A Novel and Innovative Near Field System for Testing Radomes of Commercial Aircrafts

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***Abstract*—Current techniques for testing of aircraft radomes are time consuming, not as precise as desired, and requires dedicated far field test range, compact test range, or anechoic chamber, or other specific systems for measuring one or other of the parameters. To overcome all these limitations, and to obtain a unique system for a complete diagnosis, a novel technique of radome characterization is proposed and detailed in this article. Based on a Near- Field network of probes placed in the vicinity of the radome under test, this innovative Near-Field measurement system is fully compliant with the updated standard RTCA/DO213A and leads to accurate evaluation of many parameters such as transmission efficiency and beamwidth, while reducing the measurement time required.**

I. Introduction

The maintenance of aircraft radomes is of particular importance for the commercial aviation industry due to the necessity to ensure the correct functioning of the radar antenna, housed within such protective enclosures. Given that the radar component provides weather assessment, as well as guidance and navigation functions (turbulence avoidance, efficiency of route planning in case of storms, etc.), it is imperative that every repaired radome be tested with accuracy and reliability to ensure that the enclosed weather radar keeps on operating in accordance with the after-repair test requirements of the RTCA/DO-213 (Radio Technical Commission for Aeronautics) [1].

II. Limitations of the Current Techniques

Radome tests target a reliable valuation of the disturbances a radome might have on the signals crossing it. This test must be made according to the standard that was established by the RTCA. .

The various evaluations made during the test of radomes consist on [2], [3], [4]:

- Evaluating the losses due to the absorption and the reflection (it corresponds to the transmission efficiency);
- Evaluating the radiation pattern distortions
  - deflection of the main beam;
  - half power main beam width;
  - level of the secondary lobes;
- Evaluating the deflection of the polarization;

Sidelobe level and beamwidth measurements can be performed in Far-Field distance [1]. An example of typical test set-up in Far-Field is presented in Figure 1. for testing of the radome parameters.

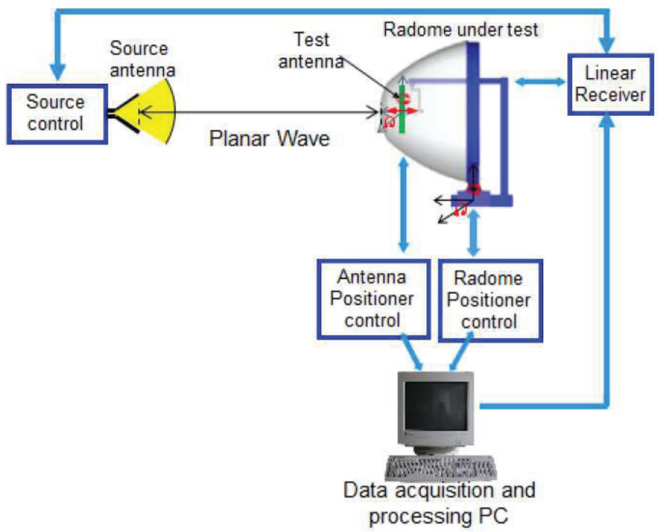

Figure 1. Typical transmission, sidelobe level and beam width measurement set-up under Far-Field conditions according to RTCA/DO-213 standard [1].

Concerning the measures of transparency and phase shift, the solution used at present is a point-to-point measure such as presented in Figure 2. , where a technician uses a portable test equipment. This method for testing of radomes is based on the double transmission [5]. These one implements a horn, and a metallic sheet placed on the internal surface of the radome. This method of test is very long and is not very reliable in terms of results. This operation introduces an uncertainty, because of the manual character of the measure, and the radome is not characterized in situation of functioning with the associated radar antenna. In addition, the discrete nature of the measure results in a lack of information that makes it difficult to have a comprehensive diagnosis and accurate parameter extraction.

In short, this technique is long and does not allow to detect with a great precision the zone of damage.

Initially the RTCA/DO-213 does not plan the use of measurement systems in Near-Field for characterization of radomes of commercial planes. Only compact antenna test ranges and Far-Field systems are mentioned in this standard.

Nevertheless, some customer needs have led to develop a dedicated Near-Field system with a gantry arm that allows complete 3D radome surface measurement with a single probe. A Near-Field to Far-Field transformation was used to obtain the fields compliant with the RTCA standard [6].

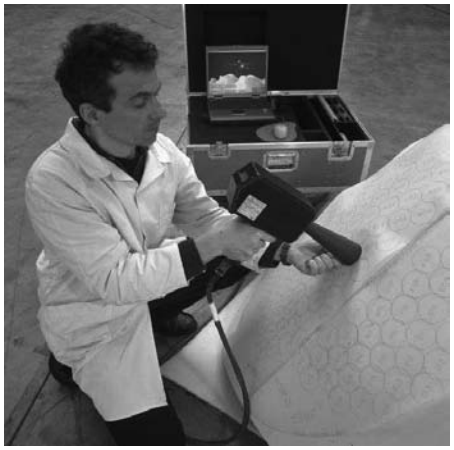

Figure 2. Use of a portable device for the diagnosis of radomes in repair shop [5].

However, one major drawback of this system lies in the measurement time which is very long, about 15 hours for a radome. This is a result of performing 92 measurement configurations recommended by the RTCA / DO-213. Indeed, there are 2 reference measurements of the atmospheric radar antenna without radome, to which it is necessary to add 45 measurements of the atmospheric radar antenna with radome as well as 45 measurements of the atmospheric radar antenna shifted of lambda/4 from its nominal station under the radome.

III. NEW RTCA/DO-213A STANDARD EVOLUTION

Recently, RTCA/DO-213 quality standard was updated and published under the name RTCA/DO-213A [7], establishing more stringent measurement requirements and incorporating the possibility of measuring radomes using Near-Field systems, as presented in Figure 3.

It introduces the possibility of working, after NF to FF transform, with a complete 3D Far-Field (instead of restricting main cuts) to better calculate the levels of the secondary lobes, the width of beam, and its deviation.

In the case of Far Field ranges, it introduces the criterion of Fraunhofer ($2D^2/\lambda$) instead of Fresnel ($D^2/2\lambda$) which is admitted more generally as reference distance in the radiofrequency domain. The effect of the Far-Field measurement distance is visible mainly on the characterization of the secondary lobes.

To summarize, the RTCA DO / 213A opens the door to the use of Near-Field measurement systems that can be used to diagnose all parameters in an exhaustive manner with more precision and speed.

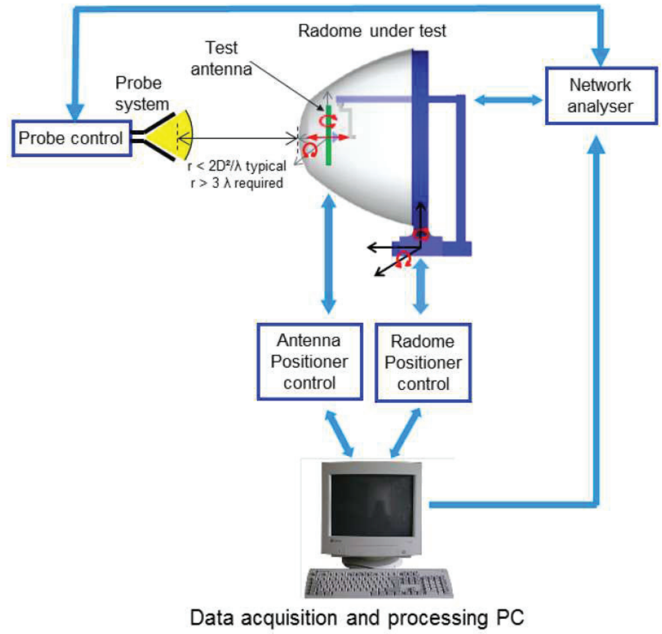

Figure 3. Typical transmission sidelobe level and beam width measurement set-up under Near-Field conditions introduced by RTCA/DO-213A standard update [7].

IV. AEROLAB CONCEPT

To overcome the time-consuming limitation of single probe NF systems with gantry arm, and taking into account the customer needs to measure at least 2 radomes a day, MVG intends to accelerate Near-Field measurements, by using a network of probes. Consequently, a compliant multi-probe Near-Field system concept – AeroLab – has been specifically designed to measure commercial aircraft nose-radomes, in order to meet the new standard requirements. Furthermore, this solution remains much more reliable for the measurement of the electromagnetic transparency of the radome, with regard to the tests made by means of horns in a general way.

A. Sizing the multi-probe architecture

In the case of the Near Field measurement systems, the time required for the characterization is a function of the physical dimensions of the radome.

The number of probes shall be consistent to meet the Nyquist criterion which sets the spatial step to be respected so that sampling in Near Field is sufficient. The Nyquist criterion (1), defines the spacing between the probes at less than half a wavelength and is a function of the frequency and size of the device under test, and gives the minimum quantity of probes on π radians.

$$N_{\pi} = k \cdot r \quad (1)$$

For the example of the Airbus A400M radome (radius of 1.312 m), which is one of the largest sizes we can meet today for commercial aircrafts, this leads to 258 probes on π at a frequency of 9.4 GHz, which represent a lot of probes.

To reduce the number of probes without increasing too much the total measurement time, the use of a quarter of an arch combined with the use of an oversampling feature is a smart solution. In this case, the use of a network of 16 probes over 95 degrees requires 9 oversampling positions with a total measurement time of 2h20 for the A400M radome with respect to RTCA/DO-213A. According to this calculation, the target of reducing the measurement time to less than 4 hours is met. The quarter-arch solution is interesting for obtaining a low-profile system which can be moved inside a repair shop.

B. Overview of AeroLab mesurement system

AeroLab measurement system is mainly composed of an arch which contains the probe network as presented in Figure 4. This arch embeds an accurate oversampling mechanism, that displaces the network of probes along the required curvature. Some foam absorbers encompass the arch, in order to avoid interactions between the DUT (Device Under Test) and any other structural components of the arch. An outer shell is also integrated for protecting all elements of the arch. .

Under the Aircraft’s radome, the weather antenna is positioned by a specific gimbal associated with a vertical translation axis positioner. The gimbal enables accurate antenna positioning with respect to the specified spherical coordinates. The vertical positioner has both the role of retracting the radar antenna and the gimbal when installing the radome in order to facilitate this operation, and set the correct vertical station of the radar antenna once measurements are ready to start. Finally, a primary equipment bay is located at the bottom of the arch.

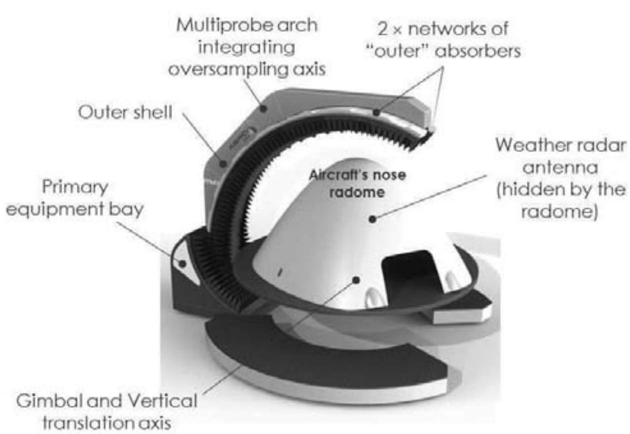

Figure 4. View of the AeroLab with its sub-assies.

The RF block diagram of the AeroLab system is sketched in Figure 5. The main elements are the synthesizers, amplification and mixer units that enable the IF signal to be processed with the NPAC (Numerical Probe Array Controller). Finally, the positioner controller synchronizes the required mechanical motions. All these devices are driven by a data acquisition and processing platform.

The measurement probes are specially developed to cover 9.3-9.5 GHz band with two orthogonal polarization ports. The low-profile probe antennas were characterized with a MVG StarLab Near-Field measurement system (see Figure 6.). The final optimization of the probes was performed by taking into account its operating environment, *i.e.* by including the absorbers materials as depicted in Figure 7.

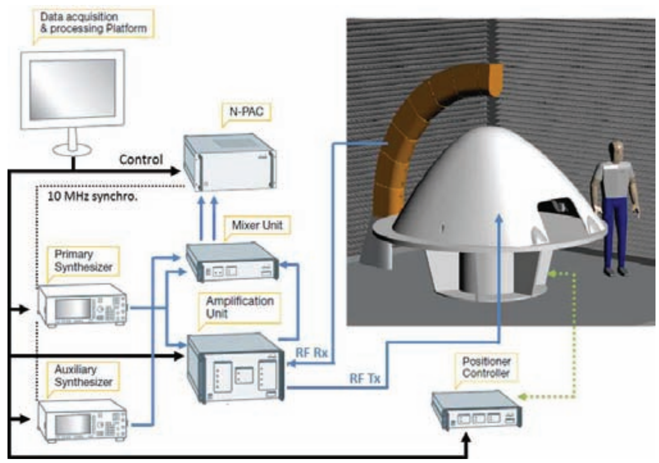

Figure 5. RF block diagram of AeroLab Near-Field measurement system.

Figure 6. RF measurement probe characterization in MVG StarLab Near-Field measurement system.

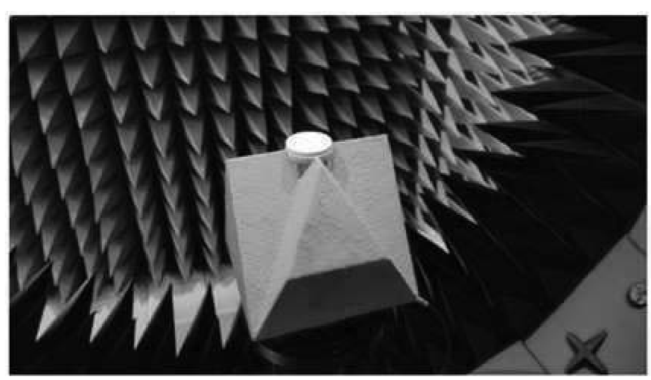

Figure 7. Optimization of RF measurement probe in its operating environment with absorber materials.

The measured radiation patterns of every polarization port is presented in Figure 8. in case of embedded probe at 9.5 GHz frequency. The natural axial polarization discrimination is nearby 45 dB.

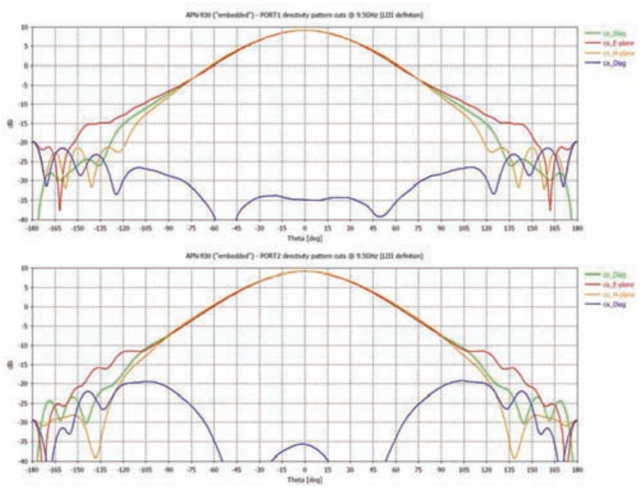

Figure 8. Radiation patterns in directivity (ports 1 and 2) for embedded probe @ 9.5 GHz.

The whole AeroLab system can be contained within a 4m x 4m x 5m shielded anechoic chamber, with a single or double leaved door (see in Figure 9.).

Figure 9. Global overview of the measurement system inside shielded anechoic chamber.

AeroLab performs Near-Field measurements. Near-Field to Far-Field transformations are then applied to the acquired data. Such a Near-Field system allows the test range to be more compact than traditional Far-field test ranges, and as a result, be independent from the updated Far-Field distance which has progressed from $D^2/2\lambda$ to $2D^2/\lambda$ in the new standard RTCA/DO-213A. AeroLab enables the measurement of the transmission efficiency and beamwidth. It also allows accurate characterization of side lobe levels by providing improved visualization of the main sectional views extracted from 3D patterns. In addition to, depending on the weather radar system within the radome under test, two distinct kinematics of scanning sequences can now be taken into account: "elevation over azimuth" and " azimuth over elevation ".AeroLab emulates both of these motion sequences through a monolithic gimbal.

C. Cartography of the radome

Once the measurements are performed, the Near-Field data are used for reconstructing the fields over the radome surface. To build a radome cartography, various techniques exist and take Near-Field data as input:

- Integral equation techniques
- Spherical back-propagation
- 3D holography

The integral equation techniques are time consuming, which represent a strong drawback in our case, since the calculation time is proportional to the number of measurements.

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

The technique of 3D holography solves the problem of previous both techniques. With this technique, it is possible to compute the fields on the radome surface without being time-consuming. The technique of holographic reconstruction takes into account the contribution of every equivalent source relying on the sphere of Near-Field measurements as presented in Figure 10. The sum of these contributions of each equivalent source on the points of the radome surface enables to compute the superficial fields on this surface.

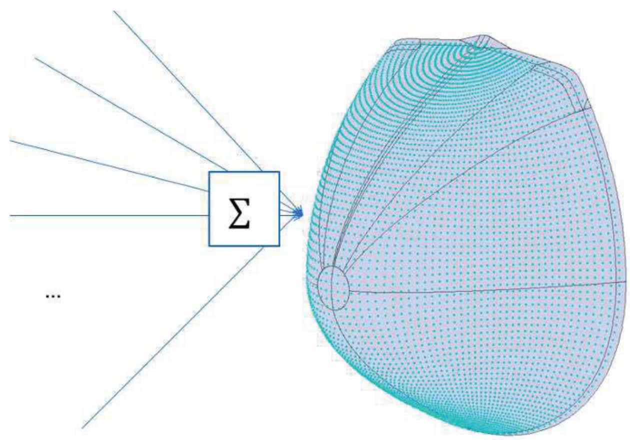

Figure 10. Contribution of every equivalent source for the reconstruction of the field on every point of the radome.

The cartography of the radome is divided into 45 sections that corresponds to the 45 measured angular positions of the radar antenna. Figure 11. shows the final cartography of the radome with these 45 measurement sections. Aerolab acts as a non-destructive control system dedicated to the diagnosis of aircraft radomes.

An example of 3D holography reconstruction result is proposed in Figure 12. and Figure 13. for amplitude and phase differences. The measurements with and without radome are compared to obtain these results. We can see that the existing inserts in the radome structure are detected due to the inhomogeneities they are causing in the material. These default values are slightly visible in amplitude and more clearly detected in phase.

Additional tests performed on a planar radome, show that, using the technique of 3D holography, it is possible to detect the presence of dielectric patches, of a minimal size λ x λ x 0.1λ. These additional results show better performance of detection in the case of the cartography of the phase difference.

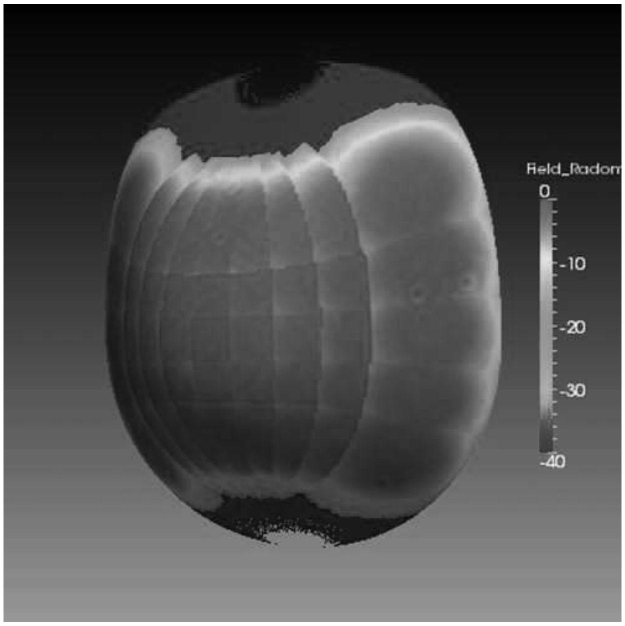

Figure 11. Visualization of the cartography of the radome with 45 measurement sections.

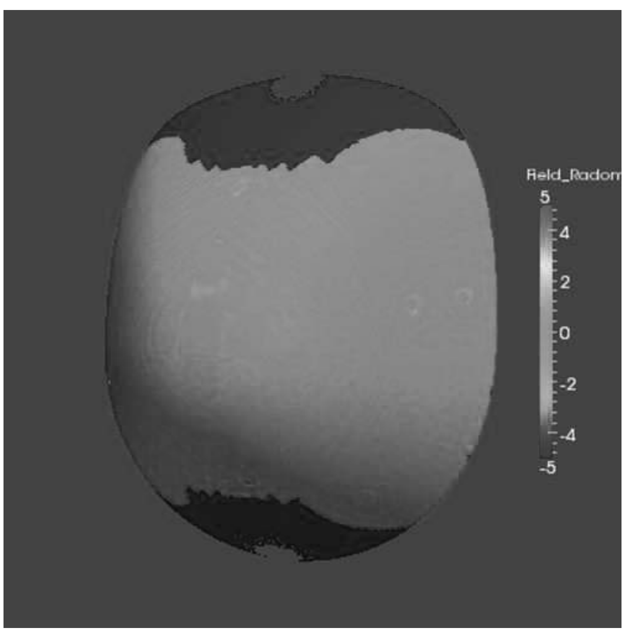

Figure 12. 3D cartography reconstruction result of the surface of the radome – amplitude difference on total field.

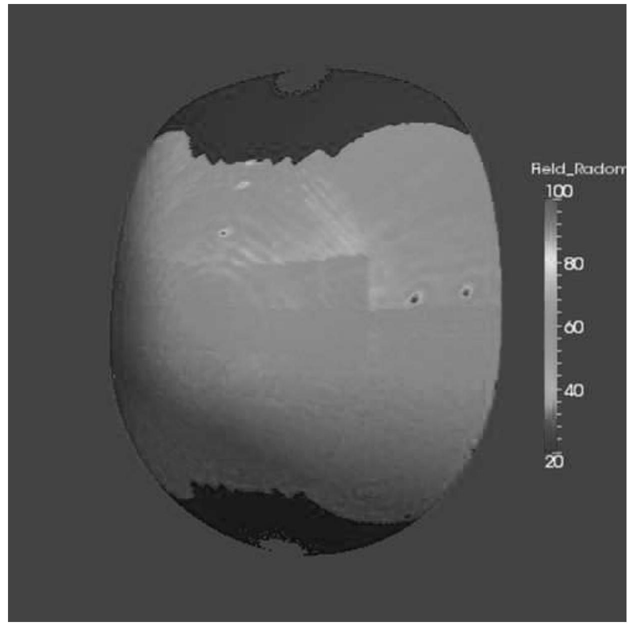

Figure 13. 3D cartography reconstruction result of the surface of the radome – phase difference for phi component.

This multi-sensor system for Near-Field tests of commercial aircraft radomes (Aerolab) is dedicated to repair shops and makes it possible to completely diagnose, in a single measurement operation, the entire radome according to the RTCA/DO213A standard. The AeroLab system, which saves measurement time and provides diagnostic with accuracy, can be accommodated in a limited volume within the repair shop.

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