Performance Evaluation of RCS Near-Field-to-Far-Field Transformation Technique for Aircrafts

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Abstract - **The performance of the radar cross section (RCS) near-field-to-far-field (NF) transformation technique using Fresnel phase and paraxial approximations is evaluated. The evaluation is conducted by using a 1-20th scaled experimental model and a full-scale numerical 3D-model of an aircraft. The results show that the NF transformation technique is effective for an object with complicated shape, as well as for near-field region closer than the Fresnel region.**

Index Terms — **Radar cross section, near-field-to-far-field transformation, aircraft.**

1. Introduction

One method of measuring the radar cross section (RCS) of an electrically and physically large object is to measure the RCS in the near-field region and to transform the measured near-field RCS to the far-field one by signal processing (NF transformation). The authors have extended the NF transformation algorithm based on the technique of using Fresnel phase approximation and paraxial approximation [1] to the ground-plane range measurement, and have verified its accuracy by using metal plates and a simplified aircraft model [2-3]. However, they did not verify the accuracy for scatterers having highly complicated shape such as actual aircrafts and for the near-field range shorter than the lower limit of the Fresnel region. This paper reports the results for these verifications.

2. NF Transformation Algorithm

Figure 1 shows the geometry and coordinate system for the NF transformation algorithm. First, the equivalent scattering coefficient, $S_e(y, z)$, which is the projection of the scattering source induced on the object being measured onto the YZ plane, is found by integrating the scattered electric field, $E^s(\rho, \theta, \varphi)$, according to the following equation:

$$\boldsymbol{S}_e(y,z)=\frac{j4\rho^2}{\lambda}\exp\left\{2jk\left(\rho+\frac{y^2+z^2}{2\rho}\right)\right\} \times\iint_{\theta_w,\phi_w}\boldsymbol{E}^s(\rho,\theta,\phi)\exp(2jky\phi+2jkz\theta)\,d\phi\,d\theta \tag{1}$$

where ρ is the distance between the origin and the source/observation point and the θ_w and φ_w are the scanning angle region of the source/observation point. Next, the far-field RCS, σ, is then calculated by integrating the equivalent scattering coefficient, $S_e(y, z)$, over the YZ plane as

$$\sigma=\left(4\pi/\lambda^2\right)\left|\iint_{y_w,\,z_w}\boldsymbol{S}_e(y,\,z)\,dy\,dz\right|^2. \tag{2}$$

When the far-field condition is satisfied in the θ direction, Eqs. (1) and (2) are reduced to one-dimensional transformation with respect to φ or y direction, as in Eqs. (3) and (4).

$$\boldsymbol{S}_e(y)\approx j2\rho^2\exp\{jk(2\rho+y^2/\rho)\} \times\int_{\phi_w}\boldsymbol{E}^s(\rho,\phi)\exp(2jky\phi)\,d\phi \tag{3}$$

$$\sigma=\left(4\pi/\lambda^2\right)\left|\int_{y_w}\boldsymbol{S}_e(y)dy\right|^2 \tag{4}$$

3. Experimental Verification Using Aircraft Scale-Model

A 1-20th scale model of an aircraft, whose dimensions are 946 mm in length, 683 mm in width, and 197 mm in height, was fabricated to carried out the experimental verification. The whole of the surface of the model is coated by metal. The coordinate system is defined that the X-axis corresponds to the nose direction of the aircraft and the Z-axis its upward direction. The measurement distance was set approximately to 12 m, the RCS pattern within the horizontal plane (XY plane) in the Fresnel region was measured at the X band, and then the measured result was transformed to the far-field RCS pattern. Since the far-field condition in the θ direction is satisfied in this case, the NF transformation was conducted by using Eqs. (3) and (4). Three RCS patterns are shown in Fig. 2. The blue line represents the Fresnel region RCS pattern measured, the red line the transformed far-field RCS pattern, and the black line the reference solution computed by the Method of Moments (MoM). It can be confirmed that the RCS pattern obtained by the NF transformation agrees well with the reference RCS pattern. The mean error of the NF transformation over the whole horizontal plane is 1.6 dB.

4. Simulation Results Using Full-Scale Numerical Model of Aircraft

A full-scale numerical 3D model of the aircraft with the same shape as the scale model in the previous section was prepared and the accuracy of the NF transformation was investigated by a numerical simulation. An equivalent edge current method was used to calculate the scattered field, while Eqs. (1) and (2) were used for the NF transformation. The radio frequency was set to the S band, and the distance for the near-field calculations was about one-third that of the distance at the lower limit of the Fresnel region. The calculation result of the equivalent scattering coefficient distribution at $\varphi = 25^\circ$ is shown in Fig. 3, which is corresponding to the scattering characteristic of the model. The simulation results of the RCS pattern in the horizontal plane are shown in Fig. 4. Only the range $0 \leqq \varphi \leqq 45^\circ$ is shown here. The black line represents the directly computed far-field RCS pattern, the blue line the RCS pattern in the near-field region, and the red line the RCS pattern after the NF transformation. It can be confirmed that the NF transformation technique can be done with relatively high accuracy, even for the near-field region. The mean error of the NF transformation over the entire horizontal plane is 2.1 dB.

5. Conclusion

The performance of the NF transformation technique for the aircraft with real shape has been evaluated experimentally and numerically. It has been confirmed that the NF transformation algorithm is useful for scatterers with complicated shape. It has also been found that it is possible to obtain transformation accuracy high enough for practical use, even for the near-field range shorter than the lower limit of the Fresnel region.

References

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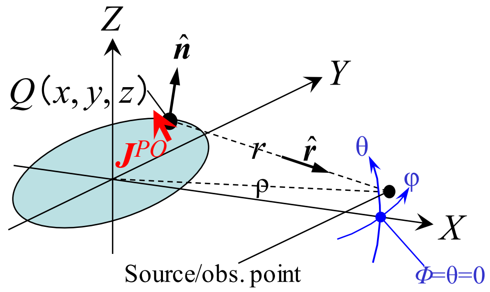

Fig. 1. Geometry for NF transformation algorithm.

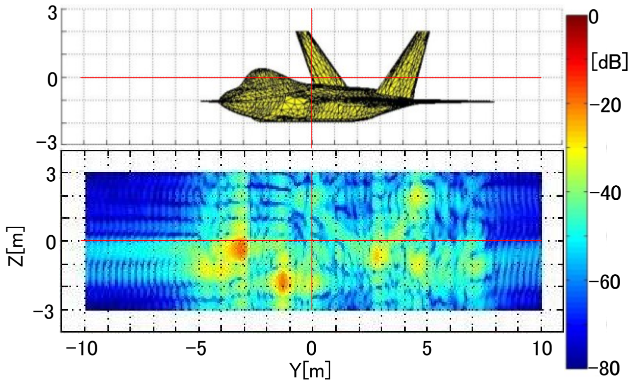

Fig. 3. Equivalent scattering coefficient distribution at ϕ =25 deg.

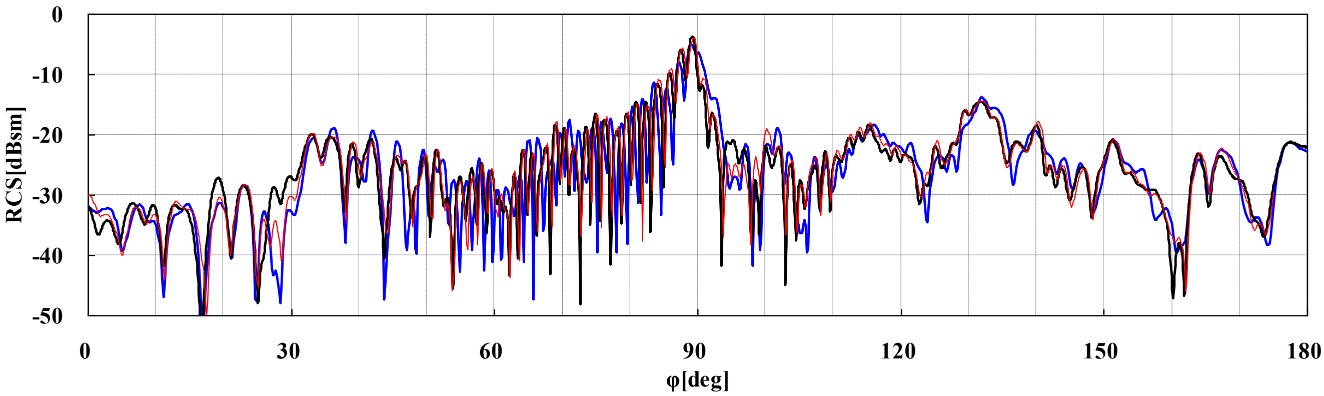

Fig. 2. RCS pattern of 1-20th aircraft experimental prototype (Horizontal plane, X-band).

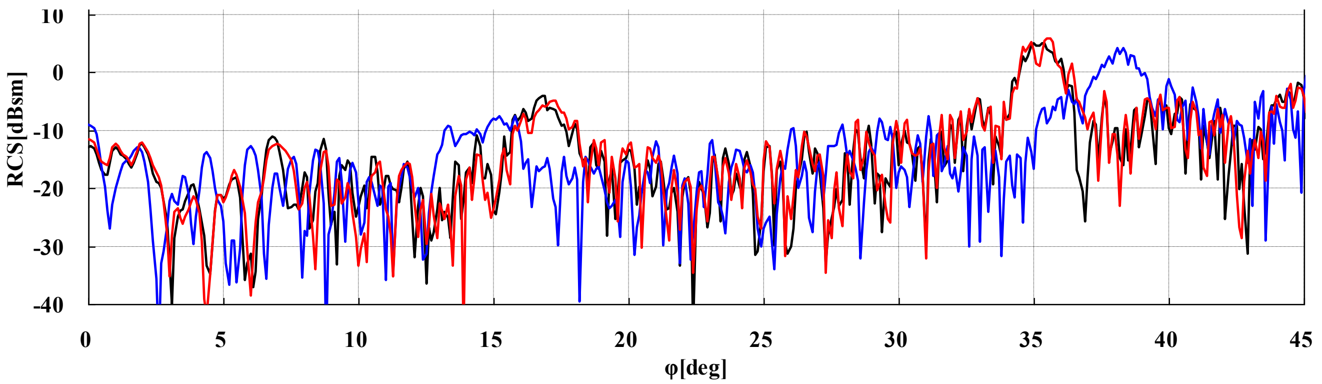

Fig. 4. RCS pattern of full-scale numerical aircraft model (Horizontal plane, S-band).