White Paper

Accuracy | Space | Time

Navigating the challenges of testing commercial aircraft radomes to RTCA-DO-213A standards

Contents:

Navigating the challenges of testing commercial aircraft radomes

As aircraft radar antennas advance in precision and capabilities, it has become increasingly crucial that the nose mounted radomes that protect them in flight be flawless. Radome characteristics must not interfere with the performance of aircraft radar systems in order to ensure optimal transmission for weather, windshear and turbulence management, in flight route planning, and overall safe navigation. Radome repair and testing procedures have traditionally been subject to regulations and standardized guidelines by the RTCA, however, technological advances, whether in antennas or test techniques, have incited progress and precision in radome performance testing.

In recent years the RTCA has reassessed its guidance standards for the testing of commercial aircraft radomes, making substantial changes to its criteria and strengthening the accuracy requirements in the testing of repaired radomes. These regulatory changes have been welcomed by the industry, however, since the implementation of the RTCA-DO-213A, testing techniques and equipment are being challenged to comply with the changes in regulations. In parallel, the logistical demands of the marketplace, like many sectors, has moved in favour of time efficiencies and using less space.

In this whitepaper we will explore the changes in the RTCA-DO-213A standards, current testing methodologies, and how they have been affected by these updates. The latest near-field technology enabling repair facilities to meet the increasing market demands of faster test and repair outputs while meeting the more stringent requirements of test accuracy imposed by the new RTCA standards will then be introduced.

A quest for accuracy: Improved standards and a new set of challenges

For nose-mounted radomes, certifying optimal functionality after repair requires accurate testing of its characteristics in accordance with RTCA-DO-213A. These tests are intended to produce a reliable evaluation of the disturbances a radome might have on the RF signals crossing it. More specifically:

- The evaluation of losses due to absorption and reflection of signals (transmission efficiency)
- Evaluation of radiation pattern distortions such as deflection of the main beam, the half power main beam width, and the level of the secondary lobes
- Evaluation of the polarisation deflection

THE TESTING REQUIREMENTS OF RTCA-DO-213A

When the RTCA updated its quality standards and published the RTCA-DO-213A, it incorporated more stringent requirements for the testing of commercial aircraft radomes. In the repair and test stage, this meant more accurate testing and better-quality result data was to be established in order to meet the standards going forward.

The updates to the DO-213 are considerable and detail a variety of improvements on test measures. Here we will discuss significant changes within RTCA-DO-213A which have reshaped the way testing and validation is now to be conducted on radomes after repair.

The Fraunhofer criterion reinforced

The RTCA nose-mounted aircraft radome test standards were initially established taking into account the technology of the time, and radome test ranges were built to meet these standards. Though measurements in the far-field were recommended for the most accurate characterization of antennas, regulations on radomes were less stringent. The far-field is based on the Fraunhofer criterion: $r = 2D^2/\lambda$, where r is the distance, D is the largest dimension of the antenna (radiator) and λ is the wavelength of the radio wave. This is the recommended reference distance for plane wave plane wave illumination, allowing for the accurate characterization of antennas.

Earlier versions of the RTCA-DO-213 standards allowed for shorter measurement distances than $2D^2/\lambda$, by a factor of 4 in certain circumstances, yielding a quadrature phase taper of 90° over the diameter D. This level of phase distortion is known to induce notable errors in a measured antenna pattern, especially on or near the main beam.

With the advances in radar antenna systems, and the more ambitious specifications for excellence in radome transparency, increased accuracy requirements in radome testing was destined to follow. Hence in revision A of DO-213, far-field criterion of $R \geq 2D^2/\lambda$, representing a quadrature phase taper of 22.5° over the diameter D, has been enforced.

The accuracy measures of radomes were set from this point forward to be in line with the same accuracy requirements of the precision antennas they were designed to protect, and radome repair and test teams have discovered their facilities lack the necessary space for testing.

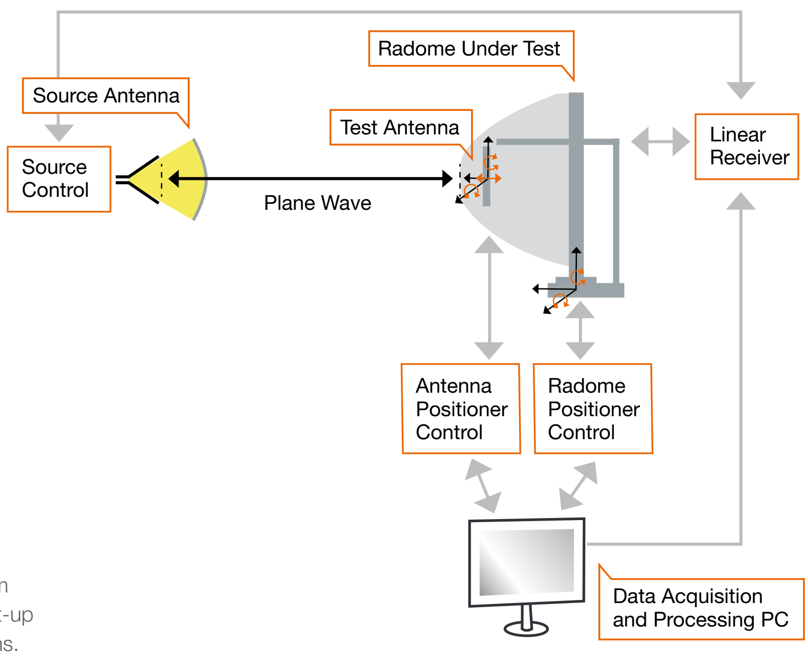


Figure 1 - A typical transmission sidelobe level and beam width measurement set-up under far-field conditions.

Testing an authentic setup

The new regulations specify that aircraft radomes must be tested in authentic radar antenna + radome conditions. The radome/antenna positioner system used should locate the test antenna within the radome at the same location as in its aircraft installation; The test antenna's aperture should match the aperture of the typical radar antenna beneath the particular aircraft radome under test; The system antenna needs to be illuminating the intended region of the radome surface for each antenna-to-radome aspect to be tested. The center of the system antenna should be translated horizontally and vertically by less than 10% from the spot on the radome being tested. In each of those orientations, the distance between the antenna and radome should also be less than 20% of the system-antenna diameter.(1)

Respecting this configuration is to ensure accuracy in evaluations of both transmission efficiencies and secondary lobe levels. Some repair and test facilities will have to update some or all of their testing setup for the purpose of testing in exact, realistic conditions as per this update.

Emulation of aircraft gimbal sequence

In addition to the true representation of the radome + antenna setup, the test gimbal sequence should take into consideration the gimbal sequence order of the actual antenna system to be tested with the radome.

Installed on an aircraft, the radar antenna scans through different parts of the radome. It is important that the corresponding spots on the radome (a region of radome surface centered around those spots) be the ones tested. The RTCA-DO-213 stipulates that for each specified antenna-to-radome aspect, the test range must meet certain requirements when the system antenna is pointed along the range axis. Figures 2 and 3 show the corresponding scanning grid for two typical antenna-to-radome stacking orders. The two grids are nearly identical when either azimuth or elevation is near zero, however they become very different at the corners of the aspect grids.

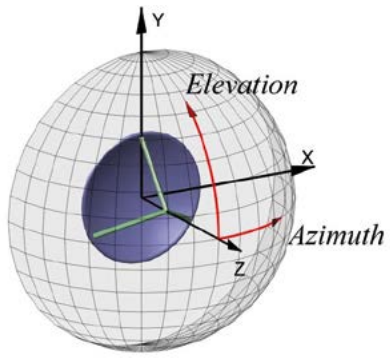


Figure 2 - Elevation/Azimuth Radar Gimbal.

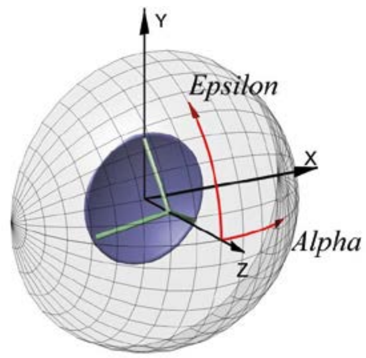


Figure 3 - Azimuth/Elevation (α/ϵ) Radar Gimbal.

The new standards require that the radome coordinates corresponding to the grid at the commanded aspect should be located along the range axis through the gimbal point in either (opposing) case (fig 2, fig 3). Second, the system antenna's polarization orientation with respect to the radome should be the same as it would be on the aircraft. And thirdly, the range antenna should have its polarization rotation adjusted to match that of the system antenna.(2)

Not all antenna-gimbal setups are elevation/azimuth, and geometries of radome positioners in conventional test systems may not provide coordinated motion of multiple axes, nor range and system-antenna polarizations, to apply the required rotations. This update has thus also posed new challenges as some teams must now search for more flexible positioning solutions if they want to be able to measure any kind of radome.

The constraints these updates have imposed have consequently opened the door to innovation, aspiring to not only more accurate testing, but also faster, flexible and more compact solutions for testing commercial aircraft radomes after repair.

(1) RTCA-DO-213A Minimum Operational Performance Standards for Nose-Mounted Radomes – Appendix C – Test Range Qualification - C.2.2 Location of System Antenna within Radome.

(2) RTCA-DO-213A Minimum Operational Performance Standards for Nose-Mounted Radomes – Appendix C – Test Range Qualification - C.2.1 Emulation of Aircraft Gimbal Sequence

New limitations to common test methods

Before the 2016 updates, radome test ranges continued to meet the established standards, with test results accepted in less than far-field conditions. Meanwhile, new testing techniques, such as compact ranges, near-field gantry arms or manual tests with antenna horns, had been adopted for their space and/or cost-effective capacities and these became more commonly used in the testing of aircraft radomes after repair. Nonetheless, the strengthened requirements in the RTCA-DO-213A, have changed the game.

Whilst the use of manual tests with antenna horns has been all but eradicated under the latest guidelines, compact ranges and gantry arms are still deemed suitable for radome after-repair tests. However, these techniques, along with traditional far-field installations no longer meet the logistical space and time constraints of an evolving industry. Let us examine the limitations of common test methods in more detail:

COMPACT RANGES: MEASURING IN INDIRECT FAR-FIELD

The radome performance requirements for transmission efficiency, sidelobe level, beam width, and beam deflection are defined as far-field quantities, or with a single plane wave incident on the combination of radome and system antennas. Compact ranges directly illuminate with a plane wave by way of a reflector, the radome and system antenna. This method provides results in indirect far-field of the required quality in accordance with the latest guidelines.

Though compact ranges allow for illumination under plane wave conditions in relatively smaller spaces than in a direct far-field range, the finite size of its reflector produces phase curvature over the test zone and induces ripple on the quiet-zone field. This can be problematic with tight tolerances across these variables. Then, there is the antenna gimbal and radome positioning movement to be emulated. As the exact representation is now necessary according to DO-213A, the complexity of the positioning setup is multiplied, particularly because the radome must be positioned vertically facing the reflector.

A third issue with compact ranges as a unique means for after-repair testing is the variation in radome sizes. A single compact range is limited to a maximum quiet zone size. The bigger the DUT , the larger the quiet zone necessary. Radome dimensions have gradually grown in proportion to the increasing sizes of aircraft, and compact ranges have to be adapted to these increasing radome dimensions while still respecting the standards. This has become challenging for many repair and test facilities as they face space and financial constraints.

ANTENNA HORN MEASUREMENT METHODS

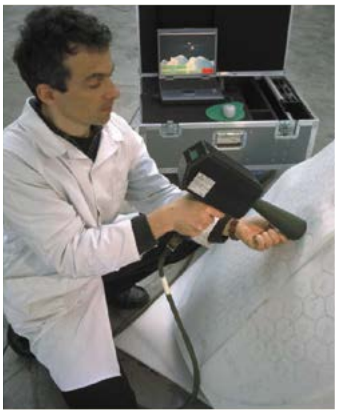


Figure 4 - Use of a portable device for the diagnosis of radomes in repair-shops.

The parameters established within the latest RTCA standard for after-repair testing of radomes states that whilst the use of hand-held horns is not forbidden, it is also explicitly not recommended. This point-to-point testing technique involves one or several antenna horns being held above the radome, with a reflective metallic sheet in an opposite position below it. An example of a typical hand-held antenna horn procedure can be seen here [Fig 4].

This approach has served some repair facilities well as a simple and cost-saving method, and results were previously sufficient for certain after-repair evaluations, however several factors render this technique largely unacceptable to the D0-213A requirements.

First, the manual human operation introduces uncertainty in the measurement results. Second, the setup is subject to certain limitations due to its unauthentic representativeness of the radome and radar antenna. And third, the complexity of transforming these measurements to a system-level, comprehensive diagnosis and accurate parameter extraction ultimately delivers unreliable results. So, when assessing the performance of a radome after repair, the new RTCA-DO-213A revisions do not forbid hand-held point-to-point measurements, but they are explicitly not recommended.

A considerable additional point for repair and test sites regarding this method is the quantity of time it takes to make a complete measurement. With the new requirements, and additional time necessary to meet them, this technique is less than sufficient for those repair facilities looking to improve radome repair and test outputs.

SINGLE-PROBE NEAR-FIELD GANTRY ARM SYSTEMS

Near field ranges operate by measuring the tangential electromagnetic field on a surface enclosing the antenna, (at a typical distance of $D^2/2\lambda < r < 2D^2/\lambda$, corresponding to the distances between the limits of the Fresnel zone with D representing the maximum diameter of the antenna, and r being the measurement distance) and then mathematically transforming the acquired data into far-field.

Near-field to far-field transformation requires comprehensive knowledge of the tangential near-field over an entire surface. It is vital to uphold the accuracy of the phase measurements and ensure that the accuracy and alignment of the positioning system is such that the corresponding error in the far-field is negligible with regards to the specific transmission efficiency to be measured.

In near-field systems, the time required for characterization is a function of the physical dimension of the radome. The number of measurement points must be consistent with the Nyquist criterion which defines the spacing between the measurement points at less than half a wavelength. It is also a function of the frequency and size of the device under test, which gives the minimum quantity of points to be measured on a sphere. Only in this way will sampling in near-field be sufficient.

For spherical measurements, the required scan area is calculated according to the following formula:

D = The minimum diameter of the sphere enclosing the radome
R_{min} = D / 2 (radius of the minimum sphere)
R = Measurement distance
$R > D^2 / 2\lambda$ min

Radome testing in the near-field was first introduced to the commercial aircraft repair market with the use of a single probe gantry arm system.

This introduction marked progress in the evolution of radome testing, nevertheless, using this method, time under test remains significant; the larger the radome, the more measurement points and the more time it takes for a complete evaluation.
For example, taking into account the Nyquist criterion, for some radome sizes, such as that of the Airbus A400M with its radius of 1.312m, 15 hours or more are needed to collect an adequate quantity of data for accurate evaluation. With this, it is clear that the use of single probe near-field technology falls short of the two-per-day repair and test rate the industry is calling for.

COMMON DENOMINATORS - TIME AND SPACE

Ultimately, all three of these techniques are single-probe test methods with point-by-point measurements to reconstruct the electromagnetic field for accurate evaluations of the radome and radar antenna setup.

The advantages of the CATR are that it provides measurement cuts relatively quickly with assessments directly in the far-field, but the initial principal cuts do not provide a complete evaluation of the radome under test, and many more measurements are needed. This is time-consuming. The advantages of the gantry arm technique is that it allows for 3D visualization of comprehensive evaluations of the radome surface, however, the considerable amount of time this takes is prohibitive facing industry demands. Finally, the advantages of the manual horn method are space and cost, but time remains an issue in addition to the high error results in using this technique.

Space has also become largely problematic in these systems with respect to the more stringent accuracy requirements established by the RTCA-DO-213A. As aircraft have grown in size, radar antenna systems have become more sophisticated, and the new radome test requirements aim to improve accuracy in results, these traditional techniques are forced to find more space or be replaced.

As for the antenna gimbal and radome positioning stacking order, any one of these test systems may be confined to only a particular testing sequence due to its positioning installation. This brings forth a lack in flexibility for tests such as transmission efficiency in which counter-steering and RF repeatability are critical. Here, as well, innovation is urgent.

Taking on the challenge, multi-probe technology in compliance with new norms

With the higher accuracy test result requirements imposed by the latest version of the RTCA-D0-213A, the increasing pressure to repair and test radomes at a much faster rate than traditional test systems could perform, and the space constraints modern business tends to impose, the industry has been in need of a fast, compact solution.

With their vast experience in multi-probe antenna measurement solutions, MVG teams took on the challenge. They set about creating a fully compliant, multi-probe, near-field concept, specifically designed to measure commercial aircraft nose-radomes. The result is AeroLab.

Intended to supersede single-probe radome test systems with a faster, more flexible, compact system to meet demands of progress in the aerospace industry, the AeroLab is a near-field multi-probe measurement system, specifically designed to test radomes within the space of an anechoic chamber no bigger than 4m x 4m x 5m. It is composed of a quarter arch supporting an array of 31 precision measurement probes and integrates oversampling capabilities to recreate an infinite number of additional virtual probes. The positioning subsystem includes an azimuth positioner for the radome, and a vertical translation-axis positioner and a unique multi-axis gimbal for the test radar antenna.

Figure 5 - Aerolab probe array and positioning system.

MULTI-PROBE TECHNOLOGY REDUCES MEASUREMENT TIME BY MORE THAN 50%

As previously mentioned, near-field measurements must respect the Nyquist criterion where a certain number of measurement points are required in order to provide sufficient data for comprehensive accurate test results. The larger the radome, the more points are necessary.

As an example, the Airbus A400M radome has a radius of 1.312 m, making it one of the largest in use. Applying the concept noted above would lead to the composition of 258 measurement points on a circle at a frequency of 9.4 GHz. This would take largely more than 4 hours to accomplish.

Aerolab has been designed to accommodate a variety of radome sizes, and with its integrated over-sampling capabilities, can constitute the required number of measurement points on even the largest of radomes. In the case of the Airbus A400M radome, the AeroLab, with an array of 16 probes scanning an angle of 95°, would require 9 oversampling positions, and could complete a measurement in 2.3 hours in compliance with the RTCA-DO-213A accuracy requirements.

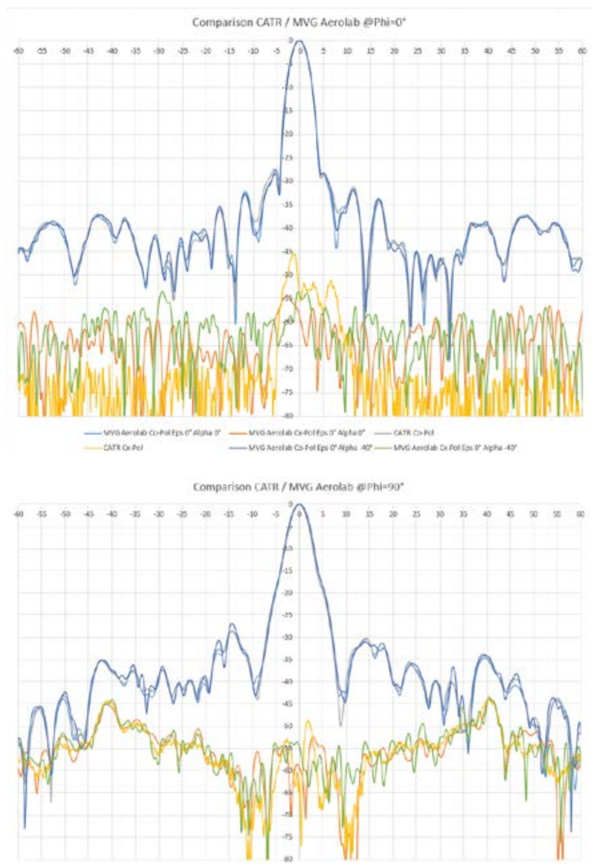


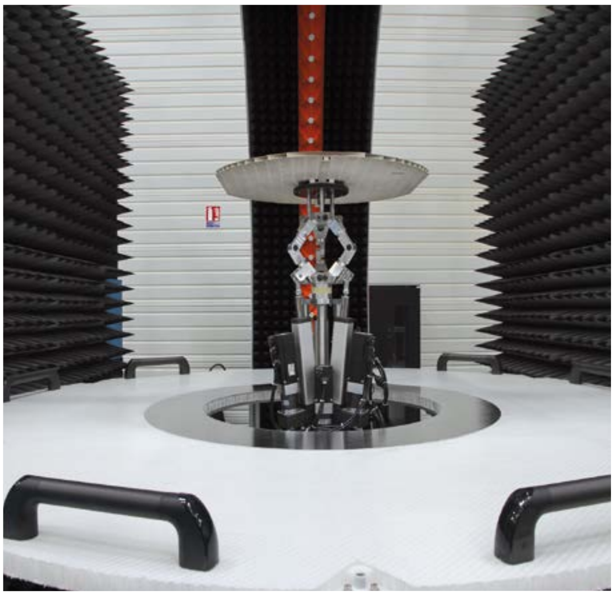
Figure 6 and 7 - Measurement comparison results between CATR and AeroLab.

TEST SET-UP FLEXIBILITY

According to the new DO-213A standards, below a radome under test, the radar antenna must be positioned on a typical gimbal, which should replicate the usual antenna + gimbal installed on the aircraft. It is also crucial to know the stacking order of the aircraft gimbal in order to emulate its typical scanning movements in opposite coordination with the radome positioner.

However, some radome positioner installations do not have the necessary flexibility (ie. polarization axes capabilities). The Aerolab brings innovation to the stacking order dilemma. It combines a particular multi-axis gimbal with a vertical translation axis (elevation) positioner for the radar antenna, and an azimuth positioner to rotate the radome.

The vertical translation positioner is used to set the required height of the radar antenna and gimbal below the radome. The innovative multi-axis gimbal enables accurate antenna positioning with respect to the specified spherical coordinates, can position the antenna at any angle and fully support any stacking order. Not only can it perform either azimuth/elevation or elevation/azimuth positioning in the order needed per radome/antenna configuration, it eliminates any need for polarization positioning of the radome. This particularity adds flexibility in accommodating a variety of radome + antenna system test combinations.



3D DIAGNOSTICS

Aerolab was designed to test radomes after repair and meet the RTCA-DO-213A minimum operational performance standards. Transmission efficiency, beam width, and sidelobe levels are measured in a fraction of the time necessary for a single probe test system.

For the characterization of the radome, measurement data is collected and plotted. There exist various techniques for the visualization of main sectional views. The 3 most common are:

- The integral equation technique
- Spherical back-propagation
- 3D holography

The measurement point methodology of near-field systems uses the integral equation technique in which we know measurement time is proportional to the number of measurements, so can be extremely time-consuming.

The technique of spherical back-propagation is an approximation which gives best results when the surface of the radome is similar to a sphere. Otherwise, the results do not lead to an accurate diagnosis.

With 3D holography, the issues with the first two techniques are solved. The 3D holographic reconstruction technique takes into account the contribution of every equivalent source on the surface of the radome and enables the computation of its superficial fields whatever shape it may be.

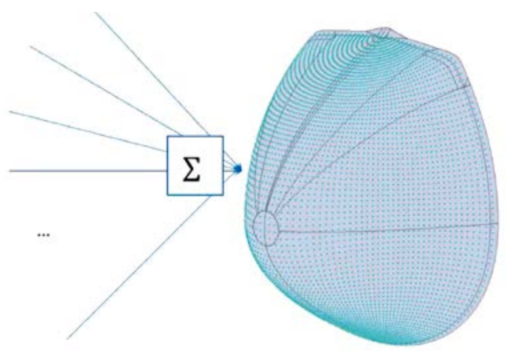


Figure 8 - Contribution of every equivalent source in the reconstruction of the EM field of the radome.

An example of a 3D holography reconstruction result is shown in figures 9 and 10 for amplitude and phase differences. The measurements with and without radome are compared to obtain these results.

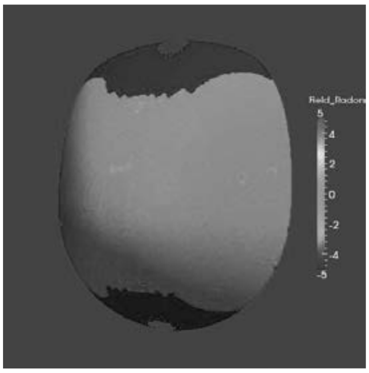


Figure 9 - Cartography reconstruction result of the surface of the radome – amplitude difference on total field.

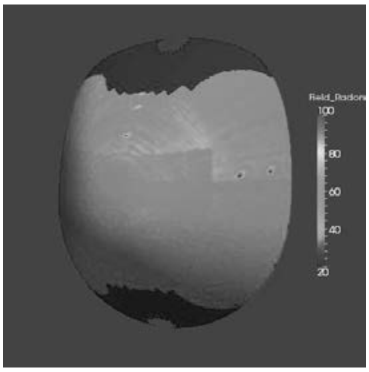


Figure 10 - Cartography reconstruction result of the surface of the radome – phase difference for phi.

The Aerolab enables repair facilities to quickly and accurately compute the fields on the radome surface using 3D holographic reconstruction from near-field measurements to detect the presence of dielectric patches of a minimal size $\lambda \times \lambda \times 0.1\lambda$.

The results show the irregularities/defects detected in the material. These defect values are slightly visible in amplitude and more clearly detected in phase. This diagnostic capability adds efficiency to radome repair and test methods. In addition to faster test results, 3D holographic diagnostics bring in-depth visualization of anomalies to light, leading to more precision in repair and speed in the entire repair and test process.

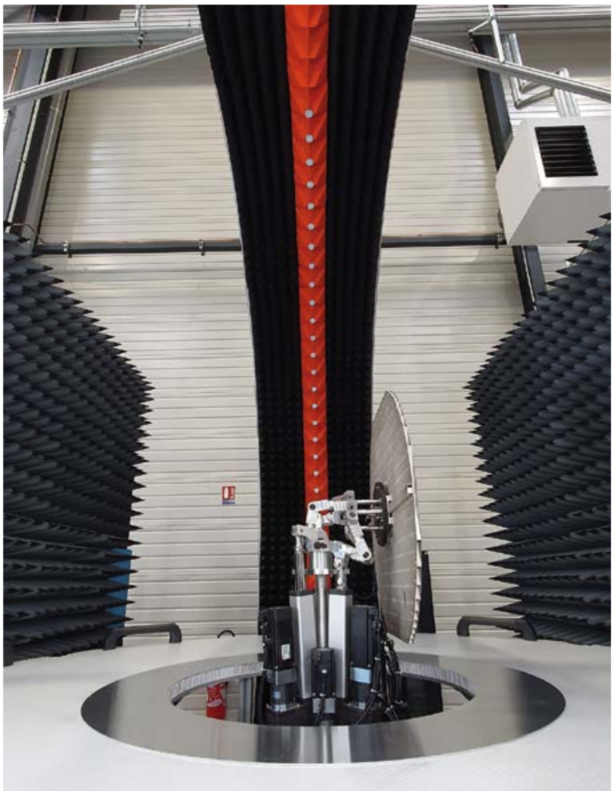
Conclusions

As the performance of aircraft radar antennas increases, it has become crucial to maintain the quality of the nose mounted radomes that protect them. There has been no questioning the reinforcement of the accuracy requirements of the RTCA-DO-213A guidelines. They aim to improve the validation process for quality repair of aircraft nose mounted radomes to better ensure the accuracy of radar antenna transmissions and ultimately the safety of the aircraft in flight.

With radome test results now required to be drawn from true far-field (Fraunhofer) criterion, radome dimensions and measurement time have posed considerable constraints on current installations and methodologies. We have shown how far-field techniques need more space in order to meet this reinforced criterion; and we have seen how current near-field techniques need increased time to complete comprehensive measurements as per the Nyquist criterion, and with respect to the new requirements.

Despite the necessary accuracy measures, the industry still calls for economies of resources. Repair and test facilities have been in need of faster repair and test processes, and the change in the standard has set them back a step.

The new near-field multi-probe measurement technique for radome testing after-repair, introduced with the Aerolab, meets the RTCA-DO-213A accuracy requirements in test results, brings flexibility in test installations, keeps testing space footprint at a minimum, and gains record time in the repair and test process. And 3D diagnostic visualization now offers a new dimension to the repair process.



KEY TAKE-AWAYS

- **New standards drive increased accuracy in radome repair tests but creates new problems for most common test methods**
- **Space, time, and flexibility become challenges to overcome for FF, CR, or near-field single probe test systems.**
- **Near-field multi-probe technology like MVG's AeroLab performs accurate, RTCA compliant radome measurements for after-repair testing in record time and in compact spaces. Testing rates at two radomes per day are now achievable.**

Testing other devices with multi-probe technology

AeroLab is the latest addition to a portfolio of multi-probe technology by MVG, designed to make testing and validating the performance of antennas compact, fast and accurate.

For the aerospace and defense markets in particular, such systems are recommended for the antenna optimization in subsystem or system level testing of aircraft, satellites, or automobiles of a variety of sizes and associated frequencies.

Go to www.mvg-world.com to find out more about Aerolab, SG 128, SG3000, SG64, SG24, StarLab, and StarLab 50 GHz.

Figure 11 - Aerolab 3D design view.

MVG - Testing Connectivity for a Wireless World

The Microwave Vision Group offers cutting-edge technologies for the visualisation of electromagnetic waves. Enhancing the speed and accuracy of wireless connectivity testing, as well as the performance and reliability of anechoic and EMC technologies, our systems are integral to meeting the testing challenges of a fully connected world.

WORLDWIDE GROUP, LOCAL SUPPORT

Our teams, in offices around the world, guide and support you from purchase, through design, to delivery and installation. Because we are local, we can assure speed and attention in project follow through. This includes customer support and maintenance once the system is in place. For the exact addresses and up-to-date contact information: **https://www.mvg-world.com/contact**

For more information, please visit our website:
www.mvg-world.com

Or email us at:
salesteam@mvg-world.com