STRATUS AUTONOMOUS

SA-WP-001 Rev 0.1

Comparative Flight Evaluation of M420 Industrial UAV Platforms Using Hobbywing X9 and X9 Plus Propulsion Systems

Preliminary Assessment for Aerial Cleaning Applications

PRELIMINARY ENGINEERING WHITE PAPER - TEST PROGRAM IN PROGRESS

S1 / Red: M420 + Hobbywing X9 propulsion
S2 / Blue: M420 + Hobbywing X9 Plus propulsion

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Document Control

Field	Value
Document ID	SA-WP-001
Revision	Rev 0.1
Status	Preliminary - active test program
Publication intent	Engineering Research & Validation / Ongoing Projects
Aircraft	S1 (Red) and S2 (Blue) M420 aerial-cleaning prototypes
Study focus	Effect of propulsion-system scaling on cleaning-flight performance
Data basis	ArduPilot flight logs, battery/charger measurements and field observations
Scope	Preliminary field evaluation; final commercial limits are not yet established.

Abstract

This paper presents a preliminary comparative field evaluation of two M420-class industrial multirotor aircraft configured for aerial cleaning. S1 (Red) uses the Hobbywing X9 propulsion package and represents the current baseline cleaning configuration. S2 (Blue) uses the larger X9 Plus propulsion package as a propulsion-scale variant. The study asks a focused engineering question: what changes when the propulsion package is enlarged while the aircraft class, 14S architecture and intended cleaning mission remain comparable?

The present datasets show that **both S1 and S2 are stable, healthy and viable aerial-cleaning platforms**. S1 has already demonstrated approximately 30-minute cleaning-style endurance in the field and provides the established baseline against which S2 is being evaluated. S2 shows a lower normalized propulsion command and tighter tracking in the specific comparison flights, consistent with the expected effect of its larger propulsion package. These observations do not make S1 inferior: they describe two different propulsion operating points and do not by themselves establish superior cleaning productivity, endurance, safety, maximum height or commercial value.

Battery recharge measurements for the referenced flights are close in absolute capacity returned, while the flights were not sufficiently matched to assign an endurance advantage to either aircraft. Rev 0.1 therefore treats S1 as the validated baseline configuration and S2 as the higher-propulsion-reserve test configuration, with future standardized testing intended to determine where each configuration offers the strongest operational value.

1. Study Objective and Research Question

The purpose of SA-WP-001 is not to rank S1 and S2 from best to worst. It is to characterize how two propulsion packages change the behavior of the same class of industrial cleaning UAV and to determine whether those differences support distinct contractor use cases.

> **Research question: How does changing from X9 to X9 Plus propulsion affect usable cleaning performance, energy use, control margin and operating envelope on the M420 platform?**

1.1 Working Hypotheses

- **H1 - Baseline capability:** S1 will continue to provide stable, practical aerial-cleaning performance with useful endurance and adequate control reserve for routine contractor operations.
- **H2 - Propulsion reserve:** S2's larger X9 Plus package will operate at a lower normalized propulsion command for comparable aircraft demand, leaving additional control/thrust reserve.
- **H3 - Energy trade:** greater propulsion reserve does not automatically mean greater endurance; standardized testing is required to determine the energy cost or benefit.
- **H4 - Product differentiation:** the two aircraft may ultimately serve different operating priorities rather than one replacing the other.

2. Aircraft Configurations

Attribute	S1 / Red	S2 / Blue
Platform	M420-class quadcopter	M420-class quadcopter
Role in study	Established baseline cleaning configuration	Propulsion-scale comparison configuration
Propulsion	Hobbywing X9	Hobbywing X9 Plus
Electrical architecture	14S	14S
Battery class	14S 40 Ah	14S 40 Ah
Flight controller	Pixhawk 6C / ArduCopter	Pixhawk 6C / ArduCopter
Cleaning hardware	Sprayer installed and flight tested	Sprayer integration/validation progressing
Primary value under study	Practical endurance, stable routine cleaning	Additional propulsion/control reserve

Because S1 already carries the representative sprayer configuration while S2's final cleaning configuration is still being completed, the present paper avoids treating every numerical difference as a direct product-performance ranking.

3. Instrumentation and Method

- ArduPilot .BIN flight logs from Pixhawk 6C flight controllers.
- ATT data for commanded-versus-actual roll, pitch and yaw behavior.
- CTUN data for normalized propulsion demand and flight-control behavior.
- Motor-output data for relative loading and control distribution.
- IMU vibration and clipping records as aircraft-health indicators.
- GPS data for flight context, altitude, speed and positioning quality.
- Pack voltage and Ultra Power 14S charger measurements, including individual cell voltage and returned capacity.
- Operator observations and cleaning-style Loiter maneuvering.

Energy comparisons in this revision rely primarily on independent battery/charger observations rather than presenting internal current-sensor troubleshooting. Instrumentation-development details are maintained in Stratus internal engineering records and are outside the scope of this public propulsion study.

4. Field-Test Context and Limitations

Testing is conducted outdoors under practical field conditions. The two aircraft cannot currently be transported and recharged at the range for same-day back-to-back testing, so comparative runs occur on separate days. This is acceptable for a preliminary field study provided environmental conditions, payload state and mission profile are documented and the results are not represented as laboratory-controlled A/B testing.

The representative cleaning mission is low-speed Loiter operation with repeated lateral passes, stops, reversals and vertical repositioning. These motions are more relevant to a professional washer than maximum-speed or maximum-altitude demonstrations.

For this program, useful cleaning capability matters more than absolute flight capability: stable positioning, practical endurance, hose/spray tolerance and adequate reserve near the work surface.

5. What S1 Has Already Established

S1 is not the 'lower-performing' aircraft in this study. It is the **baseline platform that established the cleaning mission** and provides the reference against which propulsion scaling is being evaluated.

S1 evidence	Current observation	Operational meaning
Cleaning-style endurance	Approximately 30 min demonstrated in the referenced field test	Strong starting point for practical contractor mission planning
Representative payload	Sprayer installed during S1 development/testing	Closer to the intended commercial cleaning configuration
Flight-control behavior	Stable Loiter operation with cleaning-like passes	Suitable baseline for precision low-speed work
Attitude tracking	Mean errors remained well below 1 degree in the compared dataset	High-quality control performance
Mechanical health	Zero IMU clipping; stable flight behavior	No flight-limiting mechanical issue identified
Battery condition	Excellent 14S cell balance before/after charge	Healthy energy-storage behavior
Development maturity	Battery calibration and repeated flight testing completed	More mature baseline dataset than S2

These points are important because a larger motor package is an engineering option, not evidence that the baseline propulsion system is inadequate.

6. Propulsion Operating Point

Metric	S1 / Red	S2 / Blue	Interpretation
Mean normalized throttle in compared flights	~0.200	~0.160	S2 required a lower normalized command
Relative difference	Baseline	~20% lower command	Consistent with larger propulsion package
Control saturation	Not observed	Not observed	Both retained control margin
Flight stability	Stable	Stable	Both suitable for continued testing

The approximately 20% difference is **not a statement that S2 is 20% better**. CTUN.ThO is a normalized control quantity, not a direct measurement of cleaning productivity, thrust margin in pounds, electrical efficiency or commercial capability. The result simply confirms that the larger X9 Plus package reaches the evaluated flight condition at a lower normalized command.

For S1, a mean value near 0.20 also indicates substantial remaining command range in the evaluated mission; the flight data do not show S1 operating near propulsion saturation.

7. Flight-Control Performance

Metric	S1 / Red	S2 / Blue	Assessment
Mean roll tracking error	~0.36 deg	~0.20 deg	Both very small
Mean pitch tracking error	~0.51 deg	~0.26 deg	Both very small
Mean yaw tracking error	~0.89 deg	~0.47 deg	Both below 1 deg
Overall result	Excellent baseline tracking	Excellent tracking	Difference is preliminary, not a product ranking

Both aircraft demonstrate high-quality attitude control. S2 produced smaller errors in the selected flights, but the practical significance for cleaning quality has not yet been established. Wind, maneuver profile, payload state and tuning can influence these values. The correct public conclusion is therefore that **both aircraft tracked commanded attitude accurately**, with S2 showing a favorable preliminary trend that will be retested under standardized conditions.

8. Mechanical and Vibration Health

Health indicator	S1 / Red	S2 / Blue
IMU clipping	0	0

Health indicator	S1 / Red	S2 / Blue
Flight-control stability	Stable	Stable
Flight-limiting vibration event	None observed	None observed
Mechanical anomaly affecting evaluated flight	None identified	None identified
Current assessment	Healthy	Healthy

Both configurations demonstrated healthy mechanical behavior in the evaluated datasets. No accelerometer clipping or flight-limiting vibration event was recorded. Numerical vibration differences between unmatched field flights are not used in Rev 0.1 to characterize one product as mechanically superior to the other. Standardized repeated runs will be required before vibration differences are treated as a configuration-level finding.

9. Battery, Endurance and Energy

Observation	S1 / Red reference	S2 / Blue reference
Approx. flight duration	~30 min	~26.5 min
Post-flight resting pack voltage	~52.6 V	52.7 V
Full-charge voltage	58.8 V	58.8 V
Returned capacity	17.532 Ah	17.127 Ah
Cell balance after charge	4.19-4.20 V/cell	4.19-4.20 V/cell
Interpretation	Strong demonstrated endurance baseline	Comparable absolute energy replacement in a different flight profile

S1's approximately 30-minute field result is a meaningful positive result and should be recognized as such. The S2 flight was shorter and used a different profile, so dividing returned capacity by flight time and declaring an efficiency winner would overstate the evidence.

The present data support only this conclusion: **both aircraft completed substantial flight periods while using less than half of the nominal 40 Ah pack capacity as measured by recharge replacement**, and both batteries remained very well balanced. Standardized mission-profile testing is required to establish usable endurance with an operational reserve.

10. Balanced Operational Interpretation

Operational priority	S1 / Red - evidence today	S2 / Blue - evidence today
Routine cleaning mission	Demonstrated with representative sprayer configuration	Cleaning configuration still being completed/validated
Endurance	~30 min demonstrated in referenced cleaning-style test	Not yet directly comparable
Propulsion operating point	Low normalized demand with substantial remaining range	Still lower normalized demand in evaluated flight
Control precision	Excellent	Excellent; smaller errors in selected dataset
Mechanical health	Healthy	Healthy
Higher-demand hose/wind work	Adequate capability shown; limits not established	Additional reserve is plausible but not yet validated
Maximum usable cleaning height	Not established	Not established
Commercial positioning	Strong baseline professional cleaner	Potential higher-reserve variant

11. What Can Be Said Publicly Today

- **S1 has demonstrated approximately 30 minutes of cleaning-style flight** in the referenced field test with a representative sprayer configuration.
- Both S1 and S2 demonstrated stable flight-control behavior and zero IMU clipping.
- Both aircraft maintained small attitude-tracking errors; S2 showed smaller errors in the selected comparison dataset.
- S2 operated at a lower normalized propulsion command in the selected flight, consistent with its larger X9 Plus propulsion package.
- Both 14S battery datasets showed excellent cell balance after flight and recharge.
- The current evidence does not establish a final endurance, cleaning-height, wind, payload or productivity winner.

12. What Should Not Be Claimed Yet

- S2 is categorically 'better' than S1.
- S1 is underpowered for professional cleaning.
- S2 has a validated higher maximum cleaning height.
- S2 has a validated hose-load or wind-limit advantage.
- S1 has a validated efficiency advantage.
- Either aircraft has a quantified productivity or safety advantage over the other.
- Single-flight numerical differences represent final commercial specifications.

13. Product Differentiation - Current Working Model

The appropriate working model is not 'basic versus superior.' It is **baseline efficiency and maturity versus additional propulsion reserve**. Final positioning should follow the test data.

Potential position	S1	S2
Development role	Established cleaning baseline	Propulsion-scale variant
Current strength	Mature cleaning configuration and demonstrated endurance	Additional propulsion reserve indicated
Likely future emphasis	Routine professional cleaning, endurance, operating economy	Demanding operating conditions if reserve advantage is validated
Status	Already strong enough to remain a standalone product path	Must prove that extra propulsion produces useful contractor value

A motor upgrade is only valuable if the additional reserve produces a measurable operational benefit. SA-WP-001 is designed to determine whether it does.

14. Follow-On Validation Program

Test	Purpose	Decision it supports
CMP-1 standardized cleaning profile	Repeat 20-min cleaning-style mission on both aircraft	True energy/endurance comparison
CMP-2 repeatability	Minimum three comparable runs per configuration	Separate aircraft trend from one-off flight variation
HL-1 hose-load test	Add actual suspended hose load	Determine whether S2 reserve creates useful hose capability
HT-1 cleaning-height progression	Progressive height with real hose configuration	Establish usable cleaning-height envelope
WD-1 wind/disturbance test	Document wind and repeat defined maneuvers	Quantify disturbance rejection

Test	Purpose	Decision it supports
SP-1 pressurized spray test	Operate actual pressure/nozzle system	Measure spray-reaction effects
END-1 operational endurance	Use defined reserve/termination criteria	Publish contractor-relevant usable flight time

15. Preliminary Conclusions

Rev 0.1 establishes S1 and S2 as **two healthy M420 aerial-cleaning configurations at different propulsion scales**. S1 provides the stronger baseline evidence today because it has the representative sprayer configuration, repeated development history and an approximately 30-minute cleaning-style endurance result. Its flight-control tracking is excellent, it operated far from obvious saturation in the evaluated mission, and no flight-limiting mechanical-health issue was identified.

S2's larger X9 Plus package produces the expected lower normalized propulsion operating point and showed favorable tracking in the selected dataset. Those are promising engineering results, but they are not yet proof of greater commercial cleaning capability. The next phase must determine whether the additional propulsion reserve translates into measurable advantages under hose load, wind, height and pressurized-cleaning conditions.

Accordingly, SA-WP-001 does not identify a winner. It establishes a baseline and an upgrade path, then defines the tests required to determine where each configuration delivers the greatest value to a professional cleaning operator.

Rev 0.1 conclusion: S1 is the established, capable cleaning baseline. S2 is the higher-propulsion-reserve variant under evaluation. Neither configuration is designated superior until standardized operational testing demonstrates a contractor-relevant advantage.

16. Publication Status

This document is intended for the Stratus Autonomous Projects / Engineering Research & Validation section as a preliminary technical publication. Results should be presented as ongoing engineering evidence, not finalized product specifications. Future revisions will replace preliminary single-flight comparisons with standardized multi-run data and validated operational envelopes.