Simulation Analysis of Detection Area for Flying Wing Layout UAV Using X-Band Bistatic Radar

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Abstract. The shape design of flying wing UAV can effectively reduce the detection and tracking probability of single-station radar. Bistatic radar has the advantage of anti-stealth for stealth targets due to the characteristics of multi-station distribution. However, there is no literature to study the detection area of flying wing UAV by bistatic radar. To solve this problem, FEKO electromagnetic simulation software is used to establish the X-band electromagnetic model of X-47B UAV, and the bistatic RCS of 0° pitch angle is simulated. According to the bistatic radar equation, the effective detection area of X-47B UAV lateral flight is simulated. The results show that the detection range of bistatic radar is mainly in the vicinity of 5 banded regions and bistatic radar. The five strip regions in the effective detection range correspond to the five bright lines of bistatic RCS one by one. When the baseline of bistatic radar is 20 km, the effective detection range is the largest. The research provides data support for the layout optimization of bistatic radar station and the trajectory optimization of flying wing UAV.

1. Introduction

Bistatic radar places the transmitter and receiver in two or more distant positions. In general, it is equipped with one transmitter and multiple receivers. The transmitter is generally located in a safe area far from the threat area. The receiver works silently and has the natural advantages of anti-stealth [1-2], anti-interference[3] and anti-destruction. In recent years, with the rapid development of signal processing technology, the new system of bistatic radar has gradually become the focus of research and has great potential for military applications. According to different demands, the combination modes can be divided into three forms: ground launch ground reception[4], shore launch ship reception[5] and space launch ground reception[6]. Literature[3] points out that bistatic radar can improve the target detection effect for stealth missile model, while bistatic RCS for non-stealth missile has little benefit. When the maximum bistatic angle reaches 40°, the application of bistatic radar can improve the detection ability of stealth targets. According to the empirical formulas of monostatic and bistatic RCS of stealth targets, literature[5] studied the relationship between the depth detection distance and the detection range, and pointed out the relative fluctuation and balance between the two, but lacked accurate bistatic RCS, and the research results lacked practicability.

Shape stealth design is the most important part of aircraft stealth design, which contributes more than 80% to stealth effect. The non-vertical tail design of the wing layout greatly weakens the two-sided angle effect of the lateral radar echo between the vertical tail and the horizontal tail, and greatly reduces the lateral monostatic RCS of the aircraft. In addition, the design of flat fuselage and large
swept angle wing scatters the radar wave in the forward angular domain to other angular domains, and the forward RCS is also at a low level. Therefore, the wing layout is a hot topic in the research of stealth aircraft shape. Reference[7] studied the bistatic RCS of wing layout, and pointed out that the receiving radar should be arranged at the position of double wing leading edge/fuselage side lobe sweep angle and 180° bistatic angle. At present, the research on flying wing UAV is focused on bistatic RCS, and there is no literature on the detection area of flying wing UAV by bistatic radar. It is of great military significance to study the detection range of flying-wing UAVs under different bistatic radar layouts. It can provide guidance for flying-wing UAVs to avoid radar detection, carry out close-range reconnaissance and tasks, and provide track planning. At the same time, it also provides data analysis tools for how to optimize the layout and improve the detection probability of bistatic radar in the case of flying wing UAV layout.

2. Bistatic RCS Simulation Model of Flying Wing Layout
The X-47B is the most representative flying wing UAV. Its outer wing is composed of aluminum alloy parts and carbon fiber epoxy composite skins. Its design style has subversively affected the layout design of stealth UAVs around the world and has become the object of learning and imitation in various countries. The X-47B aircraft model, shown in Figure.1, does not take into account the effects of multi-angle specular reflection caused by strong scattering sources such as inlets and nozzles. The model size is 100% of the full size, the wingspan is 18.93 m, and the length is 11.64 m. The specific performance is referred to in Reference[8].

FEKO is a world-famous electromagnetic calculation software, and its products have always been recognized by the industry in RCS calculation of RTVU targets. In this paper, FEKO is used to calculate the bistatic RCS of X-47B UAV. The frequency is 10GHz. The incident angle and reflection angle of electromagnetic wave are set as shown in figure.1, and the interval is 1°. Only the bistatic RCS of the elevation angle is 0° is calculated. The fuselage material is metal. Due to the high frequency band, the full-wave electromagnetic calculation method is slow. Considering the large electrical size of X-47B UAV, the RLGO algorithm is used for simulation, and the bistatic RCS data can be quickly obtained.

![Figure.1 Setting of incident angle and receiving angle of bistatic RCS](image)

3. Calculation of effective detection range of bistatic radar
The effective detection range of bistatic radar for flying wing UAV determines the time of radar system discovery and continuous tracking, which is the concentrated reflection of the ability of early warning detection system to resist stealth targets. According to the principle of bistatic radar detection, the target signal power of bistatic radar receiver is

\[
P_e = \frac{P_r G_1 G_r \lambda^2 \sigma}{(4\pi)^2 (R_s R_e)^2 L}
\]

(1)
Where, \( P_t \) is the transmitting power, \( G_t \) and \( G_r \) are the gain of transmitting antenna and receiving antenna, \( \lambda \) is the wavelength of radar, \( \sigma \) is the bistatic RCS of radar, \( R_t \) and \( R_r \) are the distance from transmitting station and receiving station to target, \( L \) is the loss of bistatic radar system. \( D \) is the baseline distance of the bistatic radar, the coordinate of the transmitter station is \((-0.5D, 0)\), and the coordinate of the receiver station is \((0.5D, 0)\).

The bistatic RCS of flying wing UAV is sensitive to the angle of incidence and bistatic angle, which needs to be calculated accurately according to the RCS value \( \sigma \) and the sensitivity of radar receiver \( R_{\text{min}} \). On the basis of the incident angle and the bistatic angle, the RCS value \( \sigma \) is obtained, and the corresponding radar receiver power \( P_r \) is calculated. Compared with the receiver sensitivity \( P_{\text{min}} \), if \( P_r \geq P_{\text{min}} \), it is judged that the flying wing UAV can be found, otherwise, it cannot be found. The specific flow chart is shown in figure 2.

![Figure 2](image2.png)

**Figure 2** Bistatic radar detection flow chart of flying wing UAV

![Figure 3](image3.png)

**Figure 3** 0° pitch angle bistatic RCS of X-47B

4. Analysis of simulation results

According to the above bistatic RCS simulation settings, bistatic RCS is shown in figure 3.

The performance parameters of bistatic radar are set to \( P_t = 10^6 \) W, \( P_{\text{min}} = 10^{-14} \) W, \( L = 8 \) dB, \( \lambda = 3 \) cm, \( G_t = G_r = 40 \) dB. Set a close blind area of 27 km. As shown in figure 4, when the bistatic radar is arranged at different baseline lengths \( D \), the effective detection range for X-47B flying from east to west is obtained. It can be seen from the figure that when the baseline length is different, the effective detection range is similar, and the five striplines are one-to-one corresponding to the five bright lines shown in figure 3. That is, when the incident angle and the reflection angle are different, the RCS is large and can be detected by radar. However, with the increase of baseline length, the proportion of effective detection range in the total detection range increases first and then decreases rapidly. At 20 km, there is a maximum of 0.0855 (Figure 4(d)), and at 100 km, there is a minimum of 0.054. The main reason is that the short baseline has a higher detection probability for the location near the
transceiver due to the influence of the product of the distance from the starting station to the target. The long baseline has a lower detection probability for the position in the near distance, mainly for the five main strip lines. When the baseline length of bistatic radar is 20 km, there is a higher detection probability for the flying wing UAV X-47B in the range.

5. Conclusion

For laterally flying winged UAVs, the detection range of the bistatic radar is mainly in five banded areas and areas near the bistatic radar. The five strip regions in the effective detection range correspond to the five bright lines of bistatic RCS one by one. When the baseline of bistatic radar is 20 km, the effective detection range is the largest.

The research results provide guidance for the flight path planning of UAV with wing layout to avoid radar detection, carry out close reconnaissance and penetration strike missions. At the same time, it also provides data analysis tools for how to optimize the layout and improve the detection probability of bistatic radar in the case of flying wing UAV layout. Due to the large amount of bistatic RCS data, it is difficult to construct the basic database. In the next step, the database call speed can be improved by constructing a more comprehensive bistatic RCS database. The simulation research of bistatic radar detection area under different elevation angles can be more realistic.

![Figure 4 Detection Range of Bistatic Radar in Radial Flight](image-url)

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