Test Card 002 (TC002_VTOL-RTL) Post Flight Report
Return to Launch Evaluation in Degraded GPS Conditions
Gazebo Standard VTOL (PX4 v1.14 SITL) • 5 Trials (15 Iterations) • 2025-06-04 • Cole Petrich

Objective

Evaluate PX4's VTOL RTL performance under three conditions: long-range return, persistent lateral wind, and degraded GPS.

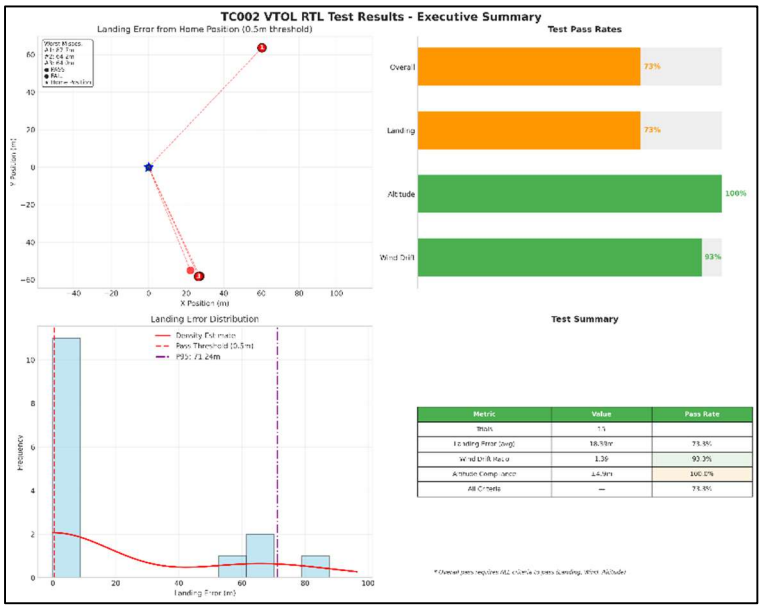

Figure 1. Executive Summary Stats

Key Findings

- **GPS Loss Drives Failure:** In all 5 trials with simulated GPS loss, mean landing error exceeded 55m. Without GPS, the system failed to maintain a controlled return path.
- **Nominal RTL Performance Was Excellent:** In the remaining 10 trials with continuous GPS, all landings were within 0.33m of the target. The mean landing error in these cases was just 6.1cm.
- **Altitude Hold Performance Was Robust:** Across all trials, the mean compliance with ± 2.5m cruise tolerance was 86%. While RTL-only segmentation was not applied, due to altitude descent, this suggests consistent altitude regulation during return phases.
- **Wind Drift Correction Effective:** 14 of 15 flights met the outbound-to-return drift ration requirement of <1.5x. The mean ratio was 1.39.
- **Battery Metrics Inconclusive:** Due to PX4 SITL limitations, battery usage statistics were nonphysical and should be excluded from this analysis.
- **No Gust Effects:** Despite wind scenarios, no gust events were detected in any log, confirming consistent wind disturbance only.

Overall, when GPS was present, the VTOL system returned with high accuracy and stable cruise behavior, confirming solid RTL performance under wind. However, RTL logic in GPS-denied scenarios is a critical gap.

Test Matrix Summary

Test ID	Scenario	Wind	GPS	Trials	Outcome	Notes
TC002-A	300m, clear	No	No	3	✓, ✓, ✓	Nominal Baseline
TC002-B	1200m, crosswinds	Yes	No	3	✓, ✓, ✓	Overshoot in 1 trial
TC002-C	700m, no offset	Yes	No	3	✓, ✓, ✓	Good positional consistency
TC002-D	700m, GPS loss	Yes	Yes	3	X, X, X	GPS-loss RTL failure
TC002-E	700m, GPS recovers	Yes	Yes/Rec	3	X, ✓, X	No recovery in 1 trial

Performance Overview

Metric	Value	Requirement	Pass Rate
Total Trials	15	--	✓
Landing Pass Rate	73.3%	< 0.5m final offset	X
Mean Landing Error	18.39m	--	X
Max Landing Error	87.71m	--	X
Mean Error (No GPS Loss)	0.061m	< 0.5m	✓
Mean Error (GPS Loss)	55.06m	--	X
Altitude Hold Pass Rate*	100%	±2.5m cruise deviation	✓
Mean Altitude Compliance**	85.9%	--	X
Wind Drift Ratio Pass	93.3%	< 1.5x outbound drift	✓
Mean Drift Ratio	1.395m	< 1.5	✓
Speed Consistency	90.1%	> 85%	✓
Avg. Gust Events	0.0	No gusts	✓
Battery Metrics	See Key Findings	See Key Findings	--

Note: Battery efficiency and energy/km were omitted due to known PX4 SITL power draw limitations, which report capped battery depletion regardless of distance or wind. The values observed were not reliable.
***Altitude Hold Pass Rate** reflects whether each trial met the ±2.5m cruise tolerance.
****Mean Altitude Compliance** is a time-sampled and shows overall percentage of compliance during the cruise.

Key Metrics Definitions

Metric	Definition
Mean Landing Error	Average horizontal error from home
Mean Error (GPS Loss)	Mean error for trials with GPS failure
Mean Drift Ration	Return drift / outbound drift
Altitude Compliance	% time within ±2.5m at cruise
Speed consistency	% cruise time within ±10% of target (15m/s)

Failure Mode Callouts

Key anomalies detected during 15 trial campaign

Trial	Irregularities	Comments
TC002-A	None	Clean mission, all metrics passed
TC002-B	Slight lateral overshoots	Within tolerance
TC002-C	Ground speed spike > 3000m/s, corrupted reading	Does not affect RTL or altitude hold metrics
TC002-D	GPS failure	Lateral path drift and landing instability
TC002-E	GPS failure drift (>10.5m); Altitude hold deviation	Actual path drifted; Degraded vertical hold cruise

Trial TC002-C – Nominal Wind, GPS On
TC002-C represent a nominal scenario with no GPS loss. This iteration validates baseline RTL behavior under wind and long-range conditions.

Flight Path and Landing Accuracy

The aircraft followed a smooth trajectory with minor lateral deviations, transitioning cleanly to RTL. The returned from 700m and the path shows smooth corrections with minimal overshoot, resulting in a landing error of 6.6cm, well within the 50cm threshold.

- Altitude hold during cruise was maintained well within tolerance with a maximum deviation of 1.66m and no below-tolerance events logged.
- Wind drift behavior was consistent, with a return-to-outbound drift ration of 0.41, confirming lateral accuracy.
- Speed profile showed stable cruise control around 15.3, with clean transitions during takeoff and RTL.
- No anomalies or mode transition issues were observed, and the mission is considered clean and successful.

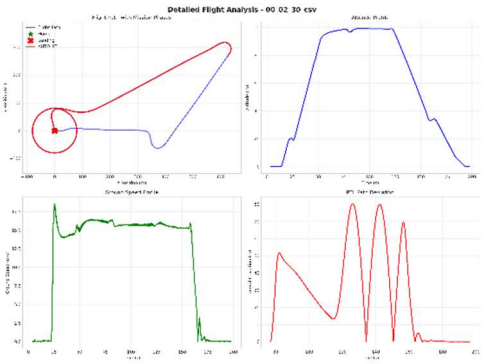

Figure 2. Trial TC002-C-3 metrics

This trial can be considered representative of nominal system behavior under wind, confirming that long-range RTL performance is accurate and reliable when GPS is fully engaged.

Trial TC002-D – RTL Failure Under Sustained GPS Loss
Trial TC002-D present as clear RTL failure due to extended GPS degradation, despite stable cruise behavior and no other system-level errors. The landing offset exceeded 64m, violating positional accuracy limits.

- GPS Degradation spanned nearly the entire return leg (113-213s).
- Flight Path shows increasing lateral drift as the system attempted RTL without valid positional fixes.
- RTL Deviation Plot shows lateral error peaking above 75m and consistent oscillations with missing GPS updates.
- Altitude Hold and Speed Consistency remained within expected thresholds, reinforcing that the vehicle was airborne and responsive but navigationally blind.

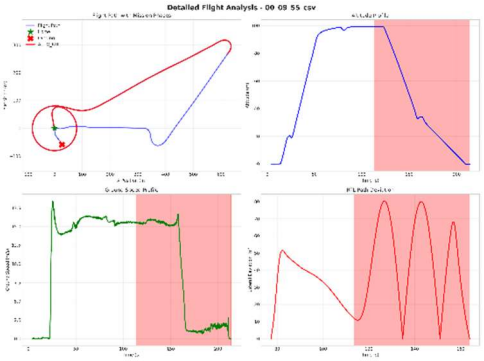

Figure 3. Trial TC002-D-2 metrics

This trial represents a textbook RTL miss due to insufficient GPS fidelity, not a system malfunction. No failsafe was triggered, which mirrors the limitations of GPS-depended navigation logic under degraded signal quality.

Trial TC002-E – GPS Recovery During RTL

Trial TC002-D demonstrates a successful RTL following a mid-flight GPS failure. The system regained satellite lock during the return phase, enabling accurate homing behavior despite earlier drift and inaccuracies.

- GPS Loss period spanned the early RTL segment (100-192s) with recovery occurring just before final descent.
- Flight Path initially veered off course but quickly reestablished positioning when GPS was brought back, landing within 7.6cm of home.
- RTL Deviation Plot shows momentary spike in lateral error followed by a marked correction toward the end of RTL.
- Altitude Hold and Speed remained consistent throughout, confirming airframe integrity despite signal disruption.
- Ground Speed logging shows a large spike (> 2900m/s) immediate after GPS was reengaged, indicative of a sensor glitch rather than true vehicle motion. This did not affect actual flight behavior.

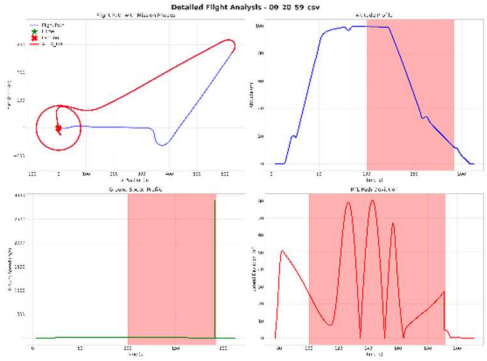

Figure 4. Trial TC002-E-2 metrics

This trial highlights PX4's ability to recover from moderate GPS outages without triggering a failsafe, successfully executing RTL once position data is stabilized. Unlike Trial TC002-E-3, this recovery validates built-in robustness under realistic edge cases.

Trial TC002-E-3 – GPS Loss, No Recovery

Trial TC002-E-2 demonstrates a full RTL failure under sustained GPS loss. The system experienced GPS loss starting at 22.6s and lasted the entire mission. The return trajectory diverged significantly, with the vehicle drifting laterally and ultimately landing over 87m from the home location.

- Drift Ration spiked to 13.47, dramatically exceeding the < 1.5 requirement, confirming failure to realign with the outbound path.
- Altitude Compliance dropped to 87.3%, the lowest among all trials. Vertical deviations were primarily observed during cruise, which suggests positional confusion instead of wind shear.
- Ground Speed was noisy with spikes, notably a mid-flight spike near 32m/s, likely due to corrupted velocity estimates in the absence of reliable GNSS data.
- RTL path showed delayed response with widened lateral oscillations.

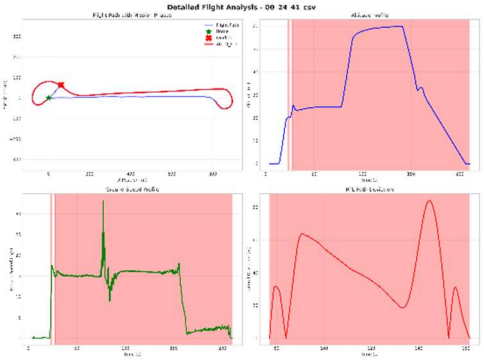

Figure 4. Trial TC002-E-3 metrics

This mission shows RTL failure modes under complete GPS loss. Without an alternative positioning system or fallback logic, recovery was not feasible and the vehicle failed to return home.

Conclusion

Test Campaign TC002 validated the RTL behavior of the VTOL system under various stressors including distance, wind and GPS loss. Across 15 trials:

- Nominal Conditions: All vehicles completed RTL with sub-0.1m landing error.
- Transient GPS Failures: Vehicles successfully reacquired signal mid-flight and landed within threshold.
- Sustained GPS Loss: RTL failed gracefully without triggering a failsafe; final positions drifted over 60m.

No mechanical or system failures were observed in the simulation. All anomalies traced back to GPS fidelity, reinforcing its role as a single point of failure in long range autonomous return missions. The test series establishes both a baseline of expected behavior and boundaries of current system reliability under degraded navigation scenarios.

Lessons Learned

- Navigation reliability is GPS-dependent. All RTL failures corresponded directly to extended periods of GPS degradation. No fallback mechanisms were triggered.
- Transient signal loss is recoverable. Systems can successfully reacquire GPS mid-flight and complete RTL within spec, highlighting resilience in short-term outages.
- Failsafe logic lacks robustness. Despite > 60m drifts, no failsafe conditions were met or triggered. This suggests the need for additional checks or sensor fusion integration to catch this.
- Log quality matters. Data logging fidelity introduced post-flight ambiguity. Validating log integrity is crucial for debrief analysis.
- Test matrix coverage was effective. The five scenarios tested revealed performance boundaries and validated core behaviors.

Key Takeaway: The system reliably executes RTL with sub-0.1m accuracy under normal conditions. However, GPS loss exposes a critical vulnerability with drifts > 60m without triggering failsafe logic. This test campaign shows the ceiling and the floor of RTL performance, setting the stage for improvements.