

Flight-Test-Based Evaluation of Voltage-Sag-Induced Hover Power Margin Reduction in a 210 kg-Class Multicopter eVTOL

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I. Nomenclature

P_{margin}	= hovering power margin [W or %]
P_{avail}	= available electrical power [W]
P_{hover}	= hover-required power [W]
V_t	= battery terminal voltage [V]
V_{oc}	= open circuit voltage [V]
R_{int}	= battery internal resistance [Ω]
I_{batt}	= battery discharge current [A]
SoC	= state of charge [%]
PII	= propulsion imbalance index based on per-channel electrical power [%]
N	= number of motor-inverter channels (= 4)
$P_{ch,i}$	= electrical input power of inverter channel i [W]
$V_{ch,i}$	= input voltage of inverter channel i [V]
$I_{ch,i}$	= input current of inverter channel i [A]

II. Introduction

Multicopter-type eVTOL aircraft sustain continuous high-power hover throughout most of their flight profile, placing the battery under prolonged high-rate discharge. This is fundamentally different from fixed-wing aircraft where cruise power is a fraction of climb power. For a 210 kg vehicle, the implication is that battery voltage sag the voltage drop caused by internal resistance under load—is not a transient concern but a sustained and growing one as the battery discharges.

Several recent studies have examined battery power limits for eVTOL platforms. Hatherall et al. [1] showed that the safe lower bound of battery reserve must be defined before the voltage collapse region, particularly during landing. Tu et al. [2] demonstrated that high C-rate discharge behavior is difficult to predict without physics-informed models. However, both works rely on laboratory characterization. There is a gap in the literature regarding flight-validated power margin data from a human-carrying Multicopter platform.

This study presents preliminary flight-test-based evidence and a measurement framework of this relationship on a human-carrying platform. A 210 kg-class prototype eVTOL developed at V-Space, a Korean-developed eVTOL with a custom battery pack was flown under hover conditions, and battery voltage behavior was recorded across the discharge cycle. The study quantifies how much the hovering power margin degrades over a single flight and across repeated operations without recharging.

III. Vehicle and Propulsion System

The test vehicle uses a symmetric four-arm layout with one 27 kW motor and one 30 kW inverter per arm. The single main battery pack (88S1P Li-ion, 325.6 V nominal, 7.16 kWh) feeds all four inverters through a shared high-voltage bus. Table 1 summarizes the key specifications

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Table 1. Test vehicle specifications.

Parameter	Value
MTOW	210 kg
Battery	88S1P Li-ion, 325.6 V, 7.16 kWh (22 Ah)
Inverter	30 kW $\times$ 4 (120 kW total)
Motor	27 kW $\times$ 4 (108 kW total)
Rotor	63 in diameter, 9.8 in pitch
Measured hover power	49.5 kW
Hover discharge rate	~6.9C (127 A at peak voltage)
FCC	ArduCopter-based
Flight Test Date	May 3, 2026

Photo 1. Test vehicle



Hovering power margin is defined as:

$$P_{\text{margin}} [\%] = (P_{\text{avail}} - P_{\text{hover}}) / P_{\text{avail}} \times 100 \quad (1)$$

At peak battery voltage (391.3 V measured), $P_{\text{avail}} = 120$ kW and $P_{\text{margin}} = (120 - 49.5) / 120 = 58.8\%$. This sets the starting point for margin analysis.

IV. Flight Test and Data Acquisition

Three sequential hover flights were conducted on May 3, 2026 at a dedicated test site under calm wind conditions (< 2 m/s), in altitude-hold mode, without recharging between flights. Battery terminal voltage was logged at 0.1-second intervals (10 Hz) via the onboard sensor, scaled at 1/4 ratio and corrected in post-processing. Per-channel inverter PWM commands and FCC flight logs were recorded simultaneously at 25 Hz and time-synchronized with the voltage data

Each hover phase was analyzed independently. In the present abstract, inter-channel behavior was assessed preliminarily using available voltage and inverter-command trends. In the full paper, the propulsion imbalance index (PII) will be calculated using per-channel electrical input power, defined as:

$$P_{ch,i} = V_{ch,i} I_{ch,i}$$

$$PII = \sigma(P_{ch,1...4}) / \mu(P_{ch,1...4}) \times 100 [\%] \quad (2)$$

V. Results

A. Voltage Behavior Across Three Flights

Figure 1 shows the battery terminal voltage profile across all three hover flights. As the battery progressively discharged across flights, both the starting voltage and minimum hover voltage decreased with each successive flight: Flight 1 began at 391.3 V and dropped to 362.0 V; Flight 2 began at 381.0 V and dropped to 360.0 V; Flight 3 began at 378.0 V and dropped to 355.0 V. The post-hover voltage recovery segments visible as the smooth rising curves between hover phases reflect open-circuit voltage rebound after high-current load removal [3].

[Figure 1: Battery terminal voltage vs. sample index full 3-flight session]

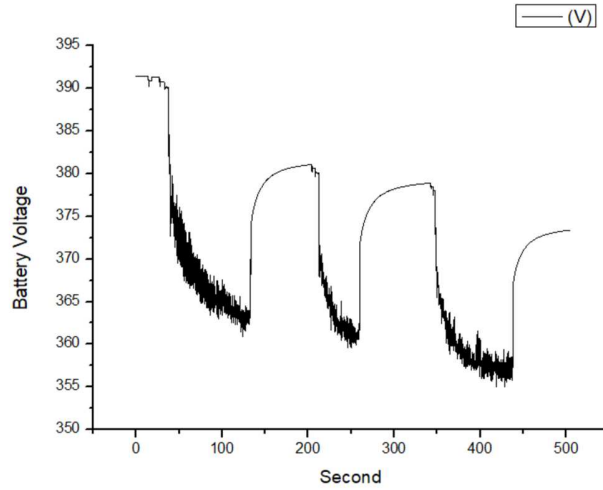


Table 2 summarizes the key voltage and power margin parameters for each flight. The data show a clear trend: as the battery discharges across flights, the minimum terminal voltage reached during hover decreases, the voltage sag depth increases, and the power margin at the lowest point narrows progressively.

[Table 2. Voltage sag and power margin summary across three hover flights.]

Parameter	Flight 1	Flight 2	Flight 3	Mean $\pm$ SD
Start Voltage [V]	391.3	381.0	378.0	383.4 $\pm$ 5.7
Min Hover Voltage [V]	362.0	360.0	355.0	359.0 $\pm$ 2.9
Voltage Drop [V]	29.3	21.0	23.0	24.4 $\pm$ 3.5
Voltage Drop [%]	7.5%	5.5%	6.1%	6.4% $\pm$ 0.8
P_margin End [%]	55.4	56.3	56.1	55.9 $\pm$ 0.4
P_margin Drop [%p]	3.3	2.4	2.7	2.8 $\pm$ 0.4

B. Power Margin Degradation

Using the measured voltage profile and estimated nominal hover power of 49.5 kW, the end-of-hover power margin was calculated for each flight. For this preliminary voltage-based analysis, P_{avail} was estimated by scaling the rated inverter power with the measured terminal voltage relative to the peak-voltage condition, assuming current-

limited operation. Flight 1 showed the largest margin reduction (3.3%p), as it started from the highest initial voltage (391.3 V) and experienced the greatest absolute voltage drop (29.3 V). Flights 2 and 3 showed reductions of 2.4%p and 2.7%p respectively, as starting voltages were lower due to cumulative battery discharge. Across all three flights, the mean margin reduction was 2.8 ± 0.4 percentage points, demonstrating good repeatability. The end-of-hover power margin consistently remained above 55%, confirming adequate operational reserve within this test envelope.

$$P_{\text{margin,end}} = (P_{\text{avail,end}} - 49.5) / P_{\text{avail,end}} \rightarrow 55.4\%, 56.3\%, 56.1\% \quad (\text{Flights 1, 2, 3}) \quad (3)$$

C. Progressive Discharge Across Flights

A key observation is the progressive shift in baseline voltage across successive flights. The minimum hover voltage decreased from 362.0 V (Flight 1) to 360.0 V (Flight 2) to 355.0 V (Flight 3), indicating cumulative battery depletion between flights. This 7 V progressive decline in minimum hover voltage across three flights without recharging demonstrates that repeated operations systematically erode the available power margin. If continued, this trend may eventually approach the lower-voltage operating region where power margin degradation is expected to accelerate [1, 3].

D. Preliminary Inter-Channel Behavior and Planned Power-Based Imbalance Analysis

Within each hover window, the four inverter channels showed uniform input-voltage trends because they were supplied by a common high-voltage bus. Therefore, the voltage-based channel variation observed in the present dataset should be interpreted only as a preliminary consistency check, not as a direct measure of propulsion imbalance. In the full paper, the propulsion imbalance index will be calculated using per-channel electrical input power, based on synchronized measurements of inverter input voltage and current. This expanded dataset will allow direct estimation of channel-wise electrical power distribution, voltage-sag-induced power margin degradation, and propulsion imbalance during repeated hover operations.

VI. Conclusion

Flight test data from a 210 kg-class multicopter eVTOL across three sequential hover flights confirm that battery voltage sag is a measurable and quantifiable factor in hover power margin. Across all three flights, terminal voltage dropped between 21.0–29.3 V (5.5–7.5%) during hover, with hovering power margin declining from an initial 58.8% to 55.4–56.3% (mean: $55.9 \pm 0.4\%$) — a mean reduction of 2.8 ± 0.4 percentage points. Critically, the minimum hover voltage decreased across successive flights (362.0 → 360.0 → 355.0 V) as the battery depleted without recharging, indicating that cumulative discharge across repeated operations progressively narrows the available power margin. These results motivate further development of minimum landing SoC criteria and multi-flight energy management strategies for large-scale UAM operations.

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