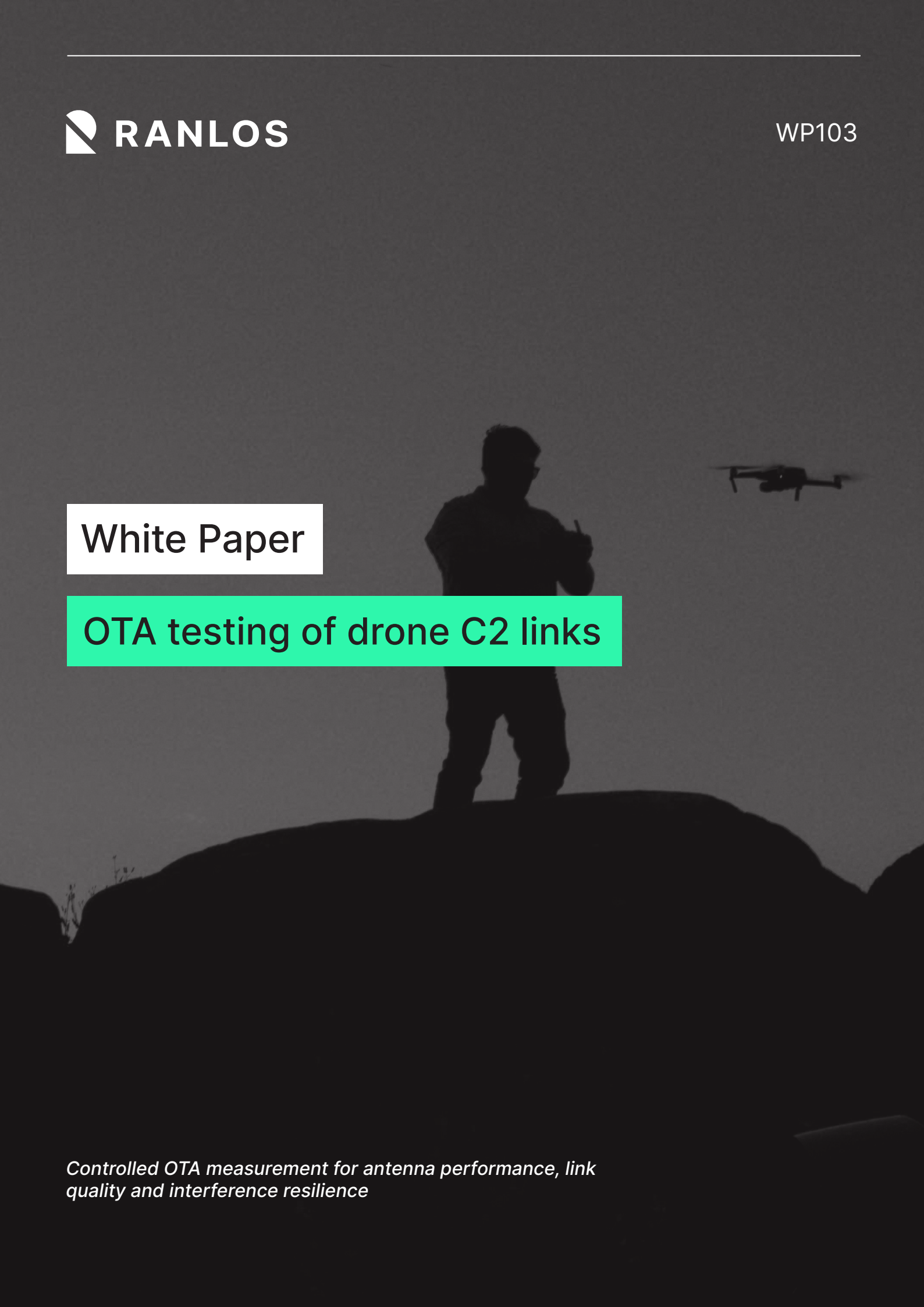
RANLOS

WP103



White Paper

OTA testing of drone C2 links

Controlled OTA measurement for antenna performance, link quality and interference resilience

Introduction

The C2 (Command & Control) link is the drone's lifeline. It carries control commands on the uplink and telemetry on the downlink, and is decisive for flight safety, certification and the ability to operate beyond visual line of sight (BVLOS). A link that loses margin at the wrong range, the wrong orientation, or in the presence of an interferer can, in the worst case, mean loss of control of the aircraft. Under EU Regulation 2019/947, BVLOS operations fall into the Specific or Certified category, where demonstrated performance – not just design compliance – is increasingly important.

Today, link stability is verified primarily through field testing: the drone is flown at various distances and the link behavior observed. This method is weather-dependent, requires airspace clearance, is hard to repeat, and gives late and costly feedback when a design needs to change. Root causes are also difficult to isolate when everything varies at once.

With RanLOS test solutions, the measurement moves into a controlled chamber or test environment. Distance, drone orientation and interference can be controlled exactly and repeatably – making it possible to characterize antenna performance, link quality and interference resilience systematically, rather than by trial and error. This white paper describes how.

Fact box: definitions and terminology

- C2 link (Command and Control link): the wireless data link between a drone and its ground control station, carrying control commands on the uplink and telemetry on the downlink. The primary safety-critical communication link in any drone system.
- BVLOS (Beyond Visual Line of Sight): drone operations where the pilot cannot maintain direct visual contact with the aircraft. Requires regulatory approval and demonstrated communication reliability in most jurisdictions.
- OTA testing (Over-the-Air): testing of a complete, integrated wireless system in its real configuration – not individual components in isolation.
- LOS / plane-wave field: Line-of-Sight propagation, where the direct signal path dominates. BeamForce reproduces this condition in a compact chamber by generating a well-defined plane-wave field over the test zone.
- 3D radiation pattern: the antenna's gain as a function of direction – how signal strength varies depending on the orientation of the aircraft. Reveals nulls and asymmetries caused by the airframe, propellers and payload.
- BER / BLER (Bit Error Rate / Block Error Rate): metrics describing how many bits or blocks in a data stream are received incorrectly. Used to characterize link quality and sensitivity thresholds.
- C/I (Carrier-to-Interference ratio): the ratio of the desired signal to an interfering signal. A key measure of interference resilience.
- SINR (Signal-to-Interference-and-Noise Ratio): combined measure of signal quality under interference and noise conditions.

The challenge: verifying a C2 link in flight

A C2 link must hold throughout the mission, regardless of how the aircraft moves. Three factors simultaneously affect the link margin and constitute the stressors that must be characterized:

- Distance. Free-space path loss grows with distance and consumes the link budget as the drone moves away from the ground station.
- Orientation. As the drone yaws, rolls and pitches, the antenna points in different directions. The airframe, propellers and payload create nulls and asymmetries in the radiation pattern that can weaken the link in certain attitudes.
- Interference. Other transmitters, or deliberate jamming, lower the signal-to-interference ratio and can take the link down entirely.

Field testing addresses these factors in an uncontrolled way. Results are hard to repeat, no single cause can be isolated, and every design change requires a new measurement campaign with its associated time, cost and risk. This easily leads to a trial-and-error process in which shortcomings are discovered late.

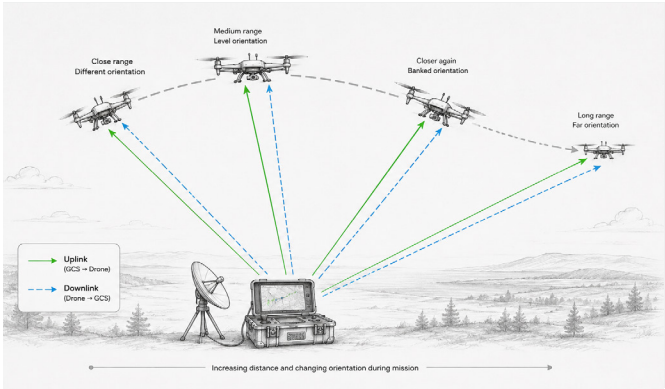


Figure 1: Shows a typical C2 communication link in flight. Drone in the air with clear line of sight to a ground control station (GCS). The figure shows the uplink and downlink and how distance and drone orientation change during the mission – it is important that the real conditions are recreated in the chamber measurement to obtain useful and accurate measurements.

The RanLOS method: a controlled LOS environment

RanLOS is based on the LOS/RLOS methodology from Chalmers University of Technology. BeamForce generates a well-defined plane-wave field – a far-field LOS condition – over the test zone in a compact chamber. The drone's antenna therefore sees the same kind of propagation as in real line-of-sight flight, but in an environment where every parameter is known and controllable.

Three decisive properties:

- **Repeatability.** Identical conditions at every measurement allow design A and design B to be compared fairly – any difference in results is due to the design, not the weather.
- **Isolation.** The shielded chamber excludes external signals, so that exactly what is intended is measured – and so that interference measurements can be performed without leaking out.
- **Speed.** Because the environment is controlled, fast and unambiguous answers to design changes are obtained – often the same day.

This is the difference between systematic engineering and trial and error: in the chamber, one variable at a time can be isolated, varied and quantified.



Figure 2: Measurement setup in the chamber. The drone mounted on a positioner in front of the BeamForce system, connected to the measurement software RanLOS BeamLab.

Measurement capabilities

3D radiation pattern and distance sensitivity

The drone is placed on a positioner in the test zone. By rotating the aircraft in azimuth and elevation, the C2 antenna's radiation pattern is characterized in three dimensions – the antenna gain as a function of direction. This reveals the nulls and asymmetries caused by the airframe, propellers and payload.

To capture the influence of distance, no long measurement range is needed. A variable attenuator in the signal path is used to determine how distance affects signal quality and receiver thresholds. Because free-space path loss follows the Friis transmission equation, a given attenuator setting can be translated mathematically into a corresponding real-world distance – the attenuator simply stands in for the propagation path.

A key simplification follows from physics: distance does not change how the antenna radiates in different directions. The relationship between attenuation (distance) and the receiver thresholds therefore needs to be characterized in only one direction. That single result can then be applied to the full 3D radiation pattern, yielding the distance sensitivity in every direction around the antenna and the drone – without sweeping the attenuator at each orientation. This directly answers the question of how stable the link is at varying distance during flight, for every orientation the aircraft may assume.

Active measurements: throughput, BER and thresholds

Beyond passive antenna measurements, BeamForce enables active measurements with live communication traffic. A communication tester is connected to BeamForce via BeamLab, and the link's actual performance can be quantified over the air:

- BER and BLER – bit error rate and block error rate
- Sensitivity thresholds – the level at which the link begins to break
- Modulation sensitivity – which modulations / MCS still sustain the link
- Throughput (capacity)

By studying these measurements against emulated distance and orientation, one can see not only the antenna gain but how the entire link – antenna, receiver and modem together – actually performs. uncontrolled reflections from nearby structures, only two vehicle approach angles available, and insufficient precision to map the sharp PER transition. These observations pointed directly to the need for a controlled setup.

Interference resilience and robustness against external interferers

Robustness against interference is often what determines whether a C2 link is usable in the real world. In BeamForce it is straightforward to test resilience against external interferers and various interference methodologies. An active interferer is operated while a throughput and threshold measurement is running, and the degradation of the link is measured as the interference conditions change.

This gives clear indications of how sensitive the link is to external interference – carrier-to-interference (C/I) tolerance, blocking and the SINR margin. With this data, robustness measures such as frequency hopping, forward error correction and antenna diversity can be evaluated and verified in the lab. Because the chamber is shielded, interference measurements are carried out without disturbing the surroundings.

Developing interference methodologies

The same setup can be used in reverse. Instead of measuring how well a link withstands interference, one characterizes how effective different interference waveforms and strategies are against a given link. This makes BeamForce a tool also for developing and evaluating interference methodologies – relevant to security and defense applications such as counter-UAS.

Because everything takes place in an enclosed, shielded chamber, this work is conducted in a controlled and repeatable manner, with no emission to the surroundings. The measurement technique is the same; it is the question that is reversed.

BeamLab: the software that ties the system together

RanLOS's measurement software BeamLab is the interface to all peripherals – instruments, turntables, positioners, attenuators and interference sources – and at the same time the interface to the operator. BeamLab is the hub that makes advanced measurement technology easy to use.

BeamLab can: propose a suitable measurement setup for the task at hand, control and manage calibration of both the plane-wave field and the attenuator's distance emulation, control the entire measurement process and the sequencing of measurement points, store results in a structured and traceable way, perform the mathematical computation of results, and present them in a suitable form including reports and plots.

The result is that the operator can focus on the question – antenna performance, link quality, interference resilience – while BeamLab handles the details of the measurement technique.

Practical advantages

RanLOS's test system BeamForce can be placed where it is needed. It is easy to move, can be used in existing chambers, simpler test environments or temporary test locations – and can be set up and put into use within a day of delivery. BeamForce systems work across a wide range of setups, which broadens flexibility and areas of application, making it an extremely cost-effective and advanced measurement tool on the market today.

The system is available in several sizes, including BeamForce 42 and BeamForce 21, to suit different dimensions and frequency ranges. Together with the compact setup of the Random Line-of-Sight methodology, this means that a full OTA lab for C2 link testing becomes possible even without a large, expensive anechoic chamber.

The comparison between traditional field testing and RanLOS chamber measurement is summarized below:

Aspect	Field testing (traditional)	RanLOS chamber measurement
Measurement environment	Uncontrolled; varies with weather and location	Stable, shielded and predictable
Repeatability	Low – hard to recreate exact conditions	High – identical conditions every time
Distance	Requires physical travel over long ranges	Emulated with a variable attenuator
Interference	Hard to isolate and control	Injected and varied under full control
Iteration time	Days to weeks per design change	Hours – answers the same day
Cost & risk	High; needs permits, personnel and flight safety	Low; no airspace management, no crash risk

"To develop and verify drone C2 systems, test methods must reflect the flight conditions and radio link dynamics in which the system is actually intended to operate."

Conclusion

With RanLOS test solutions, a drone's C2 link can be characterized in full in a stable, controlled chamber or test environment – covering 3D radiation pattern and distance sensitivity, active throughput and threshold measurements, and interference resilience and methodology. This enables the engineer to develop robust communication solutions systematically and safely, with higher repeatability than field testing and without trial and error.

References

- European Union Aviation Safety Agency (EASA), Commission Delegated Regulation (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft, 2019.
- RTCA, DO-362, Minimum Operational Performance Standards for Command and Control (C2) Data Link, RTCA, 2019.
- RanLOS, internal market reviews and customer dialogues, 2023–2026.

For more information, please visit ranlos.com or contact the RanLOS team.

