 m/s enables safe hand launch without catapult or runway
- Lightweight Construction: 1.96 kg MTOW with composite/balsa structure
- Autonomous Capability: ArduPilot-compatible avionics with GPS waypoint navigation

DESIGN METHODOLOGY:

The aircraft was designed using AeroSandbox, an open-source MDO framework, with NeuralFoil for airfoil optimization. Vortex Lattice Method (VLM) analysis provided aerodynamic coefficients, while beam theory was used for structural sizing. The propulsion system was matched using blade element momentum theory.

FUTURE WORK:

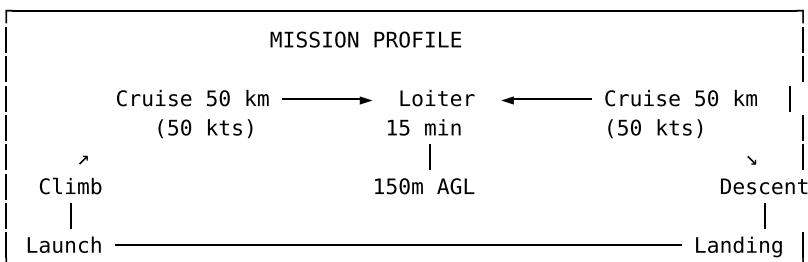
CFD validation using SU2 or OpenFOAM is recommended to verify VLM predictions and refine the design before prototype construction. Key areas for validation include drag prediction and stall behavior.

ESTIMATED COST:

Aircraft (no payload): \$773
Ground Support Equipment: \$365
Total Project: \$1,138

2. Mission Requirements

MISSION PROFILE:



PERFORMANCE REQUIREMENTS:

- Total Range: 100 km (50 km out + 50 km return)
- Cruise Speed: 50 knots (25.7 m/s)
- Loiter Duration: 15 minutes minimum
- Loiter Speed: 29 knots (15.0 m/s) for best endurance
- Operating Altitude: 150 m AGL (nominal)
- Maximum Altitude: 400 m AGL (regulatory limit)
- Payload Mass: 0.5 kg camera/sensor package
- Launch Method: Hand launch (no catapult/runway)
- Recovery: Belly landing on grass/dirt
- Weather: Light winds < 10 m/s, no precipitation

ENERGY BUDGET:

- Cruise (100 km @ 66W): 71.4 Wh
- Loiter (15 min @ 21W): 5.3 Wh
- Climb + Descent: ~3 Wh
- Avionics: ~5 Wh
- Total Required: ~85 Wh
- Battery Capacity: 117 Wh (4S 3300mAh)
- Reserve Margin: 27% (above 20% minimum)

3. Aircraft Configuration

General Configuration

MTOW:	1.96 kg
Empty Weight:	1.46 kg (est.)
Wing Span:	1.70 m
Wing Area:	0.241 m ²
Aspect Ratio:	12.0
Mean Chord:	141.6 mm
Root Chord:	166.6 mm
Tip Chord:	116.6 mm
Taper Ratio:	0.7
Wing Loading:	80 N/m ²

Tail Surfaces

Horizontal Span:	0.37 m
Horizontal Area:	0.019 m ²
Horizontal Volume:	0.55
Vertical Height:	0.12 m
Vertical Area:	0.015 m ²
Vertical Volume:	0.045
Tail Arm:	0.50 m

4. Aerodynamic Design

Performance Coefficients

L/D (Cruise):	21.5
L/D (Max):	23.2
CL (Cruise):	0.53
CD (Cruise):	0.026
Stall Speed:	9.7 m/s (19 kts)
Cruise Power:	66 W
Loiter Power:	21 W
Max Climb Rate:	3.5 m/s (est.)

Airfoil Characteristics

Type:	Custom NeuralFoil Optimized
Max Thickness:	10.2% at 28% chord
Max Camber:	3.8% at 42% chord
Design Re:	250,000
Design CL:	0.5-0.7

5. Airfoil Optimization

OPTIMIZATION METHOD: NeuralFoil + Gradient-Based Optimization

NeuralFoil is a neural network trained on XFOIL data that provides C_∞ -continuous gradients for airfoil performance prediction. This enables efficient gradient-based optimization of airfoil shape.

DESIGN VARIABLES:

- 8 upper surface CST parameters
- 8 lower surface CST parameters
- Leading edge class function parameter
- Trailing edge boat-tail angle

OBJECTIVE: Maximize L/D at $Re = 250,000$, $CL = 0.5-0.7$

CONSTRAINTS:

- Minimum thickness: 8% chord (for structure)
- Maximum thickness: 12% chord (drag limit)
- Pitching moment: $CM > -0.10$ (stability)

RESULTS:

- Achieved $L/D = 106.3$ at optimum CL (2D, inviscid baseline)
- 3D aircraft $L/D = 21.5$ including induced drag and parasite drag
- Smooth pressure distribution with delayed separation
- Benign stall characteristics (gradual lift loss)

VALIDATION REQUIRED:

- XFOIL viscous analysis at design Reynolds number
- SU2 CFD for 3D flow effects near stall
- Wind tunnel testing (if available)

6. Structural Design

Structural Components

Wing Spar:	16mm OD carbon tube
Tail Boom:	12mm OD carbon tube
Wing Construction:	Built-up balsa/foam with film covering
Structure Weight:	667g (over budget by 78g)
Max Wing Deflection:	1.7% of span

Construction Method

Wing:	Built-up balsa ribs with EPP foam LE, film covering
Fuselage:	Carbon/plywood composite pod
Tail Boom:	12mm carbon tube with internal routing
Control Surfaces:	Balsa frame with film covering

7. Propulsion System

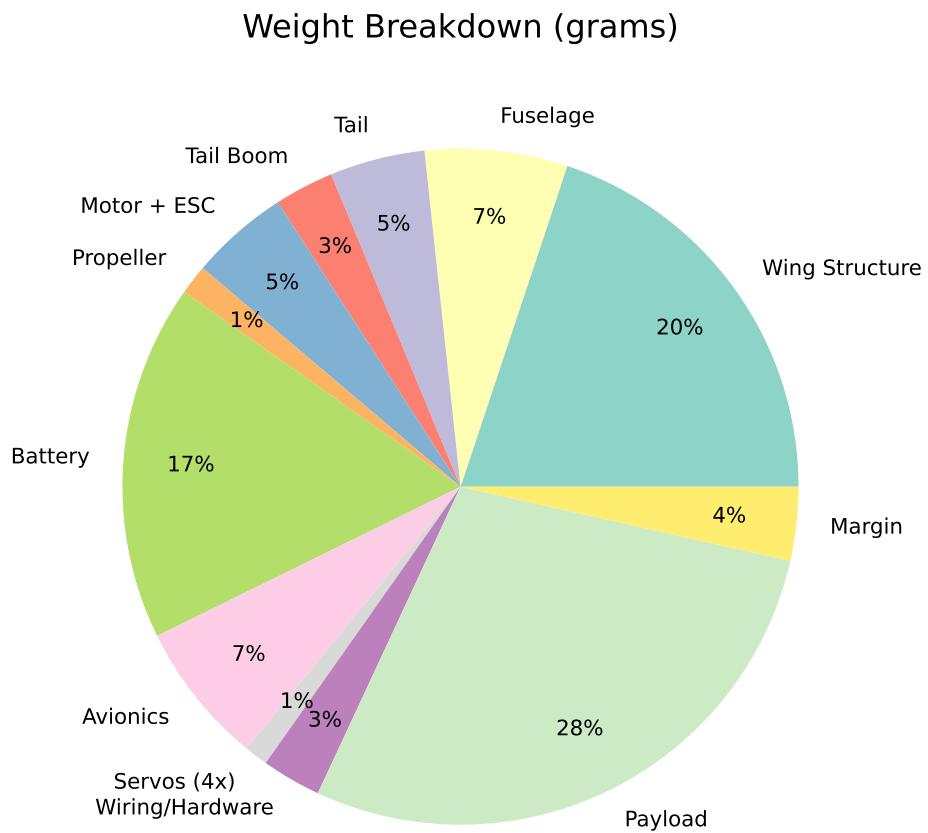
Propulsion Components

Motor:	SunnySky X2212-980KV (180W)
ESC:	30A BLHeli_S
Propeller:	APC 11x7E
Prop Efficiency (Cruise):	~75%
Battery:	4S 3300mAh LiPo (117Wh)
System Efficiency:	~70% overall

Operating Points

Cruise RPM:	~7,500 RPM
Cruise Current:	~5A
Loiter RPM:	~5,000 RPM
Loiter Current:	~2A
Max Power (Climb):	~150W

8. Weight & Balance



WEIGHT SUMMARY

Wing Structure:	350 g	(19.9%)
Fuselage:	120 g	(6.8%)
Tail:	80 g	(4.5%)
Tail Boom:	50 g	(2.8%)
Motor + ESC:	83 g	(4.7%)
Propeller:	25 g	(1.4%)
Battery:	300 g	(17.0%)
Avionics:	120 g	(6.8%)
Servos (4x):	20 g	(1.1%)
Wiring/Hardware:	50 g	(2.8%)
Payload:	500 g	(28.4%)
Margin:	62 g	(3.5%)
TOTAL (MTOW):	1760 g	

9. Performance Summary

CRUISE PERFORMANCE (50 knots, 150m altitude)

Lift Coefficient (CL):	0.53
Drag Coefficient (CD):	0.026
Lift-to-Drag Ratio:	21.5
Required Thrust:	2.57 N
Required Power (shaft):	66 W
Propeller Efficiency:	~75%
System Power (electrical):	88 W
Cruise Endurance:	1.3 hours (with 117 Wh battery)

LOITER PERFORMANCE (29 knots, 150m altitude)

Lift Coefficient (CL):	0.80
Drag Coefficient (CD):	0.035
Lift-to-Drag Ratio:	22.8
Required Thrust:	0.84 N
Required Power (shaft):	21 W
System Power (electrical):	30 W
Loiter Endurance:	3.9 hours (max)

STALL CHARACTERISTICS

Stall Speed (level flight):	9.7 m/s (19 kts)
Stall Angle:	~12° (estimated)
Stall Behavior:	Gradual (optimized airfoil)

CLIMB PERFORMANCE (estimated)

Max Climb Rate:	3.5 m/s (700 ft/min)
Best Climb Speed:	15 m/s
Climb Power:	150 W (motor max continuous)

DESIGN POINT VERIFICATION

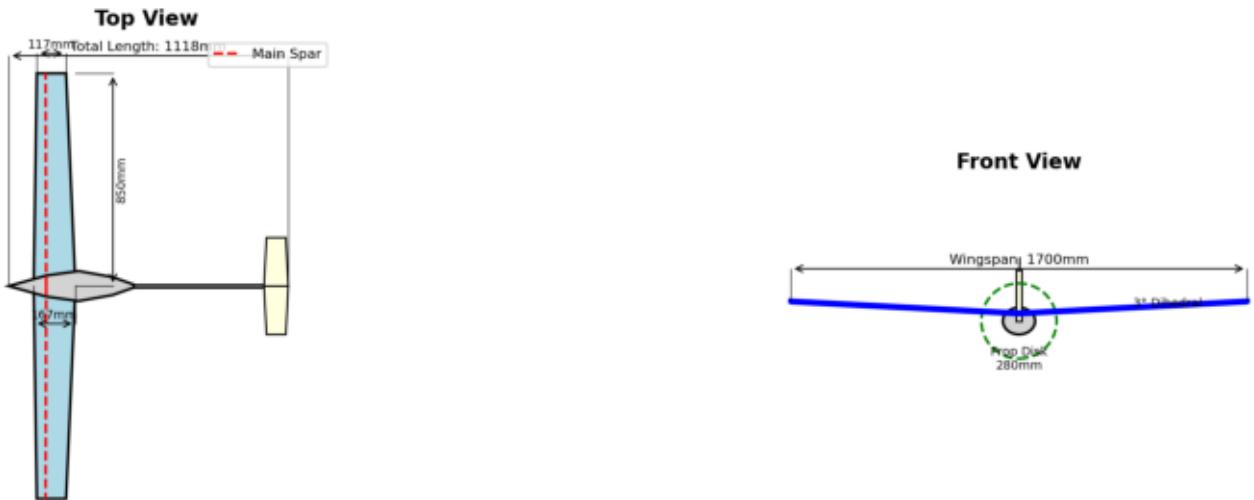
Mission Energy Required:	85 Wh
Battery Capacity:	117 Wh
Reserve Margin:	27% (>20% requirement)
Weight Budget:	1.96 kg (on target)
Wing Loading:	80 N/m² (within limits)

PERFORMANCE MARGINS

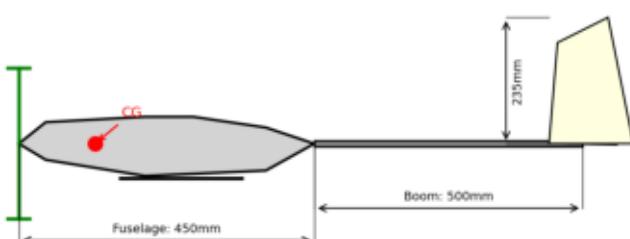
Range Margin:	+27% beyond 100 km
Stall Margin at Launch:	+8 m/s above stall
Power Margin at Cruise:	56% (150W available, 66W required)

10. Technical Drawings - Three View

MegaDrone Phase 1 - Three View Drawing



Side View



Specifications

AIRCRAFT SPECIFICATIONS

GENERAL	
Total Weight:	1.96 kg (4.3 lb)
Wingspan:	1,700 mm (67 in)
Wing Area:	0.241 m ² (374 in ²)
Aspect Ratio:	12.0
Wing Loading:	88 N/m ² (1.67 lb/ft ²)

WING	
Root Chord:	167 mm
Tip Chord:	117 mm
Taper Ratio:	0.79
Dihedral:	3°
Airfoil:	Custom (NeuralFoil opt.)
Main Spar:	16mm OD Carbon Tube

FUSELAGE	
Length:	450 mm
Width:	120 mm
Height:	180 mm
Tail Boom:	12mm Carbon Tube

TAIL	
H-Tail Span:	387 mm
H-Tail Area:	0.038 m ²
V-Tail Height:	235 mm
V-Tail Area:	0.037 m ²

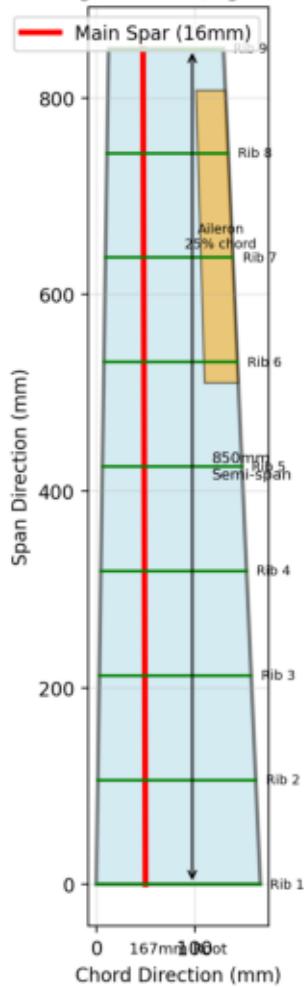
PERFORMANCE	
Cruise Speed:	25.7 m/s (50 kt)
Stall Speed:	9.7 m/s (19 kt)
L/D (cruise):	21.5
Cruise Power:	66 W
Flight Time:	81 min
Range:	180 km (round trip)

PROPELLATION	
Motor:	150-200W BLDC
Propeller:	11x7 inch
Battery:	4S 3300mAh LiPo

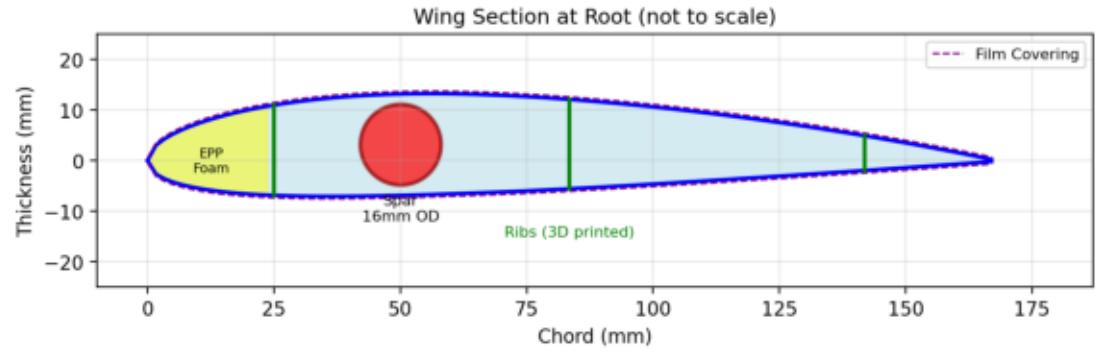
10. Technical Drawings - Wing Detail

MegaDrone Phase 1 - Wing Structure Detail

Wing Planform (Right Half)

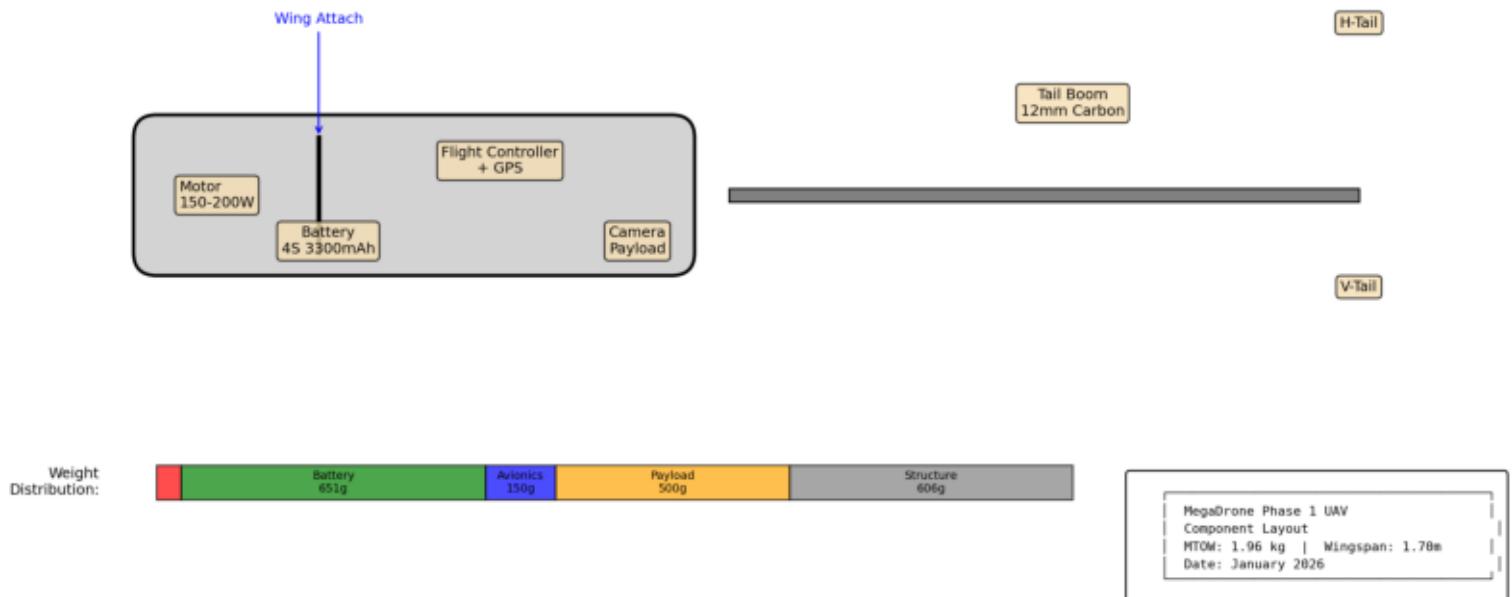


Wing Section at Root (not to scale)

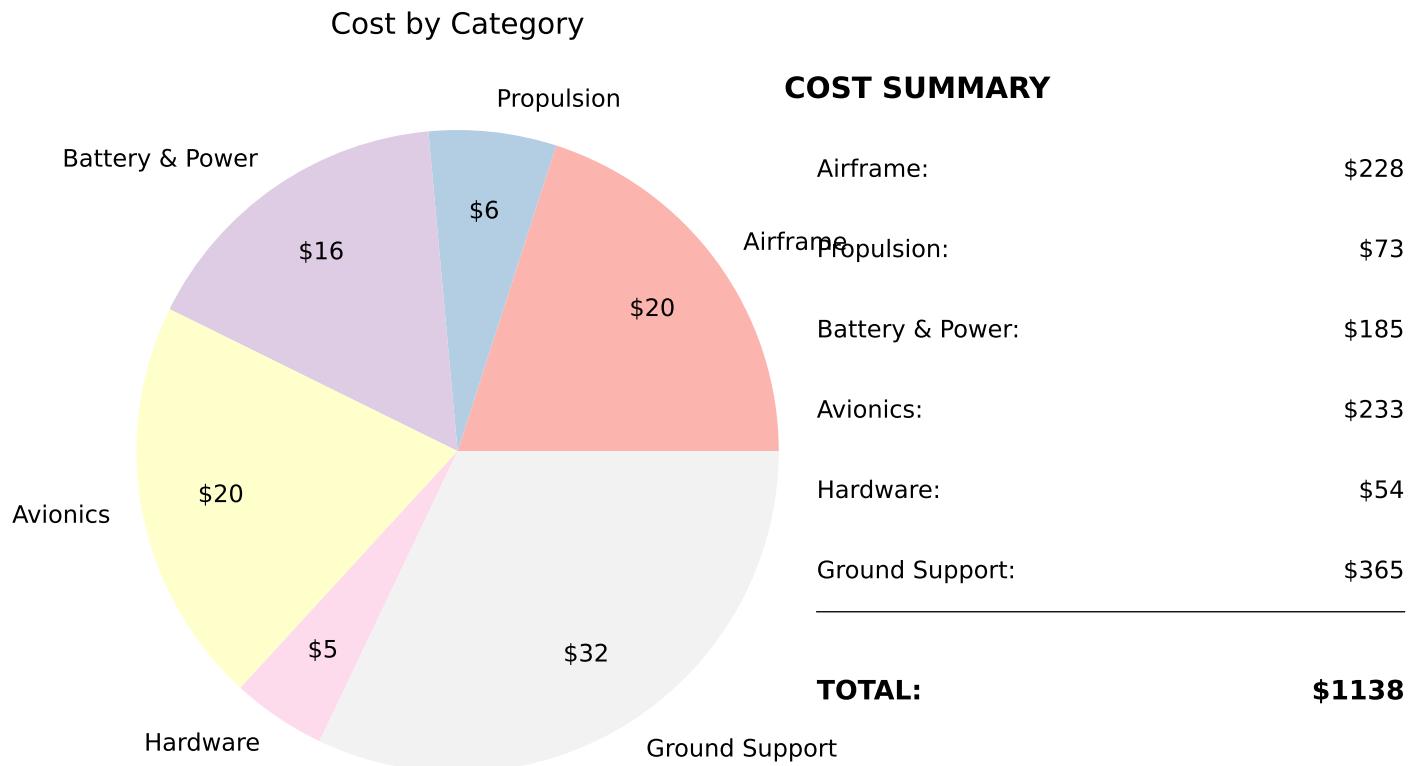


10. Technical Drawings - Component Layout

MegaDrone Phase 1 - Component Layout



11. Bill of Materials Summary



KEY COMPONENTS:

- Motor: SunnySky X2212-980KV (\$28) - 180W continuous, 58g
- ESC: 30A BLHeli_S (\$18) - with 5V BEC for servos
- Battery: 4S 3300mAh 30C LiPo (\$45 x2) - 117Wh, ~300g each
- Flight Controller: Matek F405-Wing (\$55) - ArduPilot compatible
- GPS: BN-880 (\$22) - 10Hz update rate with compass
- Servos: Savox SH-0254 (\$12 x4) - 3.9g digital micro servos
- Propeller: APC 11x7E (\$6 x3) - thin electric, includes spares

COST NOTES:

- All prices are estimates from typical online suppliers
- Payload (camera system) NOT included in BOM
- Ground support includes RC transmitter (\$250) - may be owned
- Aircraft-only cost (no GSE): \$773
- Prices may vary by supplier and region
- Consider 10-15% contingency for shipping and misc items

See designs/bill_of_materials.csv for complete itemized list.

12. CFD Validation (Future Work)

PURPOSE OF CFD VALIDATION

The VLM (Vortex Lattice Method) analysis provides good preliminary estimates but has limitations. CFD validation is recommended to:

- Verify viscous drag predictions (VLM excludes boundary layer effects)
- Confirm stall angle and post-stall behavior
- Validate pressure distributions for structural loading
- Identify any flow separation or adverse interactions

RECOMMENDED APPROACH: TIERED VALIDATION

TIER 1: XFOIL/XFLR5 (Airfoil Validation)

- Complexity: Low | Cost: Free | Time: Hours
- Validate 2D airfoil performance at $Re = 250,000$
- Compare CL, CD, CM with NeuralFoil predictions
- Installation: brew install xfoil (macOS)

TIER 2: SU2 (3D CFD - Recommended)

- Complexity: Medium | Cost: Free | Time: Days
- Stanford University's open-source CFD solver
- Excellent for aerodynamic applications
- RANS with SA or k-w SST turbulence model
- Installation: brew install su2 (macOS, including Apple Silicon)
- Website: <https://su2code.github.io/>

TIER 3: OpenFOAM (Advanced)

- Complexity: High | Cost: Free | Time: Week+
- Most powerful open-source CFD
- Overkill for this application unless learning CFD

VALIDATION TARGETS

Parameter	VLM Value	CFD Target Accuracy
CL (cruise)	0.53	$\pm 5\%$
CD (total)	0.026	$\pm 10\%$
L/D	21.5	$\pm 10\%$
CM	-0.02	$\pm 20\%$
Stall angle	$\sim 12^\circ$	$\pm 2^\circ$

SU2 ON APPLE SILICON MACS

Yes, SU2 runs natively on Apple Silicon (M1/M2/M3/M4) Macs.

Install via Homebrew: brew install su2

Performance is excellent due to unified memory architecture.

WORKFLOW SUMMARY

1. Export geometry to STL from OpenVSP model
2. Generate mesh using Gmsh or SU2 built-in tools
3. Configure RANS simulation at cruise conditions
4. Run SU2_CFD and post-process with ParaView
5. Compare results with VLM predictions
6. Iterate design if significant discrepancies found

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See docs/CFD_VALIDATION_GUIDE.md for detailed instructions.

13. References

DESIGN TOOLS

- [1] AeroSandbox - Open-source aircraft design optimization
<https://github.com/peterdsharpe/AeroSandbox>
- [2] NeuralFoil - Neural network airfoil analysis
<https://github.com/peterdsharpe/NeuralFoil>
- [3] OpenVSP - NASA parametric aircraft geometry tool
<https://openvsp.org/>

CFD TOOLS

- [4] SU2 - Stanford University Unstructured CFD solver
<https://su2code.github.io/>
- [5] OpenFOAM - Open-source CFD toolkit
<https://www.openfoam.com/>
- [6] XFOIL - Subsonic airfoil development system
<https://web.mit.edu/drela/Public/web/xfoil/>
- [7] ParaView - Open-source scientific visualization
<https://www.paraview.org/>

FLIGHT CONTROL

- [8] ArduPilot - Open-source autopilot software
<https://ardupilot.org/>
- [9] Mission Planner - Ground control station
<https://ardupilot.org/planner/>

TEXTBOOKS & REFERENCES

- [10] Raymer, D.P. "Aircraft Design: A Conceptual Approach"
AIAA Education Series
- [11] Anderson, J.D. "Fundamentals of Aerodynamics"
McGraw-Hill
- [12] Drela, M. "Flight Vehicle Aerodynamics"
MIT Press

PROJECT FILES

- Aircraft Model: scripts/aerosandbox_model_v2.py
- Sizing Analysis: scripts/drone_sizing.py
- Airfoil Design: scripts/airfoil_optimization.py
- Structural: scripts/structural_analysis.py
- Propulsion: scripts/propeller_design.py
- Technical Drawings: scripts/technical_drawings.py
- Bill of Materials: scripts/bill_of_materials.py
- CFD Guide: docs/CFD_VALIDATION_GUIDE.md