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The Study of Dynamic Electromagnetic Scattering Characteristics of Ballistic Missile

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Abstract. Studying the dynamic RCS of ballistic missile has benefit for effective detection and interception in the air and missile defense operation. Firstly, the model of ballistic trajectory is established. Then, the attitude angle of target is obtained by coordinate conversion formula. Lastly, the dynamic RCS of the target in real time is simulated by EDITFEKO program. For the different trajectories at different attitude angles, the dynamic RCS of target is simulated under conditions of various radar deployment. According to the result, the forward RCS of ballistic missile is greater than RCS of lateral religion. Anti-missile warning radar should be deployed within the range of ballistic missiles. Radar should face the lateral of ballistic missile. The results of simulation offer the basis for the deployment of anti- missile early warning radar.

Key words: ballistic missile, coordinate conversion, dynamic RCS, detection

1. Introduction

Ballistic missile has advantages of long range, high precision, large power and strong mobility. Thus, ballistic missile has become the powerful offensive weapon which poses serious challenges for air defense and antimissile. The primary task of air defense and antimissile is to detect and track ballistic targets in time. Reference [1] and reference [2] study the RCS characteristics of the ballistic target in the boost phase, and provide the basis for the recognition of ballistic target. Reference [3] analyzes the motion characteristics of ballistic targets based on the dynamic RCS characteristics in the middle section. Reentry target enters the atmosphere at the second time. By the impact of air resistance, the speed is decreased continually which has benefit for interception. The article studies the dynamic RCS characteristics of ballistic targets based on the reentry trajectory. What is more, the impacts of different locations of radar deployment and different reentry angles on the dynamic RCS characteristics are studied as well.

2. Coordinate system and attitude angle of the target

2.1. Coordinate system of radar

Radar coordinate system is defined on radar (figure 1). The origin of coordinates o_R is located at the location of radar. The z_R axis is vertical upward. The x_R and y_R axis are in the horizontal plane. West is the positive direction of x_R axis, and the south is the positive direction of y_R axis.

2.2. Coordinate system of target

Radar coordinate system is defined on the target (figure 2). The origin of coordinate o_T is located at the center of the target. x_T axis is parallel to the axis direction of the missile. The y_T axis is perpendicular to the target plane. The z_T axis is located in the target plane and perpendicular to the x_T axis that the upward direction is positive.

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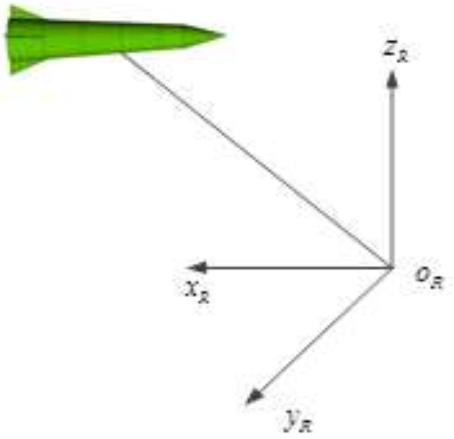


Fig. 1: Radar coordinate system

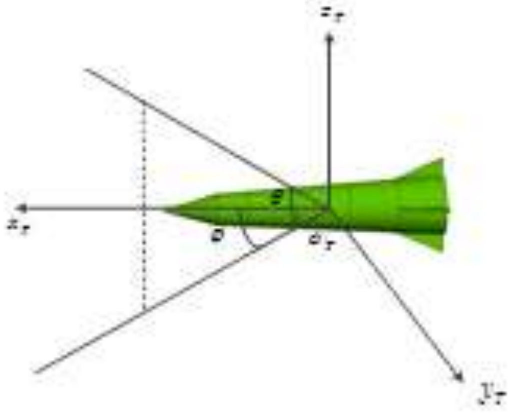


Fig. 2: Coordinate system of the target

The attitude angle of target is defined in figure 2. The azimuth angle φ is the angle between the projection of the radar line of sight on the plane $o_T x_T y_T$ and $o_T x_T$. The range of φ is $[0^\circ \quad 360^\circ]$. When the φ equals to 0°, the direction is consistent with the nose. When the φ equals to 180^o, the direction is consistent with the tail. Pitch angle θ is the angle between the projection of the radar line of sight on the plane $o_T x_T z_T$ and $o_T x_T$. The range of θ is $[-90^\circ \quad 90^\circ]$. When θ equals to -90^o, the direction is consistent with the belly. When the θ equals to 90^o, the direction is consistent with the back. When the θ equals to 0^o, the direction is consistent with the plane of fuselage.

In order to achieve the azimuth angle $\varphi(t)$ and the pitch angle $\theta(t)$ which show attitudes of the target in the target coordinate system, the coordinate transformation relation deduced from reference [4], [5] and [6] is needed. The coordinates of the targets in the radar coordinate system should be transformed into the target coordinate system.

3. The method of obtaining dynamic RCS time series

3.1. Obtaining static RCS

RCS is often used to represent the electromagnetic scattering characteristics of radar wave, which can describe the scattering ability of the target to the electromagnetic wave. It is expressed as sign σ.

When using the physical optics method to calculate the scattering field, the tangential component of total field can be expressed as follows.

$$\left.\begin{aligned} \vec{n} \times \vec{E} &= 0 \\ \vec{n} \times \vec{H} &= 2\vec{n} \times \vec{H}^i = \vec{J} \end{aligned}\right\} \tag{1}$$

The relationship between the current value of the target surface and the magnetic vector at the observation point $P(\vec{r})$ is:

$$\vec{A} = \mu \int_S \vec{J}(\vec{r}')\, G(\vec{r}, \vec{r}')\, ds' \tag{2}$$

In equation 2, $\vec{r}$ is the position vector of observation point P. $\vec{r}'$ is the position vector of integration point $Q(\vec{r}')$. G is free-space Green's function. $G = \frac{1}{4\pi r}$. Furthermore, the expression of magnetic field can be obtained as follows.

$$\vec{H}(\vec{r}) = \frac{1}{\mu}\nabla\times\vec{A} \\ = -\int_s [(\vec{n}\times\vec{H}^i)\times\vec{R}](jk+\frac{1}{R})\frac{e^{-jkR}}{2\pi R}ds \tag{3}$$

Under the condition of far field, the scattering field can be simplified as

$$\vec{E}(\vec{r}) = \frac{jk}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\int_s [\vec{R}\times\vec{R}\times(\vec{n}\times\vec{H}^i)\frac{e^{-jkR}}{R}ds] \tag{4}$$

$$\vec{H}(\vec{r}) = -\frac{jk}{2\pi}\int_s [\vec{R}\times(\vec{n}\times\vec{H}^i)\frac{e^{-jkR}}{R}ds] \tag{5}$$

Finally, static RCS of the target can be obtained as

$$\sigma = 4\pi R^2\frac{\left|\vec{E}^s\right|^2}{\left|\vec{E}^i\right|^2} \tag{6}$$

Since the far-field RCS has nothing to do with the R, the R is supposed to be infinite when the far-field RCS is defined. At the same time, according to the principle of mutual conversion between electric field and magnetic field, the definition of far-field RCS can be expressed as

$$\sigma = \lim_{R\to\infty}4\pi R^2\frac{\left|\vec{E}^s\right|^2}{\left|\vec{E}^i\right|^2} = \lim_{R\to\infty}4\pi R^2\frac{\left|\vec{H}^s\right|^2}{\left|\vec{H}^i\right|^2} \tag{7}$$

3.2. The simulation method of dynamic RCS in real time

In order to simulate the dynamic RCS in real time, establishing a model of maneuvering target track should be taken as the first step. The change of target coordinates in radar coordinate system is obtained. Then, the change of the attitude angle of the target which is defined in FEKO is obtained by coordinate transformation. Finally, the dynamic RCS series can be obtained.

4. Simulation of dynamic RCS of reentry trajectory

The target is located at the coordinate origin $o(0\text{km}\quad 0\text{km}\quad 0\text{km})$. The ballistic missile is flying with re-entry angle θ which is towards the target in plane xoy. The radar station which is deployed in the range of the missile is called forward radar. The radar station which is deployed outside the missile range is called a rear radar. The coordinates of forward radar are (100km,0km,0km) and the coordinates of forward radar are (−100km,0km,0km). Target maneuver 1: the reentry angle of target is 40°; the route shortcut is 0; the starting point of the reentry section is (95km,0km,80km), and the end-point of the reentry section is (0km,0km,0km). Target maneuver 2: the reentry angle of target is 50°; the route shortcut is 0; the starting point of the reentry section is (65km,0km,80km), and the end-point of the reentry section is (0km,0km,0km). Two kinds of maneuvering target track are shown in figure 3. As known that the route shortcut is 0, after coordinate transformation, the azimuth angle of the rear radar is 0 constantly. For the forward radar, the azimuth angle is 0 firstly and then is about 180°. The pitch angle of deployment of the radar under two maneuvering are shown in figure 4 and 5. The real-time simulation of dynamic RCS is obtained by substituting attitude angle of the target into EDITFEKO, shown in figure 6.

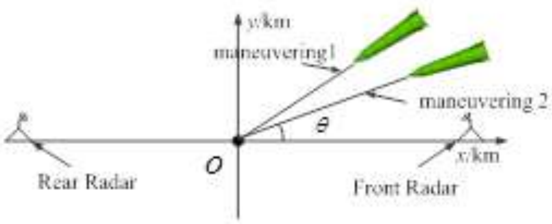


Fig. 3: Two kinds of maneuvering target track

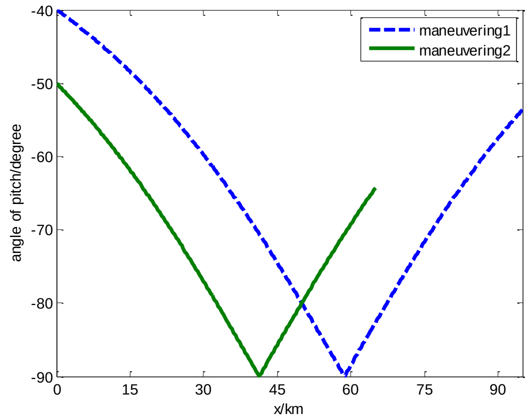


Fig. 4: Pitch angle of the target detected by the forward radar

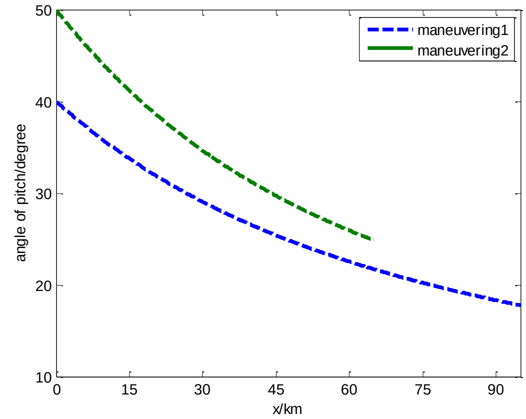
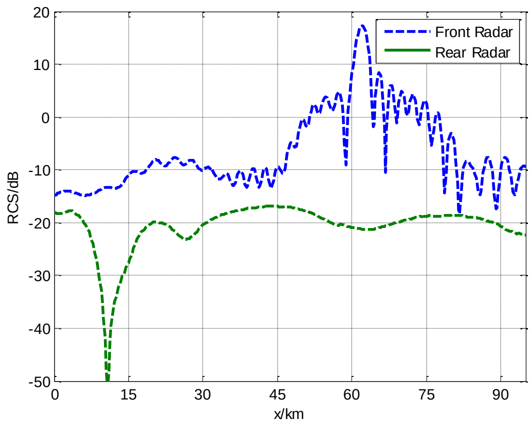
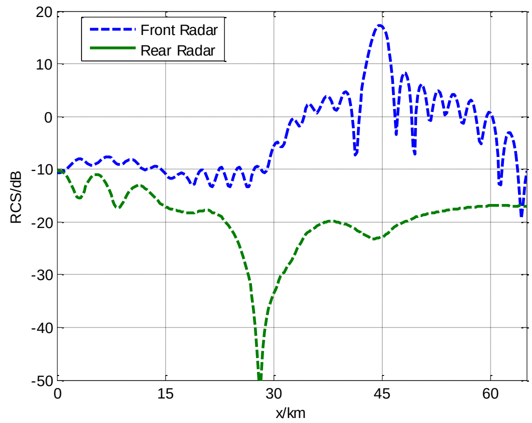


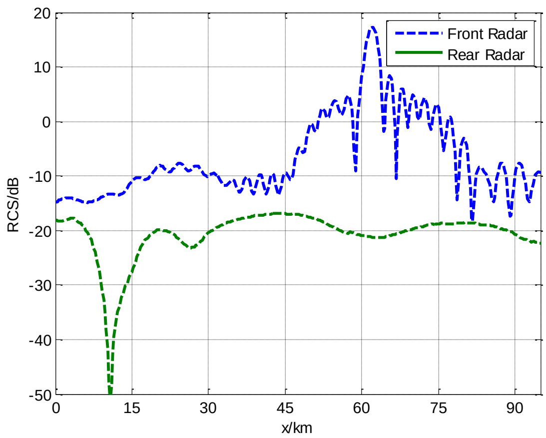
Fig. 5: Pitch angle of the target detected by the rear radar



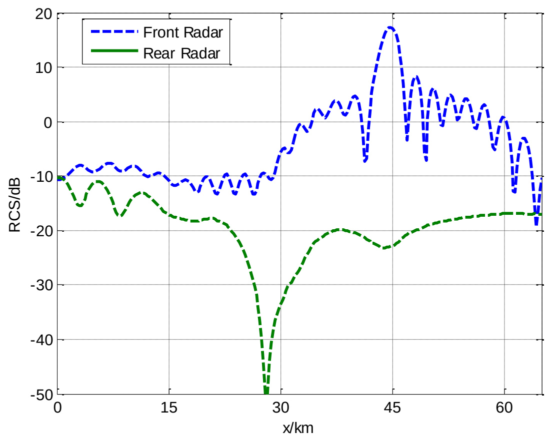
(a) Horizontal polarization dynamic RCS with reentry angle 40°L



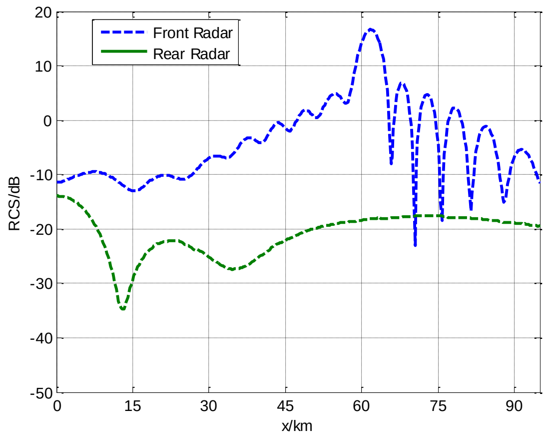
(b) Horizontal polarization dynamic RCS with reentry angle 50°L



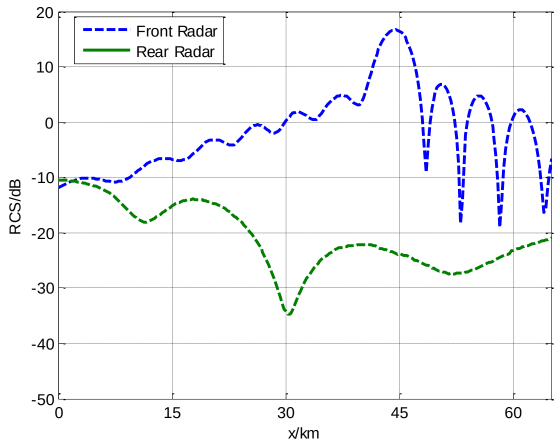
(c) Vertical polarization dynamic RCS with reentry angle 40°L



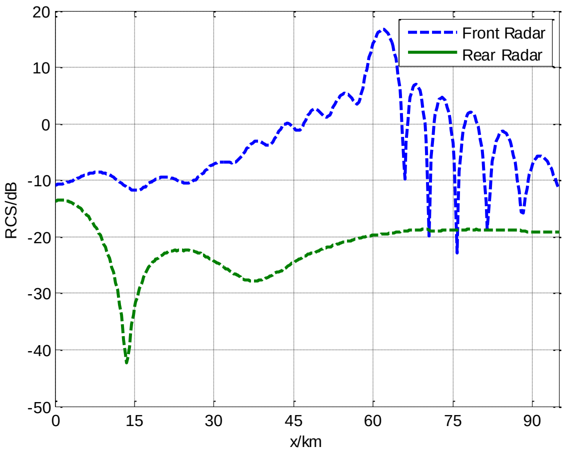
(d) Vertical polarization dynamic RCS with reentry angle 50°L



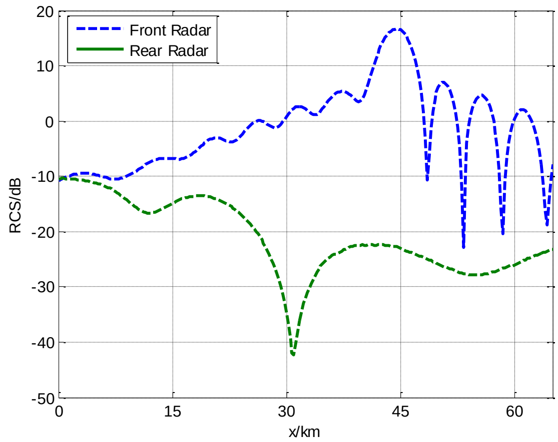
(e) Horizontal polarization dynamic RCS with reentry angle 40°P



(f) Horizontal polarization dynamic RCS with reentry angle 50°P



(g) Vertical polarization dynamic RCS with reentry angle 40°P



(h) Vertical polarization dynamic RCS with reentry angle 50°P

Fig. 6: Comparison of dynamic RCS with different reentry angles

According to the trend of dynamic RCS of the target, the dynamic RCS is more sensitive to the polarization of the electromagnetic wave compared with the frequency of electromagnetic wave emitted by radar. Furthermore, RCS of target is below -15dB in the case of rear radar. The reason is that the radar is facing the target head, and the head of the target is a strong stealth area. RCS of target which is detected by the rear radar has a minimum value when the radar faces the target head. The forward radar can detect a bigger RCS of target than the rear radar because the forward radar face the lateral region of the target, and the RCS of lateral region is larger than that of the target head. When the radar faces the lateral region of the target, the forward radar gets a maximum value. Thus, antimissile and early warning radar should be pre-deployed. From the comparison of figure 6, the RCS detected by the rear radar has little change when the target reenters with different reentry angles. The RCS of the forward radar has the maximum value of 18dB. At this location, the target can be detected by radar. However, when the reentry angle becomes larger, the location where RCS reaches the maximum is nearer the target. The response time of the radar is shortened. In all, when ballistic missile attacks target, the defense should adopt the pre-deployment. For the offensive side, the missile should reenter with a large reentry angle.

5. Conclusion

Accurate detection of ballistic missile is the premise of effective interception. Analysis of dynamic RCS is helpful for us to study the motion characteristics of ballistic targets. Then, radar can be deployed reasonably. The next step is to combine the dynamic RCS characteristics of the missile in all process, and analyze the characteristics of motions in the different stages, which can provide theoretical and data basis for improving the success rate of anti-missile.

6. References

[1]. PENG Peng, TONG Chuangming, LI Dan, et. al. RCS of Ballistic Missile Plume in Boost Phase of Flight [J]. MODERN DEFENCE TECHNOLOGY, 2013, 41(5): 22-26.

[2]. PENG Peng, TONG Chuangming, SUN Jiajia, et al. A Simulating Study of BM's Dynamic RCS Characteristics in Flight Boost Phase [J]. JOURNAL OF AIR FORCE ENGINEERING UNIVERSITY, 2013, 14(5): 44-47.

[3]. ZI Wenmao, BI Yiming, KANG Pu. Study of Radar Cross Section Control in Ballistic Missile Midcourse[J]. Ship Electronic Engineering, 2012, 32(7): 82-84.

[4]. HUANG Peikang, YIN Hongcheng, XU Xiaojian. Radar target characteristic [M]. Beijing: Publishing house of electronic industry 2005.

[5]. ZHOU Chao, ZHANG Xiaokuan, ZHANG Jingwei, et al. Analysis of Dynamic RCS Time Series of Typical Stealth Aircraft [J]. JOURNAL OF AIR FORCE ENGINEERING UNIVERSITY, 2013,14(3):15-18.

[6]. ZHOU Chao, ZHANG Xiaokuan, WU Guocheng. Analysis on RCS Time Series of Dynamic Target Based on Coordinate Transformation [J]. Fire Control and Command Control, 2014, 39(3):56-59.