

Resonance Validation of VTOL Arm Assembly

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Background

Resonance occurs when a structure's natural vibration frequency aligns with an excitation frequency from the system (in this case, the rotating propeller and motor). If these frequencies overlap, vibration can grow dramatically and lead to fatigue or failure. The goal is therefore to ensure a large enough separation between the operational excitation frequencies of the rotating propeller and the arm assembly's natural modes.

Purpose

- Identify the natural frequencies of the motor junction and arm assembly.
- Compare these frequencies to propeller excitation frequencies
- Verify that no resonant conditions occur during normal operation

Propulsion Excitation Frequencies

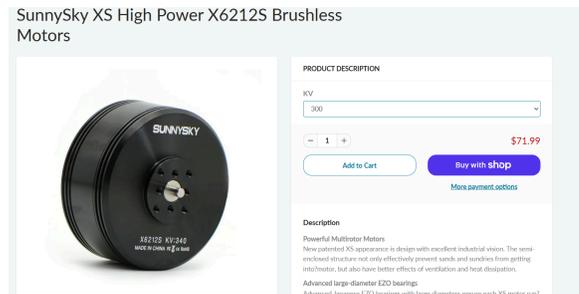
The dominant periodic excitation from the propulsion system is the blade passing frequency (BPF)

Equation:

$$BPF = \frac{RPM}{60} \cdot N_{Blades}$$

Motor and prop data:

- Motor KV: 300
- Battery: 6S LiPo (22.2 V)
- Propeller: 18 in × 14 in, 2 blades



Product Code: LP18014	
18x14	
\$23.80	
Sport	
Pitch (Inches)	14
Propeller Diameter (in.)	18
Hub Diameter	1.75 in.
Hub Thickness	0.76 in.
Shaft Diameter	5/16 in.
Product Weight	5.33 oz.
Color	GREY

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The ideal no-load motor speed is:

$$\frac{RPM}{V} = KV \quad RPM = V \cdot KV \quad RPM = 22.2 \cdot 300 \quad \mathbf{RPM = 6660}$$

6660 RPM represents a theoretical limit with no propeller. Under load, the propeller significantly reduces achievable RPM. For our tail-sitter VTOL, the highest motor speeds occur only during vertical takeoff and landing, when the propellers must generate the full aircraft weight in thrust. Once the aircraft transitions to sideways flight, lift is provided primarily by the wings and the propellers operate at substantially lower power and speed. Based on comparable motor and propeller data, a large/rough operating range is:

- ~5000 to 5500 RPM during vertical takeoff and landing (worst-case, short duration)
- ~3000 to 4000 RPM during transition and forward flight (longer duration)

Resulting excitation frequencies:

- Takeoff and landing BPF:

$$\frac{5500}{60} \cdot 2 \approx 183 \text{ Hz}$$

- Forward-flight BPF:

$$\frac{3000}{60} \cdot 2 = 100 \text{ Hz}$$

Higher harmonics exist at BPF * 2, 3, ... but contain significantly less energy.

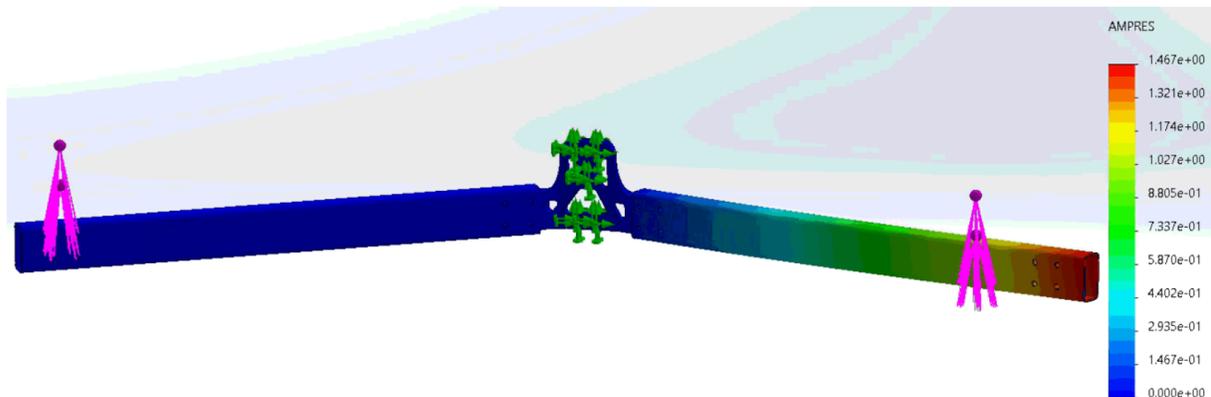
FEA Resonance Study

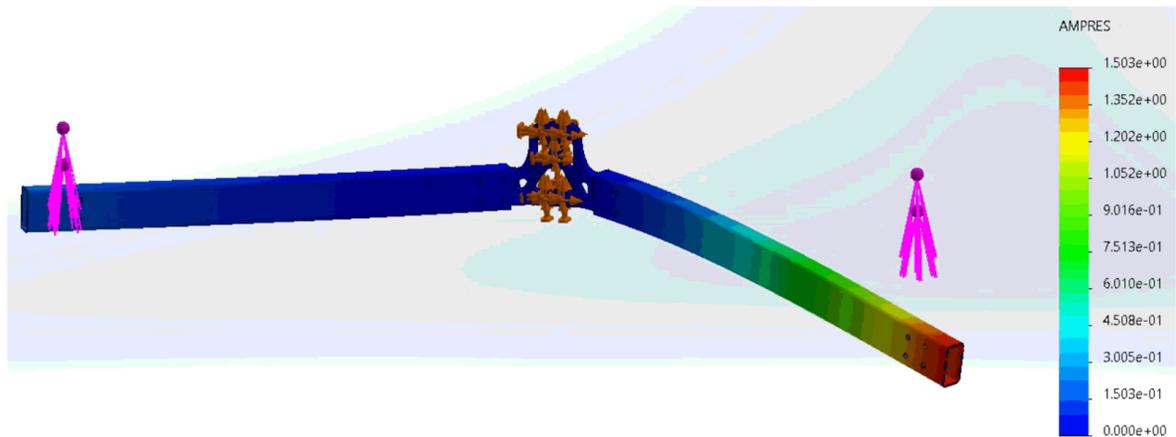
A modal analysis was performed in SolidWorks Simulations to determine the natural frequencies of the structure.

- Assembly consisting of a central aluminum Motor Junction & 2 orthotropic carbon fiber arms.
- All interfaces are bonded.
- Motors & Props represented with remote masses at their centers of gravity.

Modal Results

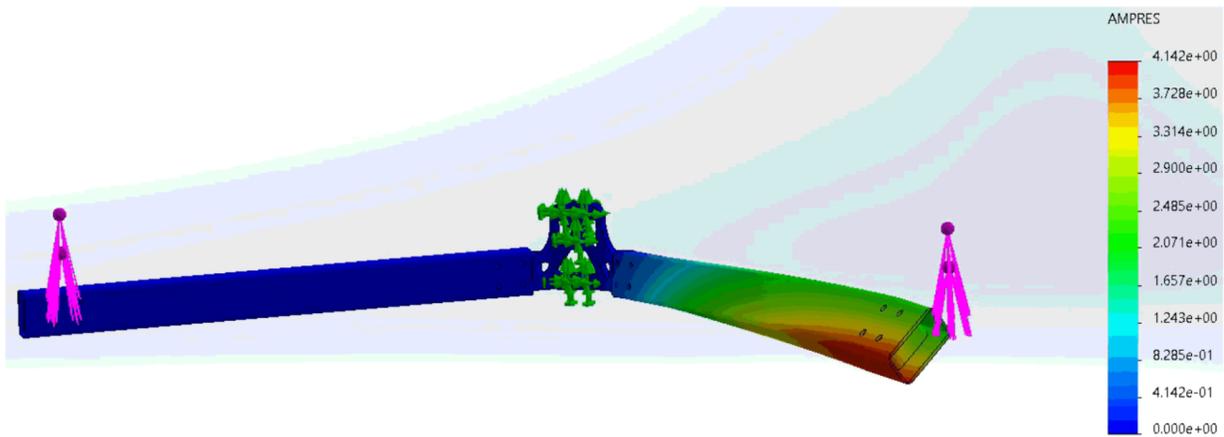
Large visual deformations are expected and are scaled for ease of interpretation. Only the mode shapes and their frequencies are meaningful.





Mode Shape 1: 21.8 Hz excites the right arm of the assembly to vibrate horizontally.

Mode Shape 2: 48.1 Hz excites the right arm of the assembly to vibrate vertically.



Mode Shape 3: 320.6 Hz excites the right arm of the assembly to vibrate torsionally.

The first five modes, appearing in closely spaced pairs due to slight asymmetry, are:

Modes	Right Arm	Left Arm
1 (Horizontal)	21.8 Hz	23.4 Hz
2 (Vertical)	48.1 Hz	49.4 Hz
3 (Torsional)	320.6 Hz	326.8 Hz
4	400.3 Hz	405.3 Hz
5	646.7 Hz	660.6 Hz

Higher-order modes (4, 5, ...) occur at much higher frequencies where the propeller produces far less vibration, and their deformation is more localized rather than affecting the whole structure. As a result, the first three modes (horizontal bending, vertical bending, and torsion) capture the behavior that matters most for resonance and are the focus of this analysis.

Resonance Assessment and Conclusion

- The primary excitation range of ~100-183 Hz does not coincide with any bending or torsional modes
- Low-frequency bending modes occur well below propeller excitation and are not strongly driven
- The first torsional mode occurs near 320 to 330 Hz, above the dominant excitation range
- Mode splitting due to asymmetry further reduces resonance risk

Based on both hand calculations and FEA results, the arm assembly is not susceptible to harmful resonance during operation and is considered safe for flight.