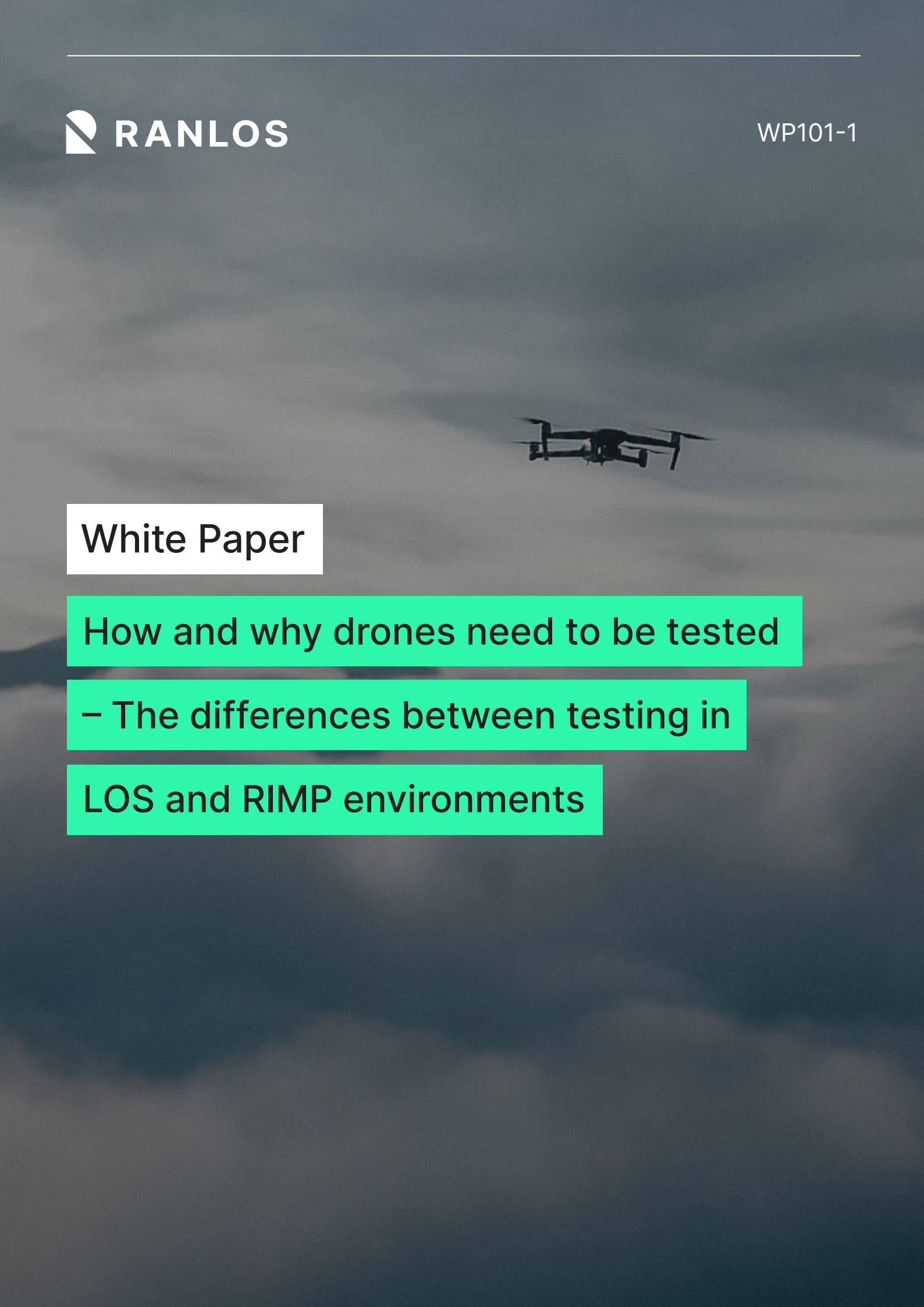
RANLOS

WP101-1



White Paper

How and why drones need to be tested – The differences between testing in LOS and RIMP environments

Introduction: How and why drones need to be tested?

Drones and UAV systems have rapidly evolved from niche technologies into a central part of modern industry, infrastructure, and security. Today, they are used in everything from industrial inspection and autonomous transportation systems to advanced defense applications. What all these applications have in common is a requirement that cannot fail: a stable and reliable wireless communication link.

Traditional measurement methods, where antennas and other radio components are tested separately – with the antenna often measured in anechoic chambers – provide valuable insights but do not capture how the complete system behaves during real operation. Once the antenna is integrated into the drone, its performance is influenced by the mechanical design, material selection, and interaction with other components. As a result, actual radio performance often differs from what was theoretically expected. This is where OTA testing (Over-The-Air) becomes essential. By testing the complete system in a controlled radio environment, it becomes possible to measure how communication actually performs under conditions that more closely resemble real-world operation.

At the same time, it is important to understand that drones do not operate in a single, uniform radio environment. Communication requirements vary depending on the application and surrounding environment.

A drone operating in an urban environment is surrounded by reflections from buildings, vehicles, and infrastructure – a so-called RIMP environment (Rich Isotropic Multipath). A drone flying over open fields, conflict zones, or a high-altitude UAV, on the other hand, operates in a radio link that is effectively dominated by a direct signal path – a LOS environment (Line-of-Sight). These two environments place different demands on drone antenna performance and may expose different types of weaknesses in the system design.

In practice, this means that both complex multipath environments and scenarios dominated by direct line-of-sight communication need to be analyzed. The following section introduces these two reference environments – RIMP and LOS – which are based on research from Chalmers University of Technology, led by Professor Per-Simon Kildal and further developed together with Jan Carlsson and colleagues. Together, they form the theoretical framework for this type of OTA testing and provide the foundation for this white paper.

> ***"To develop and verify drone systems, test methods are required to reflect the radio environments in which the systems are actually intended to operate."***

Finally, it is worth noting that many modern drone applications, particularly within industry and defense, largely operate in environments where line-of-sight conditions dominate. This means that understanding how the antenna behaves across different directions and orientations is often critical to real-world system performance – and is therefore especially well captured through LOS-based testing in controlled test environments.

Fact box: definitions and terminology

- In this paper, the term LOS (Line-of-Sight) is used to describe radio environments where the direct signal path dominates between transmitter and receiver.
- To analyze variations related to drone orientation, a statistical model sometimes referred to as RLOS (Random Line-of-Sight) is used, where "random" refers to variations in orientation – not randomness in the measurement itself.
- RanLOS is used in this document exclusively as the name of the company and its test systems, which realize a LOS environment.

Two complementary test environments

Two complementary test environments
Research conducted at Chalmers University of Technology by Professor Per-Simon Kildal and his colleagues (Carlsson, Carlberg & Kildal, LAPC 2012, as well as Kildal & Carlsson, 2013) established a theoretical framework for OTA testing based on two defined reference environments: RIMP (Rich Isotropic Multipath) and LOS (Line-of-Sight). In this context, LOS is used as the overarching concept, while RLOS (Random Line-of-Sight) describes the statistical model used to analyze variations related to random drone orientation.

These environments represent two extremes in how radio waves behave in reality. Although practical scenarios are often located somewhere between them, this distinction makes it possible to analyze and understand different aspects of wireless system performance in a structured manner.

In a RIMP environment, the signal propagates through many paths and reaches the receiver from multiple directions, which is typical for urban areas and complex installations. In a LOS environment, communication is instead dominated by a direct signal path, which is common in open environments or high-altitude operation.

The two environments highlight different characteristics of antenna and communication systems:

- **RIMP** provides insight into how the system performs in complex multipath environments
- **RLOS** demonstrates how antenna directional characteristics influence the communication link under line-of-sight conditions

An important distinction between the environments becomes apparent when analyzing statistical signal variations.

In a RIMP environment, signal level variations follow a well-established Rayleigh distribution. Simplified, this means that the signal varies randomly, but in a way that limits the influence of antenna directional characteristics on the overall result. In practice, this means that an antenna with an uneven radiation pattern can still perform relatively consistently in this type of environment, where total radiation efficiency becomes the dominant factor.

In a LOS environment, the situation is different. Since communication is dominated by a single signal path, the antenna radiation pattern directly affects the result. If the antenna contains directions with low gain – so-called nulls or dips – this can lead to an increased probability of low signal levels and therefore a higher risk of communication link failure. An example of this is illustrated in Figure 1.

Together, these two environments form a theoretical framework for analyzing wireless performance across different application scenarios. The following sections describe each environment in greater detail and explain how they are used in practical OTA testing.

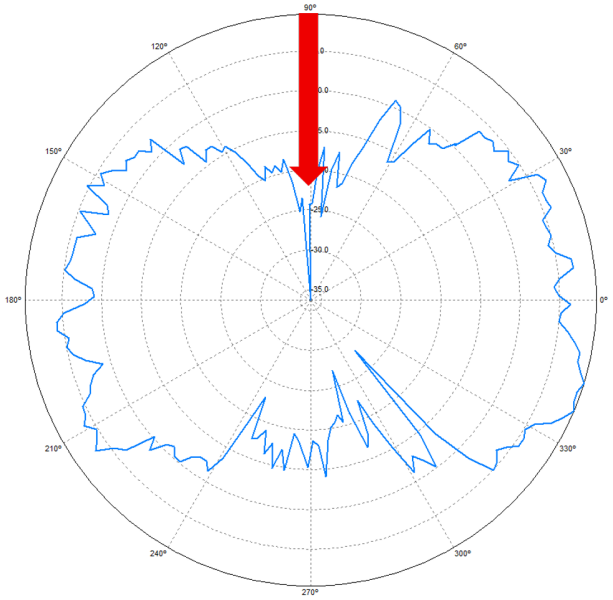


Figure 1: Antenna radiation pattern with a clear null in the pattern. Communication in this direction is therefore significantly degraded.

RIMP – Rich Isotropic Multipath

In a RIMP environment, radio waves arrive at the receiving antenna from all directions with statistically equal probability. Signals are reflected, diffracted, and scattered by surrounding objects – buildings, vehicles, vegetation, and people – creating a dense, statistically uniform multipath field. This is the typical radio environment found in cities, industrial indoor environments, and generally in dense environments.

In these cases, the amplitude of the received signal follows a Rayleigh distribution, meaning there is a statistical probability of deep signal fades – temporary drops in received signal strength. System robustness is therefore highly dependent on the antenna's ability to handle these variations, for example through diversity techniques, MIMO technology, or high radiation efficiency.

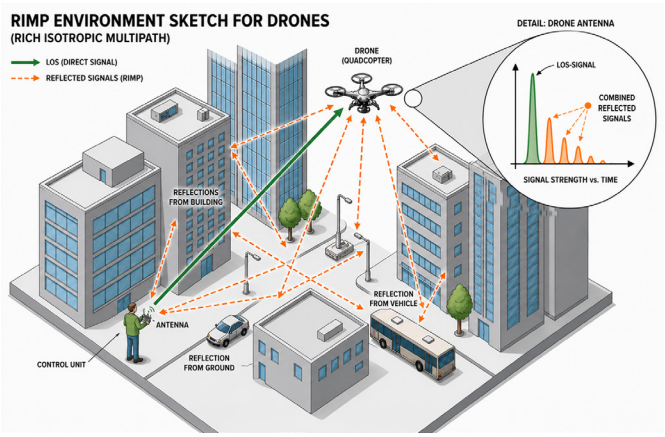


Figure 2: RIMP environment (Rich Isotropic Multipath) for drones operating in urban areas. The direct signal (LOS) is complemented by reflections from facades, the ground, and surrounding structures. The detailed view illustrates how signals arrive at the drone antenna with different delays, creating a distributed Rayleigh-like reception pattern.

What RIMP measurements reveal

RIMP measurements provide insight into how a system performs in complex radio environments dominated by multipath propagation and are used to analyze:

- Total radiation efficiency (TRP and TIS)
- Antenna correlation and the possibility of efficient diversity combining
- MIMO performance and channel capacity
- The occurrence of fading and how well the system handles these variations
- Effects of unwanted coupling between antennas in multi-antenna systems

Reverberation chamber as a RIMP laboratory

RIMP environments are realized in laboratory conditions using a so-called reverberation chamber. This is a closed metallic chamber in which rotating stirrers continuously alter the electromagnetic modes inside the chamber. The result is a statistically homogeneous and isotropic field, where signals reach the test object from all directions over time – a controlled representation of a RIMP environment. The drone is placed in the center of the chamber, and measurements are integrated over a large number of stirrer positions, resulting in a stable and reproducible average of antenna and system performance.

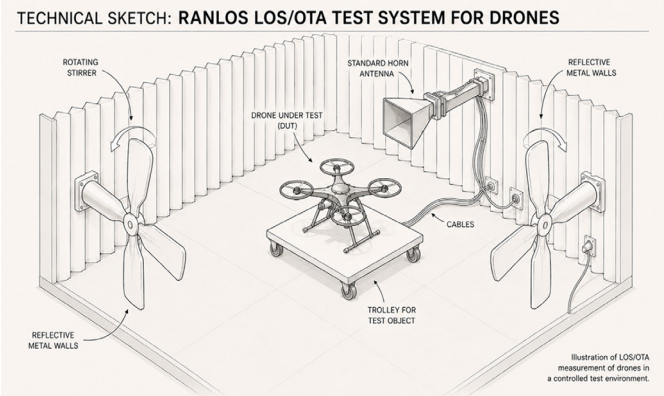


Figure 3: Reverberation chamber for RIMP laboratory measurements. The metallic walls form a resonant cavity, while two rotating stirrers continuously alter the chamber modes and generate a statistically isotropic field. The drone (EUT) is positioned on a positioning platform in the center.

Limitations of RIMP in the context of drones

An important characteristic of the RIMP environment is that variations related to antenna directional characteristics are largely averaged out by the surrounding multipath structure. This means that an antenna with an uneven radiation pattern can still perform relatively consistently in RIMP, since signals always reach the receiver through alternative propagation paths.

For systems where communication primarily takes place under line-of-sight conditions – such as many drone applications within defense and security – this may result in critical weaknesses, such as low-gain directions, remaining undetected during RIMP testing even though they may become decisive during real-world operation.

LOS – Line-of-Sight (RLOS model)

In a LOS environment, the radio environment is dominated by a direct radio channel between transmitter and receiver – where the direct signal path dominates over any reflections. This is the typical situation for drones flying at high altitude, over open terrain, highways, water, or sparsely populated rural areas. The communication link is often stable and predictable, but antenna directional characteristics become critical to actual system performance.

Unlike multipath environments, where signals reach the receiver through multiple paths, there is effectively no alternative signal path in a LOS environment that can compensate for variations in antenna directional characteristics. This means that antenna behavior in each individual direction directly impacts the received signal.

The random aspect in this model (RLOS) does not originate from the environment itself, but from drone movement. During real operation, the drone may assume arbitrary three-dimensional orientations relative to the ground control station. It is this set of orientations – rather than time variations in the radio environment – that creates signal level variations and is analyzed statistically.

What LOS/RLOS measurements reveal

LOS/RLOS-based measurements provide a direct understanding of how antenna directional characteristics influence the communication link and are used to analyze:

- Antenna pattern coverage across the entire 3D sphere
- Polarization matching relative to the ground control station antenna
- Link budget and maximum communication range
- The occurrence of nulls and blind spots

Unlike RIMP, where the environment may mask certain variations, the LOS environment clearly reveals how the system performs in every direction and orientation.

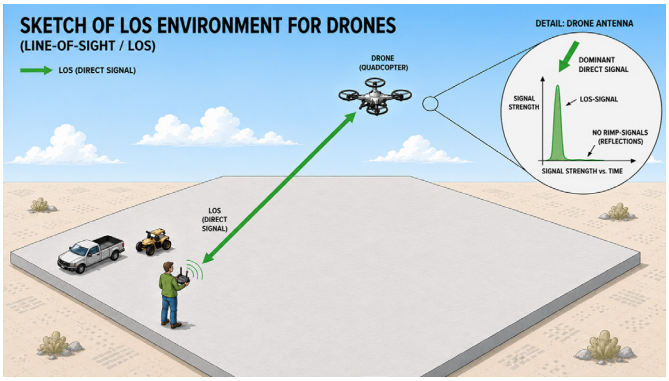


Figure 4: LOS environment (Line-of-Sight) over open terrain. Only the direct signal path reaches the drone – no environmental reflections are present. Antenna 3D coverage therefore becomes critical as drone orientation relative to the ground station changes randomly.

Implications for drone systems

Since communication in a LOS environment is dominated by a direct signal path – without reflections that can compensate for weak directions – antenna behavior becomes critical in every orientation. For drones, this means that the communication link may vary significantly depending on the orientation of the system at any given moment.

For example, if the antenna has uneven coverage, low-gain directions, or poor polarization alignment between transmitter and receiver (that is, how the antennas are oriented relative to one another), this may cause the signal level in certain positions to become too weak – even if the link performs well in other orientations.

In practice, this means that system performance becomes highly orientation dependent. This may appear as:

- Temporary communication interruptions (intermittent link failures)
- Variations in signal strength depending on direction
- Limitations in operational range while maintaining a stable link

This type of behavior is particularly critical in applications where drone orientation cannot be precisely controlled, or where a stable and predictable communication link is essential for mission success.

LOS testing using CATR technology

To reproduce LOS conditions (often analyzed in practice using the RLOS model) within a controlled laboratory environment, CATR technology (Compact Antenna Test Range) is used. A CATR system is designed to generate a planar wavefront inside the test zone, corresponding to how a radio signal behaves when originating from a transmitter located far away.

In practice, this means the system transforms a near-field source into a far-field-like wave in real time. The test object – in this case the drone – is therefore exposed to a signal that behaves as if it originated from a distant transmitter, with a defined direction and polarization and without interference from unwanted reflections. RanLOS BeamForce systems are based on this principle, where an antenna array together with a reflector shapes the signal into a plane wave within the test zone. At the same time, absorbing material may be used inside the chamber to minimize reflections, ensuring that the measurement represents a line-of-sight scenario as closely as possible.

To capture how the system behaves during real operation, the drone is rotated in multiple dimensions during measurement. This means antenna performance is not only evaluated in a single direction, but across a large number of orientations corresponding to how the drone actually moves in flight. The result is not a single measurement point, but rather a description of how the system performs across the entire 3D sphere and under different orientations. This makes it possible to identify directions or orientations where performance is limited – something that may otherwise be difficult to detect using traditional test methods.

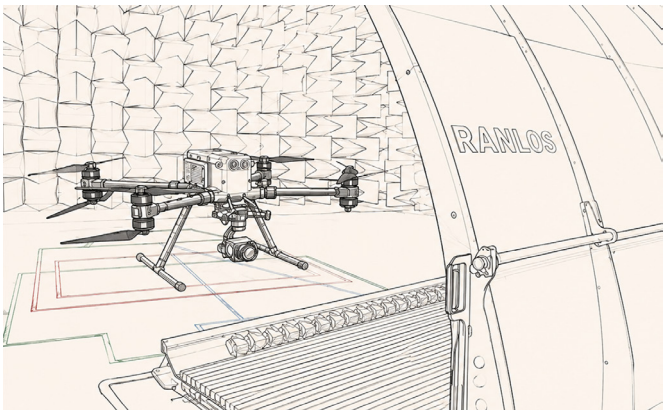


Figure 5: RanLOS CATR solution

Why LOS testing is critical for drones

For many drone applications, the decisive question is not how the system behaves in a complex multipath environment, but whether communication remains stable as the drone changes orientation under line-of-sight conditions.

This is particularly relevant for:

- Industrial applications in open environments
- Long-range operations
- Defense and safety-critical systems

RanLOS test solutions directly address this challenge. By exposing the true directional behavior of the antenna, the method makes it possible to identify critical weaknesses early in the development process – before they become field problems.

When is LOS-based testing sufficient?

Although RIMP and LOS environments together provide a complete picture of radio system performance, it is not always necessary in practice to test in both environments. In many applications, the line-of-sight scenarios represented by LOS conditions dominate real-world operation. In these cases, antenna directional characteristics, orientation-dependent variations, and actual communication range become the decisive factors for link performance. This means that LOS/RLOS-based testing can often provide sufficient – and directly relevant – information for both development and verification.

Typical applications where RanLOS is sufficient:

- **Drones operating in open environments**
  Applications such as agriculture, forestry, or energy infrastructure often involve drones operating across large open areas with clear line-of-sight conditions. In these cases, understanding coverage, range, and orientation-dependent variations becomes more important than analyzing multipath effects.
- **High-altitude or long-range operations**
  In scenarios where the drone operates far above the ground or at long distances from the operator, communication is dominated by a direct radio link. System robustness therefore depends heavily on antenna behavior across different directions.
- **Defense and safety-critical systems**
  In many defense applications, maintaining a stable line-of-sight communication link is essential to ensure control and data communication. RanLOS testing provides direct insight into these critical scenarios.
- **Development and design optimization**
  During development of new drone systems, antenna designs, or antenna placement optimization, RanLOS provides rapid and clear feedback on how design changes affect real-world performance. This enables faster iteration and improved design decisions.

What LOS/RLOS testing captures

RanLOS testing focuses on the parameters that are often directly connected to real-world communication issues:

- How the antenna covers different directions
- How the system is affected by orientation
- Where there is a risk of low signal levels
- How communication range varies in practice

In many cases, these are precisely the factors that determine whether a system performs reliably or not.

When RIMP adds value

At the same time, it is important to emphasize that RIMP testing remains highly relevant in scenarios where multipath propagation dominates, for example:

- Dense urban environments
- Industrial installations
- Complex indoor environments

In these cases, RIMP provides complementary insight into how the system handles reflections, fading, and multiple propagation paths.

In summary, for complete characterization, both RIMP and LOS testing are valuable. However, for many drone applications – particularly in line-of-sight scenarios – LOS-based testing, realized through RanLOS test solutions, provides the most relevant, practical, and directly actionable insight.

Standardization and regulatory relevance

OTA testing of drones is an active area within both standardization and regulatory development. Organizations such as ETSI and 3GPP are developing frameworks and requirements for wireless communication in UAV systems, including 5G-based C2 links. At the same time, European regulations through EASA and U-space place increasing demands on communication link robustness verification as part of the certification process.

A common principle within these efforts is that testing must reflect the radio environments in which the systems are actually intended to operate. This means that both multipath scenarios (RIMP) and line-of-sight scenarios (LOS/RLOS) are included in the methodology. This further emphasizes the need for test methods that not only fulfill technical requirements, but are also relevant from a regulatory perspective.

Conclusion

Drones operate across a broad spectrum of radio environments – from complex multipath propagation in urban areas to open line-of-sight conditions in rural environments and at high altitude. Each environment places different demands on antenna and system performance and may reveal different types of weaknesses in the design.

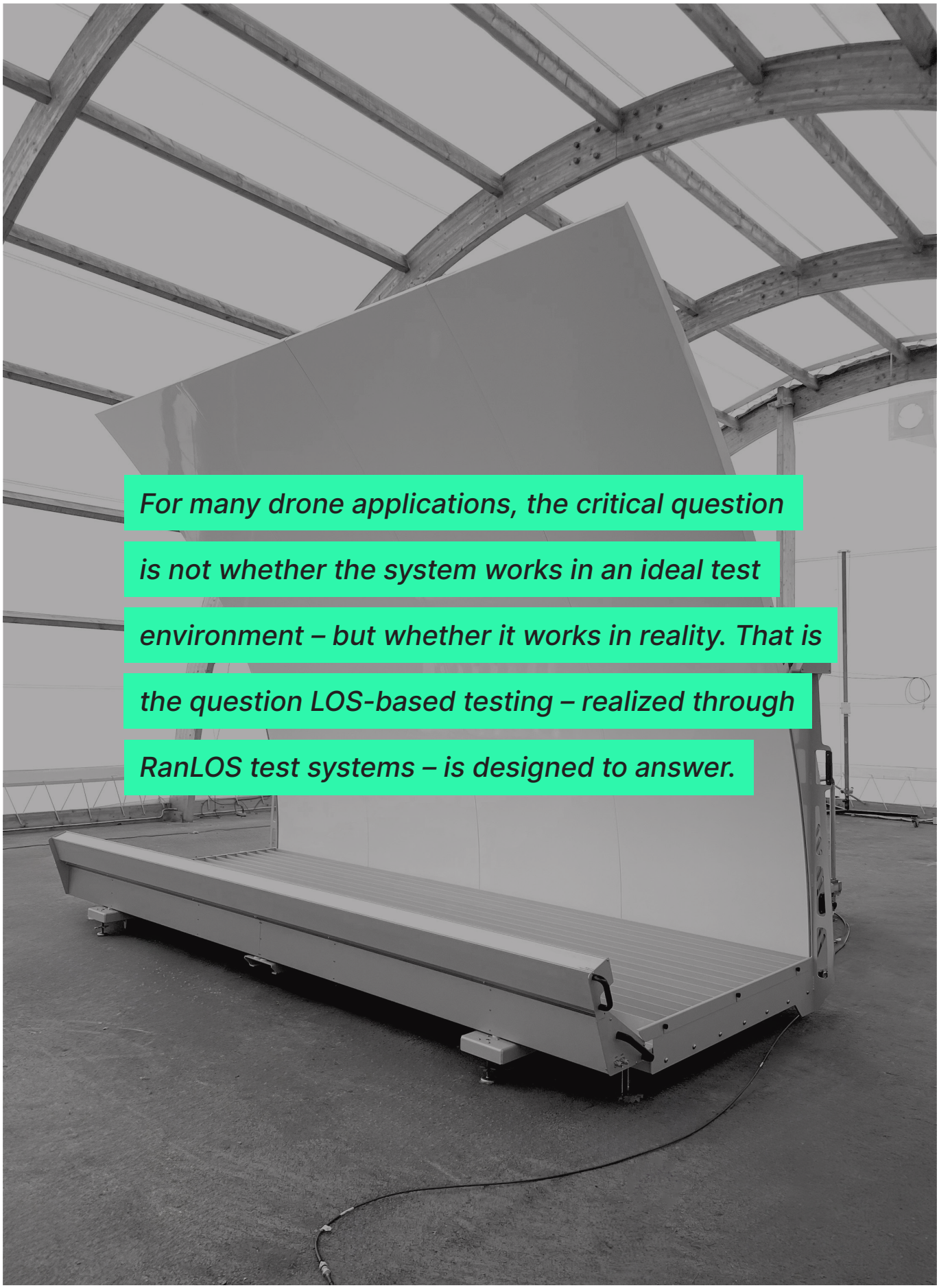
Research from Chalmers University of Technology has established a clear framework in which RIMP and LOS represent two complementary extremes. Together, they provide deep insight into how wireless systems behave under real operating conditions.

For development and verification, this means:

- RIMP testing provides insight into system performance in complex multipath environments
- LOS-based testing reveals how antenna directional characteristics affect the communication link under line-of-sight conditions
- The combination of these methods reduces the risk of hidden weaknesses that could otherwise lead to communication failures or failure to meet regulatory requirements

At the same time, practical applications show that many drone systems largely operate in environments where line-of-sight conditions dominate. In these cases, LOS-based testing becomes particularly relevant – and RanLOS CATR-based solutions make it possible to perform this type of testing in a repeatable and development-oriented manner.

This means that line-of-sight scenarios can be reproduced in laboratory environments and integrated as a continuous part of the development process, enabling faster iteration, improved decision-making, and reduced risk in later stages.


For many drone applications, the critical question is not whether the system works in an ideal test environment – but whether it works in reality. That is the question LOS-based testing – realized through RanLOS test systems – is designed to answer.

References

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2. P.-S. Kildal, J. Carlsson, “New Approach to OTA Testing: RIMP and pure-LOS as Extreme Environments & a Hypothesis“, EuCAP, 7th European Conference on Antennas and Propagation, Gothenburg, Sweden, 8-12 Apr., 2013.

