

Quadcopter

Quadcopter.STEP · Safety case · 15 cases · Completed 28 Oct 2026 · 10:24

Verdict

Not proved safe

2 of 13 safety claims not proved.
Lowest factor of safety 3.37 against
1.50 required: Propellers at full power.

Model as solved

17 bodies meshed at the Standard
detail level: 347,903 quadratic
tetrahedra, 642,943 nodes. Bonded
where parts touch. Carbon fiber (E
70.0 GPa, yield 600 MPa, 1600 kg/m³)
on every part. Structure 0.229 kg as
meshed, plus 0.471 kg carried, for
0.700 kg all-up.

Setup review

The setups were not reviewed by
Dutchman before solving.

ANALYSIS SUMMARY

ANALYSIS

Safety case

9 kinds of analysis
CASES

15

15 solved

STATUS

Not proved safe

11 of 13 claims proved
MAX DISPLACEMENT

6.99 mm

Propellers at full power

MASS

0.700 kg

0.230 kg structure
DESIGN STRESS

177.9 MPa

Propeller · yield 600.0 MPa · Prop...

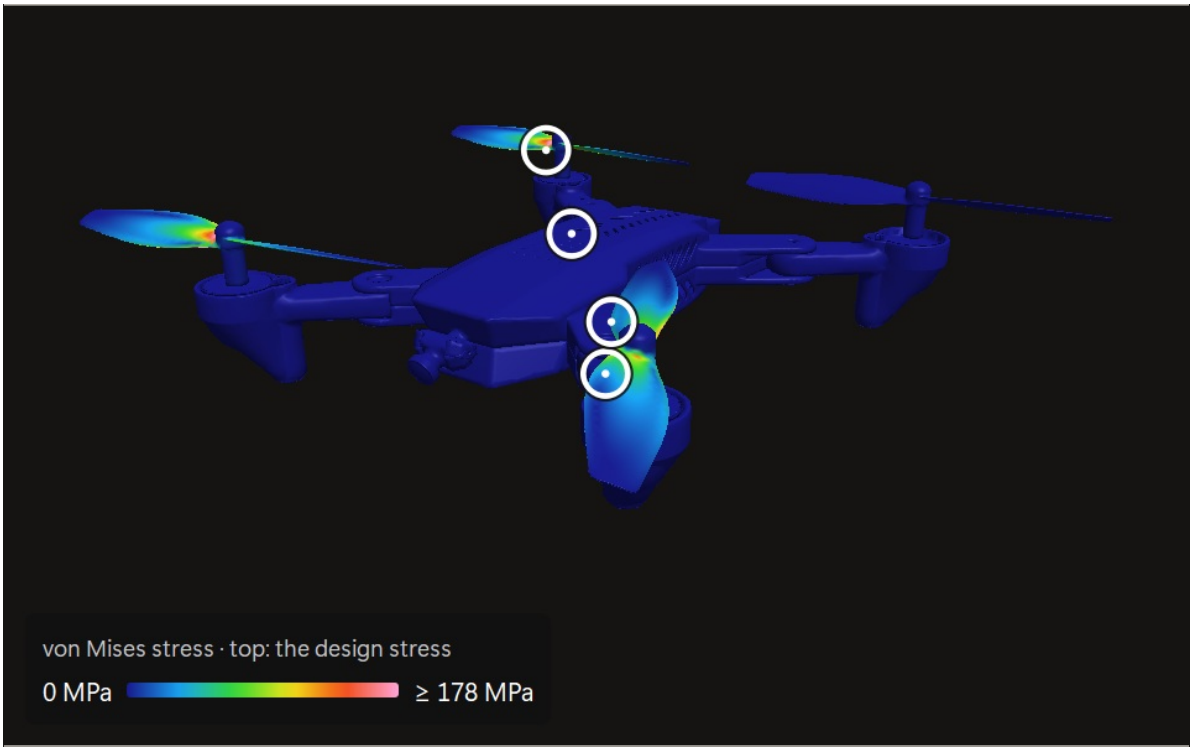
DETAIL

Standard

SAFETY FACTOR

3.37

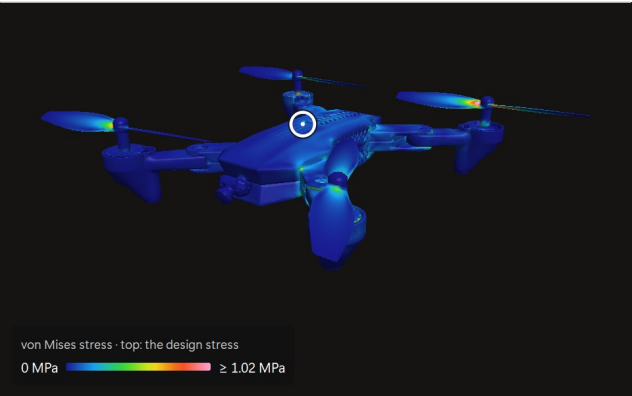
required 1.50 · Propellers at full p...



Propellers at full power

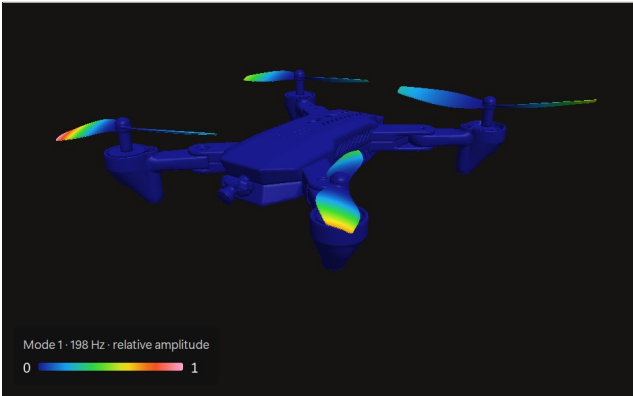
Static structural · FoS 3.37 · design stress 177.9 MPa

Every solved case from the same three-quarter view, the stress on the surface and a ring on each weak spot.



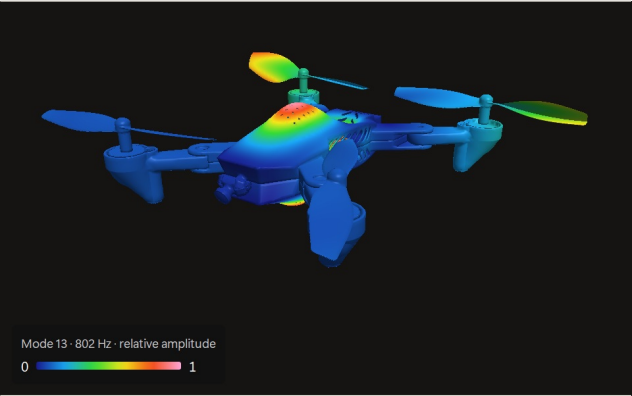
Motor failure

Static structural · Passed · FoS 270.46 (required 1.30) · design stre...



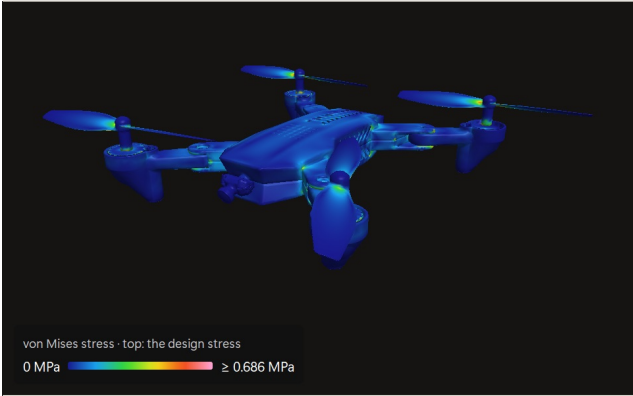
Natural frequencies

Modal · Done · f_1 198 Hz



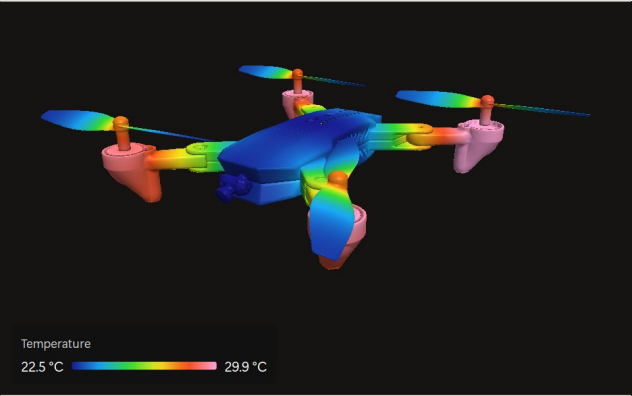
Vibration at the avionics deck

Harmonic response · Passed · 9.45 g peak



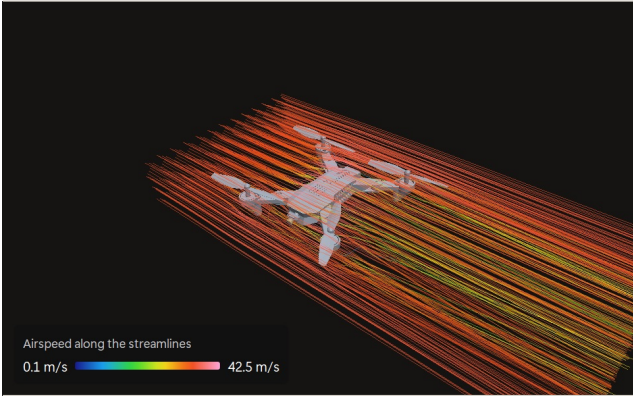
Side gust at 8 m/s

Static structural · Passed · FoS 402.55 (required 1.50) · design stre...



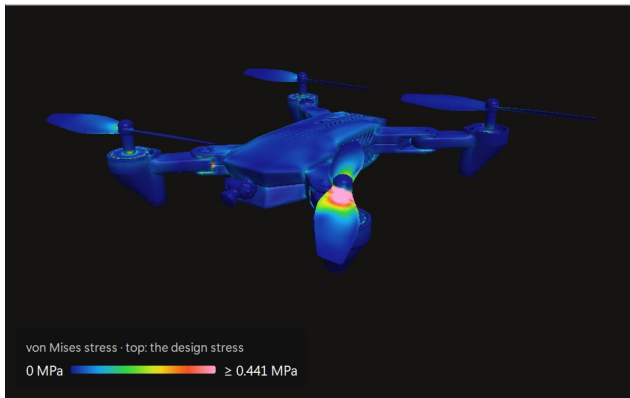
Motor heat

Thermal · Passed · 30 °C peak



Aerodynamics at 35 m/s (CFD)

External airflow · Done · 5.59 N drag



Airflow pressure

Static structural · Passed · FoS 625.39 (required 1.50) · design stre...

LOAD CASES AND CONSTRAINTS

CASE	ANALYSIS	LOADS	HELD BY	RESULT
Hover	Static	4 × 1.7 N up at the motor hubs + 15 mN·m each · free flight (balanced by its own inertia)	Free flight (inertia relief)	FoS 390.62 · 0.707 MPa · 0.011 mm
Max thrust	Static	4 × 4.3 N up at the motor hubs + 38 mN·m each · free flight (balanced by its own inertia)	Free flight (inertia relief)	FoS 156.06 · 1.8 MPa · 0.027 mm
Forward-flight pitch	Static	front 4.3 N · rear 0.9 N · free flight (balanced by its own inertia)	Free flight (inertia relief)	FoS 254.15 · 1.1 MPa · 0.045 mm
Motor failure	Static	one mount 0 N · 3 × 2.7 N up · free flight (balanced by its own inertia)	Free flight (inertia relief)	FoS 270.46 · 1.0 MPa · 0.044 mm
Hard landing (transient)	Transient	3.8 g, 40 ms deceleration of the whole aircraft (26.2 N peak) · held where the feet touch the ground	The feet: fixed x, y, z	FoS 417.08 · 1.4 MPa · 0.039 mm
Landing gear stability	Buckling	3.8 g deceleration (26.2 N through the legs) · held where the feet touch the ground · 4 modes	The feet: fixed x, y, z	×527.93 to buckle
Natural frequencies	Modal	30 modes · free-free, as in flight · with what it carries	Free-free, no supports	f ₁ 198 Hz
Vibration at the avionics deck	Harmonic	4 × 0.56 N in the rotor plane at the motor mounts · 267–1265 Hz · measured on the body · free-free, as in flight	Free-free, no supports	9.45 g peak
Side gust at 8 m/s	Static	0.8 N sideways on the body + hover thrust · free flight (balanced by its own inertia)	Free flight (inertia relief)	FoS 402.55 · 0.686 MPa · 0.011 mm
Motor heat	Thermal	4 × 4 W at the motor mounts · convection at 25 W/(m ² K)	Convection to 20 °C air	30 °C peak
Fatigue screen	Fatigue screen	derived from Hover + Max thrust	Derived from other cases	derived
Fatigue life	Fatigue life	derived · 12 min duty cycle from Hover + Max thrust	Derived from other cases	derived

CASE	ANALYSIS	LOADS	HELD BY	RESULT
Propellers at full power	Static	4 propellers at full power: each 4.3 N thrust with its drag torque, at the rpm its own size needs · free flight (balanced by its own inertia)	Free flight (inertia relief)	FoS 3.37 · 177.9 MPa · 6.99 mm
Aerodynamics at 35 m/s (CFD)	CFD	inlet 35 m/s · integrated body force	Fixed in a 35 m/s stream	5.59 N drag
Airflow pressure	Static	CFD surface pressure · free flight (balanced by its own inertia)	Free flight (inertia relief)	FoS 625.39 · 0.441 MPa · 0.039 mm

ASSUMPTIONS

Every number the run rests on and where it came from. The editable ones can be changed before solving.

ASSUMPTION	VALUE	SOURCE	NOTE
Airframe	4-motor multirotor	Read from the model	98% of the surface recognised
Arm length	130 mm	Read from the model	5-inch class
All-up mass	0.700 kg	Size class	0.7 kg 5-inch class (size class): 0.23 kg structure (carbon_fiber at the model's volume) + 0.47 kg carried (battery, motors, payload: assumed, on the body)
Thrust / weight	2.500	Size class	
Flight length	12.0 min	Phasm default	one pass of the duty cycle the fatigue life is counted over
Design life	500 h	Phasm default	judged with a scatter factor of 4
Hover motor speed	20000 rpm	Size class	1P and 2P (two-blade) excitation bands $\pm 15\%$
Propeller mass	0.011 kg	Size class	1.5% of all-up mass per rotor; it sets the once-per-rev imbalance force
Rotor balance grade	16.0 mm/s	ISO 21940-11	G16 = a production propeller that has not been individually balanced
Avionics vibration limit	3.000 g	Autopilot guidance	sustained IMU level above which the attitude estimate degrades
Max airspeed	35.0 m/s	Size class	
Material	carbon_fiber	Assumed for a 5-inch class	yield 600 MPa · fatigue 300 MPa · ultimate 600 MPa; typical for this class, not chosen: confirm it in Setup
Required safety factor	1.500	Phasm default	against yield; 1.3 for the motor-out case
Bond shear strength	15.0 MPa	Phasm default	design value of the adhesive between bodies; a structural epoxy's unless set
Bond peel strength	7.500 MPa	Phasm default	design value against pulling the bond apart; a structural epoxy's unless set
Parts found	4 motor mounts · propellers · landing gear	Read from the model	
Landing sink rate	1.500 m/s	Size class	vertical speed at touchdown
Gear stroke	30.0 mm	Phasm default	distance the touchdown is arrested over
Landing impact	3.820 g	Computed	$v^2/(2 \cdot s \cdot g)$ from 1.5 m/s over 30 mm, bounded to 1.5–8 g
Impact duration	40.0 ms	Computed	$2 \cdot s/v$ half-sine contact

ASSUMPTION	VALUE	SOURCE	NOTE
Design gust	8.000 m/s	Size class	lateral $\frac{1}{2}\rho V^2 \cdot A \cdot C_d$ on the side profile
Deflection limit	0.020	Phasm default	peak displacement / longest bounding-box side
Per-part materials	motor_hub: motor (stiff, mass carried) · propeller: carbon_fiber	Assumed with the class material	elements take the material of their part label; a propeller is never the airframe's foam or plastic, and a motor is metal-stiff (its mass is in the carried share); confirm in Setup
Detail	1.000	Entered in Setup	quadratic tetrahedra
Structural damping	0.020 fraction of critical	Phasm default	the swept response scales as $1/(2\zeta)$, so the peak is inversely proportional to this; a tap test on the real airframe measures it
Propeller	6.2x2.6, 2 blades (largest that fits the arms)	Arm length	11229 rpm and 18 W per rotor at hover

MESH CONVERGENCE

The governing case was refined where the solver's own error estimate was high, 3 solves in all. Its figure moved 0.2 % on the last: settled (under 5 %). 8 of 8 refined spots settled. The mesh was planned by the rules: 0 parts meshed finer and 6 coarser than drawn.

CASE	MESH	NODES	FIGURE BY VOLUME	CHANGE
Propellers at full power	As run	642,943	116.4 MPa	—
Propellers at full power	Refinement 1	689,217	117.3 MPa	0.7 %
Propellers at full power	Refinement 2	758,803	117.6 MPa	0.2 %

HAND CHECKS

The run's numbers against first-principles estimates.

QUANTITY	PHASM	HAND ESTIMATE	HOW
Hover thrust per motor	1.72 N	1.72 N	$0.70 \text{ kg} \times 9.81 \text{ m/s}^2 / 4 \text{ motors.}$
Full thrust per motor	4.29 N	4.29 N	Thrust-to-weight $2.5 \times 0.70 \text{ kg} \times 9.81 \text{ m/s}^2 / 4 \text{ motors.}$
Landing deceleration	3.82 g, 26.2 N	3.82 g, 26.2 N	A 1.5 m/s sink stopped over the 30 mm gear stroke: $(1.5 \text{ m/s})^2 / (2 \times 0.03 \text{ m}) = 37.5 \text{ m/s}^2$, or 3.82 g, on 0.70 kg. The run's force is on the 0.698 kg it meshed and carried.
Structure mass as meshed	0.229 kg	0.230 kg	The model's volume, 143,991 mm ³ , at 1,600 kg/m ³ (carbon fibre).
Drag at 35 m/s	5.59 N (C_D 0.96 on 0.0078 m ²)	4.7–7.0 N	$\frac{1}{2} \times 1.225 \text{ kg/m}^3 \times (35 \text{ m/s})^2 \times 0.0078 \text{ m}^2 \times C_D$, with C_D 0.8 to 1.2 for a bluff multirotor frame on its frontal area.

WHAT THIS RUN DOES NOT CAPTURE

- Carbon fibre as an isotropic solid.
It is modelled with one stiffness in every direction and judged by von Mises, so the strength and fatigue margins are indicative. A laminate's strength needs its layup and a laminate criterion such as Tsai-Wu or Hashin; the stiffness, resonance and stability results stand on their own.
- Mission inputs from the size class.
The loads follow from numbers typical of a 5-inch class, not measured on this aircraft: all-up mass 0.7 kg, thrust-to-weight

2.5, motor speed 20,000 rpm, propeller mass 10.5 g, 35 m/s top speed, 1.5 m/s landing sink, 8 m/s gust. Each can be changed before solving. The material, carbon fibre, is the class's typical one, not one chosen for this model.

- Parts bonded where they touch.

The 17 bodies are bonded where they touch, and bodies within 12 mm of each other are bonded across the gap. Each of the 13 bonds was checked on the force and moment it carries, against 15 MPa shear and 7.5 MPa peel. Where carried equipment meets the airframe (8 mounts: motors, propellers, stores) the load each puts on what holds it is given for sizing its fasteners, not judged as a bond. A bolted, pinned or folding joint is softer than a bond, so the vibration response is indicative.

- Thrust not trimmed about the centre of mass.

The free-flight cases are balanced by the aircraft's own inertia with the thrust as planned, so the aircraft also turns: up to 461 rad/s² in Propellers at full power, about 6.5 g at the motors, and 15.8 rad/s² even in Hover. The stresses include the load that turns it, which a trimmed aircraft in steady flight does not carry.

- Propellers standing still.

The natural frequencies are computed with the propellers at rest. A spinning blade is stiffened by its own centrifugal load, so the propeller modes sit higher in flight than listed here, and the vibration response near them shifts with it.

- Linear, small-deflection analysis.

Every case is solved linear-elastic with small deflections, and the joints neither slide nor open. Behaviour past first yield, large deflections and a joint coming apart are outside what these numbers show.

- Material assumed: Carbon fiber, assumed for a 5-inch class

- Surface non-manifold: 108 edges shared by more than two faces

- Linear-elastic analysis on the geometry as imported, with the stated material and loads; a screening-grade result, not a substitute for a qualification test.

- Not run: Cycle-by-cycle fatigue (FEA) (not implemented on this platform yet)

- Not run: Aeroelastic / flutter (not implemented on this platform yet)

SAFETY CLAIMS

CLAIM	STATUS	WHY
Static strength	Proved	Worst case Max thrust at FoS 156.06 (104.0× the requirement).
Asymmetric thrust	Proved	Worst case Forward-flight pitch at FoS 254.15 (169.4× the requirement).
No resonance with the motors	Not proved	mode at 332 Hz sits in the 1P band (283–383 Hz); mode at 717 Hz sits in the 2P band (567–767 Hz); mode at 747 Hz sits in the 2P band (567–767 Hz); mode at 766 Hz sits in the 2P band (567–767 Hz).
Fatigue screen	Proved	Goodman ratio $0.077 \leq 0.67$: infinite-life screening passes (8.7× margin).
Frame temperature	Proved	Peak 30 °C against a 80 °C limit (2.64×).
Service life	Proved	No cycle in the flight reaches the material's fatigue strength: run-out, not a finite life. The damage sum puts it past 1e20 flight hours against a 500 h design life, but that is the S-N curve extrapolated beyond its anchor, so read it as a bound, not a number.
Avionics vibration	Not proved	9.45 g at 799 Hz on body exceeds the 3.0 g the avionics tolerate.
No buckling under the landing load	Proved	Landing gear stability goes unstable at 527.93x its load, 352.0x the 1.5x required.
Hard landing	Proved	Worst case Hard landing (transient) at FoS 417.08 (278.1× the requirement).
Survives a design gust	Proved	Worst case Side gust at 8 m/s at FoS 402.55 (268.4× the requirement).
Deflection stays within limits	Proved	Worst deflection 0.01% of the longest side (Forward-flight pitch) against a 2.0% limit.

CLAIM	STATUS	WHY
Propellers at full power	Proved	Worst case Propellers at full power at FoS 3.37 (2.2× the requirement).
Thrust margin at max speed	Proved	1.3 × drag = 7.26 N against 10.3 N of thrust beyond hover (1.4× margin).

METRICS

VIBRATION AT THE AVIONICS	9.45 g at 799 Hz	limit 3.0 g · measured on body
STABILITY	Landing gear stability × 527.93	a multiplier on each case's own load
NATURAL FREQUENCIES	198 Hz · 198 Hz · 198 Hz · 198 Hz · 19	excitation 1P 283–383 Hz, 2P 567–767 Hz
AERODYNAMIC DRAG	5.59 N	10.3 N of thrust in hand
FATIGUE SCREEN	12 % of the limit	limit 0.67 · σ_a 0.2 MPa, σ_m 0.5 MPa · worst part motor hub
FRAME TEMPERATURE	30 °C	+10 °C above ambient · limit 80 °C
SERVICE LIFE	Unlimited	-9,223,372,036,854,775,808 flights · design life 500 h · scat...
DYNAMIC AMPLIFICATION	Hard landing (transient) × 1.04	transient peak over the static case
DEFLECTION	2.15 % of the longest side	worst case: Propellers at full power

MATERIAL UTILISATION BY PART

Each part's peak von Mises stress over its own yield strength, from the case that stresses it hardest. 80 % and above is critical, 50 % a warning.

PART	UTILISATION	PEAK STRESS	CASE
propeller	50 %	297.8 MPa	Propellers at full power
motor hub	7 %	19.3 MPa	Propellers at full power
landing foot	3 %	20.8 MPa	Propellers at full power
arm	3 %	15.5 MPa	Propellers at full power
body	0 %	2.9 MPa	Propellers at full power

MARGINS OF SAFETY BY PART

PART	MATERIAL	MS YIELD	MS ULTIMATE	CASE
arm	Carbon fiber	233.34	233.34	Propellers at full power
body	Carbon fiber	449.02	449.02	Propellers at full power
landing foot	Carbon fiber	133.39	133.39	Propellers at full power
motor hub	Motor (stiff, mass carried)	80.21	92.40	Propellers at full power
propeller	Carbon fiber	1.25	1.59	Propellers at full power

REACTIONS AT THE SUPPORTS

SUPPORT	FORCE	CASE
Free-flight hold (should be ~0)	0.03 N	Propellers at full power

HOTSPOTS AND SUGGESTED FIXES

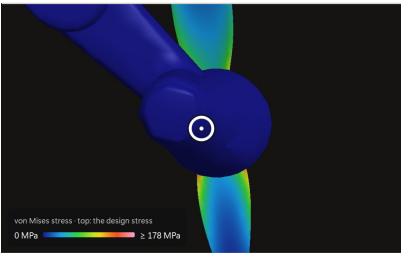
propeller

177.9 MPa

thicken the blade root and the hub, or give the propeller a stiffer, stronger material;
a lower full-power rpm with a larger propeller also helps

Under Propellers at full power

30 % of the part's yield (600 MPa)



motor hub	1.8 MPa
add gussets or a thicker firewall at the motor mount	
Under Max thrust	
1 % of the part's yield (276 MPa)	
landing foot	2.4 MPa
thicken the gear legs or add a diagonal strut	
Under Max thrust	
0 % of the part's yield (600 MPa)	
arm · right	1.6 MPa
increase the arm cross-section or gusset the arm-body joint	
Under Max thrust	
0 % of the part's yield (600 MPa)	
arm · left	1.6 MPa
increase the arm cross-section or gusset the arm-body joint	
Under Max thrust	
0 % of the part's yield (600 MPa)	

MATERIALS

Nominal handbook values, not statistically derived allowables.

APPLIES TO	MATERIAL	E	YIELD	ULTIMATE	DENSITY
Every part	Carbon fiber	70.0 GPa	600 MPa	600 MPa	1600 kg/m ³

MASS PROPERTIES

STRUCTURE	0.230 kg	the airframe's own mass
ALL-UP	0.700 kg	what the loads use
CG	-1, -1, 0 mm	
BOX	325×62×279 mm	
VOLUME	144.0 cm ³	

BASIS OF THE ACCEPTANCE CRITERIA

This verdict rests on 22 acceptance criteria: 2 from published standards, 7 from industry practice, 13 Phasm's own defaults.
Material strengths are nominal values, not certification allowables.

CRITERION	VALUE	BASIS	SOURCE	GOVERNS
ultimate factor of safety	1.5	Standard	14 CFR 23.2230 (and 25.303 for transport aircraft)	How much above the limit load the structure must survive before the case is called safe.: 1.5 is the ultimate factor of safety in US civil airworthiness rules: the structure must carry limit load without detrimental permanent deformation and ultimate load (limit times 1.5) without failure. Small unmanned aircraft are not certified under Part 23, so this is borrowed, not required; it is the number the industry borrows.

CRITERION	VALUE	BASIS	SOURCE	GOVERNS
rotor balance grade	16 mm/s	Standard	ISO 21940-11	The rotor imbalance the forced-response and fatigue loads are derived from.: Balance grade G16: permissible residual eccentricity times running speed. It is the grade of a production propeller that has not been individually balanced, which is the state a drone leaves the shop in. A balanced rotor would justify a lower grade and a smaller load.
fatigue scatter factor	4	Industry practice	Safe-life practice	The divisor applied to calculated life to get the life that may be claimed.: Fatigue test data for a given stress scatters by roughly an order of magnitude. A divisor of 3-5 on calculated life is the usual safe-life allowance; 4 sits in the middle of that range. No single clause fixes it: the number a certifying authority accepts depends on how much test evidence supports it, and here there is none.
vibration limit g	3 g	Industry practice	Autopilot vendor guidance	The acceleration at the avionics above which the vibration claim fails.: Both major open autopilot stacks treat sustained IMU levels above roughly 3 g as degrading the attitude estimate, and below about 1.5 g as clean. This is a limit on the flight controller working, not on the structure surviving.
resonance separation	0.15 fraction	Industry practice	Vibration design practice	How far a natural frequency must sit from an excitation frequency.: A separation of 10-20% between a mode and a forcing frequency is the usual rule for avoiding resonant amplification. It is a rule of thumb, not a criterion any standard fixes; the honest criterion is the measured response, which is what the harmonic sweep computes.
film coefficient	25 $W/(m^2 \cdot K)$	Industry practice	Convection correlations	Convection from the frame to the air in the thermal case.: Still air is nearer 10 $W/(m^2 \cdot K)$ and a propeller's downwash 40-80. 25 is a middling forced-convection value for a frame sitting in its own rotor wash. The result is sensitive to it.
motor efficiency	0.8 fraction	Industry practice	Small outrunner performance	How much motor input power becomes heat in the thermal case.: A hobby-class outrunner runs 75-85% efficient at cruise; the remainder is the heat load.
mesh convergence movement	5 % eak-stress movement one mesh level finer	Industry practice	Finite-element mesh convergence practice	How far the governing peak stress may still move when the mesh is refined before the margin is trusted.: A mesh study stops when the quantity it reports changes by less than a few percent on refinement; 5% is a common working threshold. No standard fixes the number for a screening analysis, and a reviewer may ask for a tighter one.

CRITERION	VALUE	BASIS	SOURCE	GOVERNS
material allowables	nominal	Industry practice	Handbook typical values	The strength the margins are measured against.: The material properties used here are nominal published values. They are NOT A-basis or B-basis allowables: statistically derived from tested lots to bound the weak end of the population, as MMPDS provides for metals and CMH-17 for composites. A nominal yield strength is roughly the middle of a distribution, so a margin computed against it is met by about half of the material that will be built with. No amount of analysis quality changes that; only a statistically-derived allowable does, and a certification submission needs one.
fatigue safety factor	1.5	Phasm default	Phasm default	The factor applied to the stress spectrum before the life is counted.: Chosen to match the static factor so a case is not judged more leniently in fatigue than in strength.
design life hours	500 flight hours	Phasm default	Phasm default	The life the fatigue claim is made against.: A placeholder for a service life the operator has not stated. Change it and the fatigue verdict changes with it.
flight minutes	12 minutes	Phasm default	Phasm default	The length of one flight, which sets how many load cycles a service life contains.: Typical of a battery-electric multirotor sortie. The count of cycles scales directly with it.
max deflection ratio	0.02 fraction of span	Phasm default	Phasm default	Peak displacement allowed, as a fraction of the longest dimension.: A stiffness criterion, not a strength one: a frame can be strong enough and still flex enough to upset the flight controller or foul a propeller. 2% is the product's judgement and nothing more.
max frame temperature c	80 degrees C	Phasm default	Phasm default	The temperature above which the thermal claim fails.: Set by what an epoxy matrix and a typical ESC mind, not by what aluminium minds. A specific resin's glass-transition temperature or a component's rated maximum should replace it whenever one is known.
landing peak g max	8 g	Phasm default	Phasm default	The cap on the hard-landing deceleration a screening transient will represent.: The peak follows from sink rate and gear stroke; above roughly 8 g the event is short and sharp enough that a linear screening transient stops being a fair representation of it, so the number is capped rather than extrapolated.

CRITERION	VALUE	BASIS	SOURCE	GOVERNS
gust load factor increment max	2.5 g	Phasm default	Phasm default	The cap on the load-factor increment a gust may add for a fixed-wing airframe.: A sub-kilogram model in a 10 m/s gust computes an absurd increment on paper; the airframe stalls or the wing sheds lift long before reaching it. The cap is a bound on the model, not a limit from a standard.
aero margin	1.3	Phasm default	Phasm default	The margin applied to computed aerodynamic loads before they are used structurally.: Covers the gap between a steady RANS drag estimate and the unsteady load the airframe actually sees.
mesh degenerate limit	0.001 fraction of elements below shape quality 0.01	Phasm default	Phasm default	How many near-flat (degenerate) elements a mesh may hold before its stresses are not trusted.: A tetrahedron with a shape quality under 0.01 is nearly flat and its stress is noise. A handful in a large mesh is normal for real CAD; 0.1% is the product's judgement of where a handful stops.
mesh poor limit	0.05 fraction of elements below shape quality 0.1	Phasm default	Phasm default	How many poorly shaped elements a mesh may hold before its stresses are not trusted.: Poor elements stiffen a mesh and smear its peaks; 5% is the product's judgement, not a published limit.
assumption probe	0.2 fraction worse than assumed	Phasm default	Phasm default	How much worse each load-scaling assumption is made when testing whether the verdict rests on a guess.: Typical-for-the-class values (mass, sink rate, gust) are rarely known better than this before a prototype is weighed or flown. Advisory: it does not block a verdict.
recognised min pct	60 % of the surface ecognised	Phasm default	Phasm default	How much of the model the part reader must identify before the loads' regions count as identified structure.: Below it the regions the loads are applied to are guesses; the number is the product's judgement.
bonded share min	0.95 fraction of the mass in one bonded group	Phasm default	Phasm default	When a model of several bodies counts as one structure rather than loose pieces.: Bodies that touch are tied together where they touch. If the largest tied group carries less than this share of the mass, the rest is not part of the structure the loads travel through; the number is the product's judgement.

CONCLUSION

Not proved safe

Design stress sits in the propeller at 177.9 MPa (30% of yield) under Propellers at full power; the motor hub follows at 1%.

No resonance with the motors: mode at 332 Hz sits in the 1P band (283–383 Hz); mode at 717 Hz sits in the 2P band (567–767 Hz); mode at 747 Hz sits in the 2P band (567–767 Hz); mode at 766 Hz sits in the 2P band (567–767 Hz).

Avionics vibration: 9.45 g at 799 Hz on body exceeds the 3.0 g the avionics tolerate.

Linear-elastic, screening-grade analysis on a carbon_fiber solid with loads from the stated assumptions (0.70 kg, 2.5:1 thrust-to-weight); load regions come from the part-segmenter labels. Not a substitute for a physical test.

Checks: 5 checks passed · 1 not passed.

Report status: Ready

APPENDIX: HOW THE VERDICT WAS REACHED

Built from the run's evidence file alone: every value below is a field of it.

THE VERDICT

What the run concluded, and the one sentence that says why.

ITEM	VALUE
Model	Quadcopter.STEP
Verdict	Not proved safe 2 of 13 safety claims not proved. The material model did not pass: carbon fiber judged by von Mises (an isotropic solid) against no laminate judged by von Mises. Next: read the strength and fatigue margins of carbon fiber as indicative only; a laminate's strength needs its layup and a laminate criterion (Tsai-Wu, Hashin), which this run does not have. The stiffness, resonance and stability results stand on their own. No resonance with the motors, Avionics vibration fail on evidence that gate does not reach. Governing structural case: Propellers at full power at FoS 3.37. First natural frequency 198 Hz. Drag 5.59 N at the assumed airspeed.

WHAT IT ASSUMED

Every number the loads were built from, and where each came from: read from your model, set by you, typical for its class, a standard or default, or calculated from the others.

ASSUMPTION	VALUE	WHERE IT CAME FROM
Airframe	4-motor multirotor	From your model 98% of the surface recognised
Arm length	130.1 mm	From your model 5-inch class
All-up mass	0.7 kg	Typical values: check these 0.7 kg 5-inch class (size class): 0.23 kg structure (carbon fiber at the model's volume) + 0.47 kg carried (battery, motors, payload: assumed, on the body)
Thrust / weight	2.5	Typical values: check these
Flight length	12 min	Standards and defaults one pass of the duty cycle the fatigue life is counted over
Design life	500 h	Standards and defaults judged with a scatter factor of 4
Hover motor speed	20000 rpm	Typical values: check these 1P and 2P (two-blade) excitation bands $\pm 15\%$
Propeller mass	0.0105 kg	Typical values: check these 1.5% of all-up mass per rotor; it sets the once-per-rev imbalance force
Rotor balance grade	16 mm/s	Standards and defaults G16 = a production propeller that has not been individually balanced
Avionics vibration limit	3 g	Standards and defaults sustained IMU level above which the attitude estimate degrades

ASSUMPTION	VALUE	WHERE IT CAME FROM
Max airspeed	35 m/s	Typical values: check these
Material	Carbon fiber	Typical values: check these yield 600 MPa · fatigue 300 MPa · ultimate 600 MPa; typical for this class, not chosen: confirm it in Setup
Required safety factor	1.5	Standards and defaults against yield; 1.3 for the motor-out case
Bond shear strength	15 MPa	Standards and defaults design value of the adhesive between bodies; a structural epoxy's unless set
Bond peel strength	7.5 MPa	Standards and defaults design value against pulling the bond apart; a structural epoxy's unless set
Parts found	4 motor mounts · propellers · landing gear	From your model
Landing sink rate	1.5 m/s	Typical values: check these vertical speed at touchdown
Gear stroke	30 mm	Standards and defaults distance the touchdown is arrested over
Landing impact	3.82 g	Calculated $v^2/(2 \cdot s \cdot g)$ from 1.5 m/s over 30 mm, bounded to 1.5–8 g
Impact duration	40 ms	Calculated $2 \cdot s/v$ half-sine contact
Design gust	8 m/s	Typical values: check these lateral $\frac{1}{2} \rho V^2 A C_d$ on the side profile
Deflection limit	0.02	Standards and defaults peak displacement / longest bounding-box side
Per-part materials	motor_hub: motor (stiff, mass carried) · propeller: carbon_fiber	Typical values: check these elements take the material of their part label; a propeller is never the airframe's foam or plastic, and a motor is metal-stiff (its mass is in the carried share): confirm in Setup
Detail	1	Set by you quadratic tetrahedra
Structural damping	0.02 fraction of critical	Standards and defaults the swept response scales as $1/(2\zeta)$, so the peak is inversely proportional to this; a tap test on the real airframe measures it
Propeller	6.2x2.6, 2 blades (largest that fits the arms)	Typical values: check these 11229 rpm and 18 W per rotor at hover

WHAT IT CLAIMS, AND THE CASES THAT PROVE IT

Each safety claim, the rule it is judged by, the cases whose results are its evidence, and how it came out.

CLAIM	PASS RULE	PROVED BY	RESULT
Static strength	factor of safety ≥ 1.5 against yield	Hover; Max thrust	Proved: 104 of what is required The frame does not yield under steady hover or full-throttle thrust. Worst case Max thrust at FoS 156.06 (104.0× the requirement). Acceptance number: Ultimate factor of safety (1.5): Published standard, 14 CFR 23.2230 (and 25.303 for transport aircraft) Acceptance number: Material allowables (nominal): Industry practice, Handbook typical values
Asymmetric thrust	factor of safety ≥ 1.5 (pitch) and ≥ 1.3 (motor-out)	Forward-flight pitch; Motor failure	Proved: 169 of what is required Pitch authority and a motor failure do not overload the centre plate or an arm. Worst case Forward-flight pitch at FoS 254.15 (169.4× the requirement). Acceptance number: Ultimate factor of safety (1.5): Published standard, 14 CFR 23.2230 (and 25.303 for transport aircraft) Acceptance number: Material allowables (nominal): Industry practice, Handbook typical values
No resonance with the motors	every mode $\geq 15\%$ away from 1P and 2P at hover rpm	Natural frequencies	Not proved: 0.0044 of what is required No natural frequency sits in the hover excitation bands. mode at 332 Hz sits in the 1P band (283–383 Hz); mode at 717 Hz sits in the 2P band (567–767 Hz); mode at 747 Hz sits in the 2P band (567–767 Hz); mode at 766 Hz sits in the 2P band (567–767 Hz). Acceptance number: Resonance separation (0.15 fraction): Industry practice, Vibration design practice
Fatigue screen	Goodman $\sigma_a/\sigma_e + \sigma_m/\sigma_u \leq 1/1.5$	Fatigue screen	Proved: 8.7 of what is required Hover-to-full-throttle cycling stays below the material's fatigue strength. Goodman ratio $0.077 \leq 0.67$: infinite-life screening passes (8.7× margin). Acceptance number: Fatigue safety factor (1.5): Phasm judgement, Phasm default Acceptance number: Fatigue scatter factor (4): Industry practice, Safe-life practice Acceptance number: Design life hours (500 flight hours): Phasm judgement, Phasm default Acceptance number: Flight minutes (12 minutes): Phasm judgement, Phasm default Acceptance number: Rotor balance grade (16 mm/s): Published standard, ISO 21940-11 Acceptance number: Material allowables (nominal): Industry practice, Handbook typical values

CLAIM	PASS RULE	PROVED BY	RESULT
Frame temperature	peak frame temperatu ≤ 80 °C	Motor heat	Proved: 2.6 of what is required Motor heat does not take the structure past the temperature it tolerates. Peak 30 °C against a 80 °C limit (2.64×). Acceptance number: Max frame temperature c (80 degrees C): Phasm judgement, Phasm default Acceptance number: Film coefficient (25 W/(m²*K)): Industry practice, Convection correlations Acceptance number: Motor efficiency (0.8 fraction): Industry practice, Small outrunner performance
Service life	Miner life ≥ 500 h after a scatter factor of 4	Fatigue life	Proved: 1350905672755447296 of what is required The airframe reaches 500 flight hours on the assumed duty cycle. No cycle in the flight reaches the material's fatigue strength: run-out, not a finite life. The damage sum puts it past 1e20 flight hours against a 500 h design life, but that is the S-N curve extrapolated beyond its anchor, so read it as a bound, not a number. Acceptance number: Fatigue safety factor (1.5): Phasm judgement, Phasm default Acceptance number: Fatigue scatter factor (4): Industry practice, Safe-life practice Acceptance number: Design life hours (500 flight hours): Phasm judgement, Phasm default Acceptance number: Flight minutes (12 minutes): Phasm judgement, Phasm default Acceptance number: Rotor balance grade (16 mm/s): Published standard, ISO 21940-11
Avionics vibration	peak accelerati ≤ 3.0 g anywhere in the rotor excitation band	Vibration at the avionics deck	Not proved: 0.32 of what is required The deck the flight controller sits on stays below the level its accelerometer tolerates. 9.45 g at 799 Hz on body exceeds the 3.0 g the avionics tolerate. Acceptance number: Rotor balance grade (16 mm/s): Published standard, ISO 21940-11 Acceptance number: Vibration limit g (3 g): Industry practice, Autopilot vendor guidance Acceptance number: Resonance separation (0.15 fraction): Industry practice, Vibration design practice

CLAIM	PASS RULE	PROVED BY	RESULT
No buckling under the landing load	lowest buckling load factor ≥ 1.5	Landing gear stability	Proved: 352 of what is required No compressed member goes unstable at the touchdown load. Landing gear stability goes unstable at 527.93x its load, 352.0x the 1.5x required. Acceptance number: Ultimate factor of safety (1.5): Published standard, 14 CFR 23.2230 (and 25.303 for transport aircraft)
Hard landing	transient peak factor of safety ≥ 1.5	Hard landing (transient)	Proved: 278 of what is required The landing gear and its attachment survive a hard touchdown including dynamic overshoot. Worst case Hard landing (transient) at FoS 417.08 (278.1x the requirement). Acceptance number: Landing peak g max (8 g): Phasm judgement, Phasm default
Survives a design gust	factor of safety ≥ 1.5 against yield	Side gust at 8 m/s	Proved: 268 of what is required A 8 m/s gust across the airframe does not yield the frame. Worst case Side gust at 8 m/s at FoS 402.55 (268.4x the requirement). Acceptance number: Gust load factor increment max (2.5 g): Phasm judgement, Phasm default
Deflection stays within limits	max displacem $\leq 2.0\%$ of the longest bounding-side	Hover; Max thrust; Forward-flight pitch; Motor failure; Side gust at 8 m/s	Proved: 143 of what is required Peak deflection under every steady case stays within the stiffness limit. Worst deflection 0.01% of the longest side (Forward-flight pitch) against a 2.0% limit. Acceptance number: Ultimate factor of safety (1.5): Published standard, 14 CFR 23.2230 (and 25.303 for transport aircraft) Acceptance number: Max deflection ratio (0.02 fraction of span): Phasm judgement, Phasm default Acceptance number: Material allowables (nominal): Industry practice, Handbook typical values
Propellers at full power	factor of safety ≥ 1.5 against the propeller's own material	Propellers at full power	Proved: 2.2 of what is required The propellers and their hubs carry full power: the pull of the spin at full rpm, the thrust and the drag torque. Worst case Propellers at full power at FoS 3.37 (2.2x the requirement).

CLAIM	PASS RULE	PROVED BY	RESULT
Thrust margin at max speed	$1.3 \times \text{drag} \leq (T/W - 1) \times \text{weight}$	Aerodynamics at 35 m/s (CFD)	Proved: 1.4 of what is required Drag at max airspeed leaves usable thrust beyond hover. $1.3 \times \text{drag} = 7.26 \text{ N}$ against 10.3 N of thrust beyond hover (1.4× margin). Acceptance number: Aero margin (1.3): Phasm judgement, Phasm default

THE SETUP REVIEW

Before solving, each way the model is held and loaded was drawn and given a second look: accepted, questioned and why, and the other support used when one was better.

CASES	HELD	LOADED	REVIEW
All cases	As planned	As planned	Not reviewed: No vision model is configured on this server.

THE CHECKS ON THE ANALYSIS

What the analysis checked about itself before its verdict could stand: each check's result, the number it measured and the number it was held to.

CHECK	RESULT	MEASURED	HELD TO
The geometry check	Passed	recognised as a multirotor (98% classified); largest bonded group 100.0% of the mass (17 bodies); mass: structure 0.33x the all-up mass, 7.72 kg/m2 of bounding box	airframe recognised (60%+ of the surface), one bonded group with 95%+ of the mass, closed surface, mass not from solid-modelled volume, carried mass declared, mass within 3x of the structure, size class and bounding box The model is a recognised airframe the plan's assumptions fit. Acceptance number: Recognised min pct (60 % of the surface recognised): Phasm judgement, Phasm default Acceptance number: Bonded share min (0.95 fraction of the mass in one bonded group): Phasm judgement, Phasm default
Evidence coverage	Passed	13 of 13 planned cases returned a result	all 13 needed All 13 planned cases ran.
Mesh convergence	Passed	0.2% movement on the last of 3 passes, 116.45 MPa -> 117.59 MPa (prop_power)	under 5% movement on the last refinement The governing figure moved 0.2% on refinement. Mesh level 0: peak stress 178 MPa on 638970 nodes Mesh level 1: peak stress 178 MPa on 642943 nodes Acceptance number: Mesh convergence movement (5 % peak-stress movement one mesh level finer): Industry practice, Finite-element mesh convergence practice

CHECK	RESULT	MEASURED	HELD TO
Mesh quality	Passed	0.03% degenerate, 0.1% poor (Airflow pressure, median shape quality 0.77)	under 0.1% degenerate (shape quality below 0.01) and under 5% poor (below 0.1) Median shape quality 0.77; sliver elements within limits. Acceptance number: Mesh degenerate limit (0.001 fraction of elements below shape quality 0.01): Phasm judgement, Phasm default Acceptance number: Mesh poor limit (0.05 fraction of elements below shape quality 0.1): Phasm judgement, Phasm default
Assumption sensitivity	Passed	FoS 2.34 with Landing sink rate 1.5 m/s 20% worse	FoS 1.5 required The margin survives every load-scaling assumption being 20% worse (worst case FoS 2.34). Acceptance number: Assumption probe (0.2 fraction worse than assumed): Phasm judgement, Phasm default
The material model	Not passed	carbon fiber judged by von Mises (an isotropic solid)	no laminate judged by von Mises Next: Read the strength and fatigue margins of carbon fiber as indicative only; a laminate's strength needs its layup and a laminate criterion (Tsai-Wu, Hashin), which this run does not have. The stiffness, resonance and stability results stand on their own. carbon fiber is modelled as an isotropic solid and judged by von Mises, which is not a failure criterion for a laminate.

ACCEPTANCE NUMBERS AND THEIR BASIS

Every number the verdict was measured against, and what stands behind it: a published standard, industry practice, or Phasm's own judgement.

This verdict rests on 22 acceptance criteria: 2 from published standards, 7 from industry practice, 13 Phasm's own defaults. Material strengths are nominal values, not certification allowables.

NUMBER	VALUE	BASIS	SOURCE
How much above the limit load the structure must survive before the case is called safe.	1.5	Published standard	14 CFR 23.2230 (and 25.303 for transport aircraft) 1.5 is the ultimate factor of safety in US civil airworthiness rules: the structure must carry limit load without detrimental permanent deformation and ultimate load (limit times 1.5) without failure. Small unmanned aircraft are not certified under Part 23, so this is borrowed, not required; it is the number the industry borrows.

NUMBER	VALUE	BASIS	SOURCE
The rotor imbalance the forced-response and fatigue loads are derived from.	16 mm/s	Published standard	ISO 21940-11 Balance grade G16: permissible residual eccentricity times running speed. It is the grade of a production propeller that has not been individually balanced, which is the state a drone leaves the shop in. A balanced rotor would justify a lower grade and a smaller load.
The divisor applied to calculated life to get the life that may be claimed.	4	Industry practice	Safe-life practice Fatigue test data for a given stress scatters by roughly an order of magnitude. A divisor of 3-5 on calculated life is the usual safe-life allowance; 4 sits in the middle of that range. No single clause fixes it: the number a certifying authority accepts depends on how much test evidence supports it, and here there is none.
The acceleration at the avionics above which the vibration claim fails.	3 g	Industry practice	Autopilot vendor guidance Both major open autopilot stacks treat sustained IMU levels above roughly 3 g as degrading the attitude estimate, and below about 1.5 g as clean. This is a limit on the flight controller working, not on the structure surviving.
How far a natural frequency must sit from an excitation frequency.	0.15 fraction	Industry practice	Vibration design practice A separation of 10-20% between a mode and a forcing frequency is the usual rule for avoiding resonant amplification. It is a rule of thumb, not a criterion any standard fixes; the honest criterion is the measured response, which is what the harmonic sweep computes.
Convection from the frame to the air in the thermal case.	25 W/(m ² *K)	Industry practice	Convection correlations Still air is nearer 10 W/(m ² *K) and a propeller's downwash 40-80. 25 is a middling forced-convection value for a frame sitting in its own rotor wash. The result is sensitive to it.
How much motor input power becomes heat in the thermal case.	0.8 fraction	Industry practice	Small outrunner performance A hobby-class outrunner runs 75-85% efficient at cruise; the remainder is the heat load.
How far the governing peak stress may still move when the mesh is refined before the margin is trusted.	5 % peak-stress movement one mesh level finer	Industry practice	Finite-element mesh convergence practice A mesh study stops when the quantity it reports changes by less than a few percent on refinement; 5% is a common working threshold. No standard fixes the number for a screening analysis, and a reviewer may ask for a tighter one.

NUMBER	VALUE	BASIS	SOURCE
The strength the margins are measured against.	nominal	Industry practice	Handbook typical values The material properties used here are nominal published values. They are NOT A-basis or B-basis allowables: statistically derived from tested lots to bound the weak end of the population, as MMPDS provides for metals and CMH-17 for composites. A nominal yield strength is roughly the middle of a distribution, so a margin computed against it is met by about half of the material that will be built with. No amount of analysis quality changes that; only a statistically-derived allowable does, and a certification submission needs one.
The factor applied to the stress spectrum before the life is counted.	1.5	Phasm judgement	Phasm default Chosen to match the static factor so a case is not judged more leniently in fatigue than in strength.
The life the fatigue claim is made against.	500 flight hours	Phasm judgement	Phasm default A placeholder for a service life the operator has not stated. Change it and the fatigue verdict changes with it.
The length of one flight, which sets how many load cycles a service life contains.	12 minutes	Phasm judgement	Phasm default Typical of a battery-electric multirotor sortie. The count of cycles scales directly with it.
Peak displacement allowed, as a fraction of the longest dimension.	0.02 fraction of span	Phasm judgement	Phasm default A stiffness criterion, not a strength one: a frame can be strong enough and still flex enough to upset the flight controller or foul a propeller. 2% is the product's judgement and nothing more.
The temperature above which the thermal claim fails.	80 degrees C	Phasm judgement	Phasm default Set by what an epoxy matrix and a typical ESC mind, not by what aluminium minds. A specific resin's glass-transition temperature or a component's rated maximum should replace it whenever one is known.
The cap on the hard-landing deceleration a screening transient will represent.	8 g	Phasm judgement	Phasm default The peak follows from sink rate and gear stroke; above roughly 8 g the event is short and sharp enough that a linear screening transient stops being a fair representation of it, so the number is capped rather than extrapolated.

NUMBER	VALUE	BASIS	SOURCE
The cap on the load-factor increment a gust may add for a fixed-wing airframe.	2.5 g	Phasm judgement	Phasm default A sub-kilogram model in a 10 m/s gust computes an absurd increment on paper; the airframe stalls or the wing sheds lift long before reaching it. The cap is a bound on the model, not a limit from a standard.
The margin applied to computed aerodynamic loads before they are used structurally.	1.3	Phasm judgement	Phasm default Covers the gap between a steady RANS drag estimate and the unsteady load the airframe actually sees.
How many near-flat (degenerate) elements a mesh may hold before its stresses are not trusted.	0.001 fraction of elements below shape quality 0.01	Phasm judgement	Phasm default A tetrahedron with a shape quality under 0.01 is nearly flat and its stress is noise. A handful in a large mesh is normal for real CAD; 0.1% is the product's judgement of where a handful stops.
How many poorly shaped elements a mesh may hold before its stresses are not trusted.	0.05 fraction of elements below shape quality 0.1	Phasm judgement	Phasm default Poor elements stiffen a mesh and smear its peaks; 5% is the product's judgement, not a published limit.
How much worse each load-scaling assumption is made when testing whether the verdict rests on a guess.	0.2 fraction worse than assumed	Phasm judgement	Phasm default Typical-for-the-class values (mass, sink rate, gust) are rarely known better than this before a prototype is weighed or flown. Advisory: it does not block a verdict.
How much of the model the part reader must identify before the loads' regions count as identified structure.	60 % of the surface recognised	Phasm judgement	Phasm default Below it the regions the loads are applied to are guesses; the number is the product's judgement.
When a model of several bodies counts as one structure rather than loose pieces.	0.95 fraction of the mass in one bonded group	Phasm judgement	Phasm default Bodies that touch are tied together where they touch. If the largest tied group carries less than this share of the mass, the rest is not part of the structure the loads travel through; the number is the product's judgement.

MATERIAL STRENGTHS

The strengths every margin is measured against, and where they came from. Nominal handbook values sit in the middle of what real material achieves; they are not certification allowables.

MATERIAL	USED FOR	YIELD	ULTIMATE	FATIGUE	SOURCE
Carbon fiber	The airframe	600 MPa	600 MPa	300 MPa	Nominal values (Industry practice): Handbook typical values
Motor (stiff, mass carried)	Motor hub	276 MPa	Not stated	Not stated	Nominal values (Industry practice): Handbook typical values
Carbon fiber	Propeller	600 MPa	Not stated	Not stated	Nominal values (Industry practice): Handbook typical values