Research on RCS Simulation of Early Warning Radar Detecting Aircraft Target

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Abstract: RCS is an important parameter reflecting the equipment performance of early warning radar. At first, the transformation formulas of radar coordinate system and target coordinate system under different attitude angle are deduced. Secondly, taking a certain aircraft as an example, the static RCS database of the whole airspace of the target is constructed. The simulation efficiency of RCS of the target is increased. The data is closer to reality, and accuracy of the simulation is improved. The method has value of reference for the research on electromagnetic characteristics of the radar target.

1. Introduction

When the technology of radar technology and the confrontation of stealth and anti-stealth develops quickly, modern warfare presents a complex situation of technicalization, mobility and rapid response. Radar detection of aircraft mainly depends on the radar cross section (RCS) [1] of the target obtained. RCS represents the physical quantity of the echo intensity produced by the target under the irradiation of incident wave. It is the most important concept to describe the characteristics of radar target [2]. Dynamic [3] and static measurements are the main methods to study RCS. Dynamic measurement has higher application value than static measurement because it is in the actual complex environment. There are two ways to obtain dynamic RCS data: field test and theoretical simulation. The cost of field test is high, and there are many error factors, which lead to low accuracy of the measurement. Therefore, the method of simulation is adopted by most researchers.

Based on the simulation of static RCS in radar coordinate system, the transform relationship between radar and target coordinate system is deduced in this paper. Simulation of dynamic RCS based on quasi-static method and overlapping random dithering model make attitude angle more consistent with the actual situation. Finally, the dynamic RCS curves of the target in different polarization modes under the predetermined track are simulated. The results of simulation are consistent with the theoretical expectation, which verifies the correctness of the method.

2. Line-of-sight angle of radar

Reference [4] obtains the real-time attitude and position of the target. Then the real-time radar line-of-sight angle is calculated. The algorithm for calculating the line-of-sight angle of radar is as follows.

$$\begin{bmatrix} x(t) \\ y(t) \\ z(t) \end{bmatrix} = \boldsymbol{Q} \cdot \begin{bmatrix} x_1(t) \\ y_1(t) \\ z_1(t) \end{bmatrix} \quad (1)$$

In the above formula, (x_1(t), y_1 (t), z_1 (t)) are the coordinates of radar in the body reference coordinate system. θ, ψ, γ are pitch angle, yaw angle and roll angle. The body reference coordinate system is defined as the translation of the coordinate origin of the radar coordinate system to the airframe center. The azimuth and pitch angles of the radar line of sight in the body coordinate system are as follows.

$$\varphi(t) = \arctan\frac{y(t)}{x(t)} \tag{2}$$

$$\theta(t) = \arctan\frac{z(t)}{\sqrt{x(t)^2 + y(t)^2}} \tag{3}$$

3. Construction of static RCS database in all space domain

The static RCS of the target is simulated by FEKO software. The method of moments is used to simulate and calculate the characteristic library of static RCS of the target in the whole space domain [5]. The simulation condition is that the incident angle is 181*361 degree in whole space. The angle interval is 1 degree and the frequency band is X band. The static RCS of the target in all space domain is shown in Fig. 1. In the figure, The RCS of the nose and tail of the aircraft is significantly lower than that of the belly and back of the aircraft.

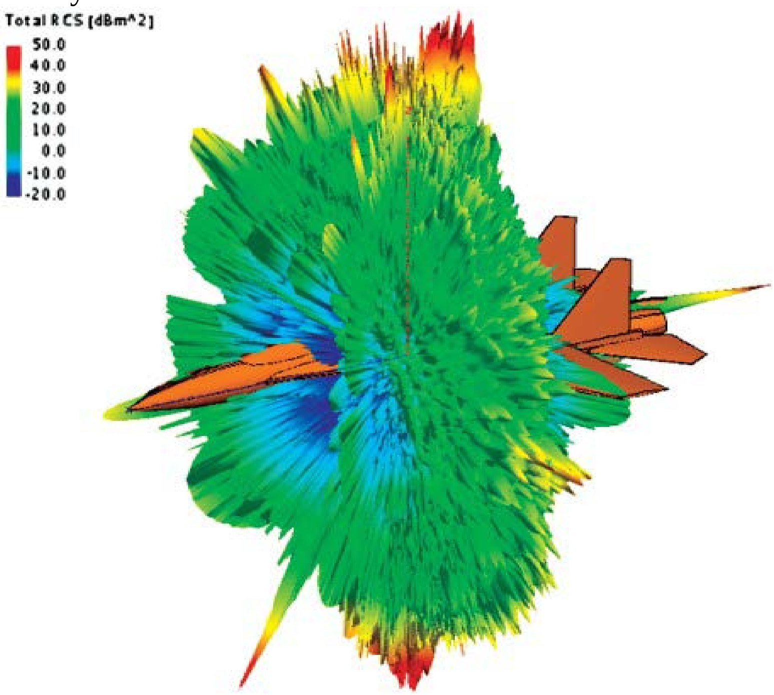


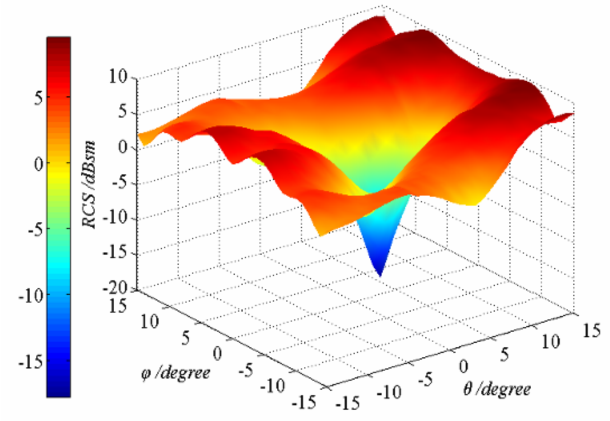
Figure 1. The static RCS of the target in all space domain

$$\boldsymbol{Q} = \begin{bmatrix} \cos\psi\cos\theta & -\sin\psi\cos\theta & \sin\theta \\ \sin\psi\cos\gamma - \cos\psi\sin\theta\sin\gamma & \sin\psi\sin\theta\sin\gamma + \cos\psi\cos\gamma & \cos\theta\sin\gamma \\ -\sin\psi\sin\gamma - \cos\psi\sin\theta\cos\gamma & \sin\psi\sin\theta\cos\gamma - \cos\psi\sin\gamma & \cos\theta\cos\gamma \end{bmatrix}$$

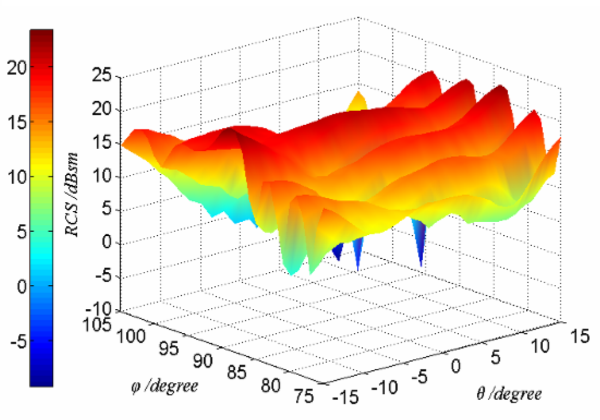
4. Analysis of simulation results

Cruise and penetration are the two most important stages in combat. When cruising, the aircraft usually makes horizontal flight at side stations, and the lateral direction of the aircraft is exposed to radar. In the process of penetration, the nose cone direction of aircraft has the most threat. Most of the published literature studies characteristics of RCS in the local azimuth range of the fuselage plane. It is inconsistent with the actual situation, because the aircraft cannot be at the same altitude as the radar. Therefore, this section mainly analyses RCS characteristics of two local airspace areas, lateral and head directions of aircraft. For convenience of expression, the azimuth angle greater than

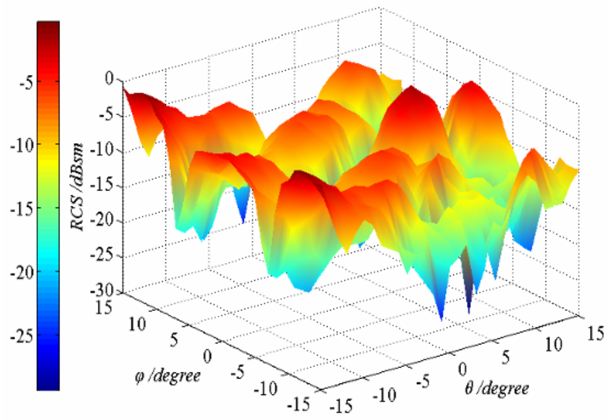
180 degrees is denoted by negative values. The attitude angle range in head direction is (-15°≤φ≤15°, -15°≤θ≤15°), and the attitude angle range in lateral direction is (75°≤φ≤105°, -15°≤θ≤15°). The color charts of local spatial RCS with vertical polarization in three bands are shown in Fig. 2.



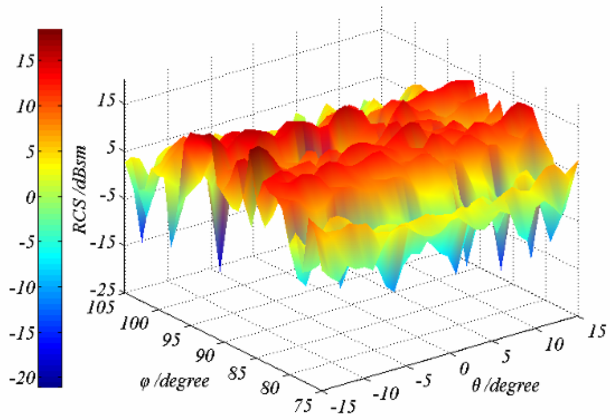
(a) Head direction in the VHF band



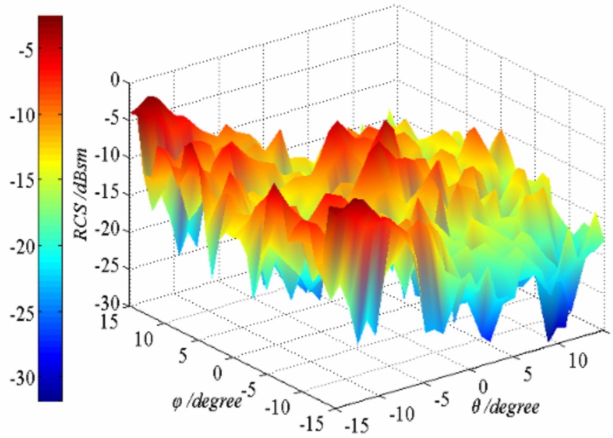
(b) Lateral direction in the VHF band



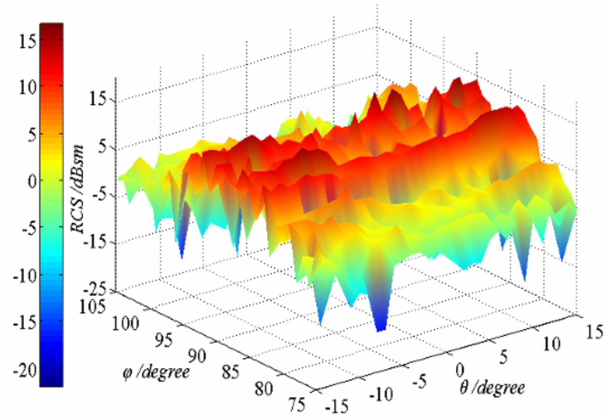
(c) Head direction in the P band



(d) Lateral direction in the P band



(e) Head direction in the L band



(f) Lateral direction in the L band

Figure 2. Color charts of static RCS in local airspace of a certain aircraft

The statistical method is used to study RCS with different attitude angles and frequencies, because the RCS of aircraft target varies dramatically with attitude angle. Four statistical parameters, median, mean, maximum and minimum, are selected respectively. The comparison results are shown in Table 1.

Table 1. Statistical parameter of RCS in the key attitude angle REGION (dBsm)

	median	mean	maximum	minimum
Head direction in the VHF band	3.81	3.36	9.48	-17.75
Lateral direction in the VHF band	13.06	12.78	23.31	-9.12
Head direction in the P band	-11.05	-1.05	-0.35	-29.32
Lateral direction in the P band	4.68	4.32	18.47	-21.03
Head direction in the L band	-14.48	-4.82	-2.53	-31.79
Lateral direction in the L band	2.29	2.32	16.62	-21.89

In the same frequency band, RCS values in different attitude angles are compared. In the three frequency bands, the lateral RCS value is higher than the head RCS value, and the ratio of average median is less than 1, which accords with the actual situation. When radar detects, the probability of detection can be improved by multiradar networking. Comparing RCS values at different frequency bands in the same attitude angle range, it can be seen that RCS decreases with the increase of frequency. Mean RCS of head direction at L-band is -14.82 dBsm (0.03 m^2).It is consistent with the conclusions in the open literature. The mean and median of nose RCS in VHF band are about 3dBsm (2m^2). The key frequency bands of stealth design are all microwave bands. In the meter band, because the size of target and the wavelength of electromagnetic wave are in the same order of magnitude, the resonance easily occurs, which results in the significant increase of RCS value in the meter band. This is the principle of meter wave radar anti-stealth. Fig. 2 also shows that the higher the frequency, the more drastic the change of RCS value.

5. Conclusion

The traditional study of target RCS is based on 0 pitch angle or 0 azimuth angle. The paper overcomes the shortcomings of traditional analysis. Based on the RCS characteristics of the key attitude angle range, the static electromagnetic scattering characteristics of the aircraft target in the head and lateral directions are studied. The simulation results are consistent with the conclusions of the open literature and theoretical analysis, which verifies the correctness of the static RCS simulation results in this paper. At the same time, the accuracy of the target model is verified. It provides data basis for the follow-up research of radar detection.

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