Research on Target Detection Probability Model of Penetration Plane During the Final Stage

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Abstract. Based on comprehensive consideration of factors such as the enemy's ground-to-air radar jamming system, air defense missile system and the side direction deviating distance target of Penetration Plane, effective range of airborne weapon, target detection probability model of penetration plane during the final stage were established, finally, through the simulation, the main factors of model were analyzed and verified.

Introduction

The implementation of the penetration aircraft to ground attack, the enemy will be joint air defense system information and fire one of the threats, in order to ensure the successful completion of the penetration aircraft scheduled task, on the one hand, to reduce the probability of hitting the enemy is attacking aircraft air defense missile weapon system; on the other hand, should be in the penetration aircraft airborne radar jamming, complete search and identify targets, and ensure enough time to implement missile attacking [1] on target.

The aircraft penetration probability of target detection is the penetration aircraft within the effective range of airborne weapons, can detect targets on the ground and is not the probability of destroying enemy air defense missile weapon system, the existing literature on the attack effectiveness in attacking aircraft has made some research achievements, such as the literature [2-3] established under the conditions of interference search radar target effectiveness model [4-6] under the condition of no interference; the penetration of air to ground strike related effectiveness model was established in [7-8]; electronic jamming to air entering the target and first attack probability model. But the literature, without considering the enemy ground to air radar jamming system, air defense missile weapon system and penetration into the target plane when the lateral deviation effect of target distance and the effective range of airborne weapon target discovery probability. In this paper, we establish the probability model of the aircraft to detect the target in the ground attack stage, and analyze the influence of the above factors on the probability of penetration of the aircraft.

Influencing Factors Analysis

The Calculation of the Effective Suppression Area of Ground Target for Ground to Air Radar Jamming Equipment. The ground plane, ground to air radar jamming equipment and air defense missile weapon system guidance radar are connected as the X axis to establish the plane coordinate system, as shown in fig. 1.
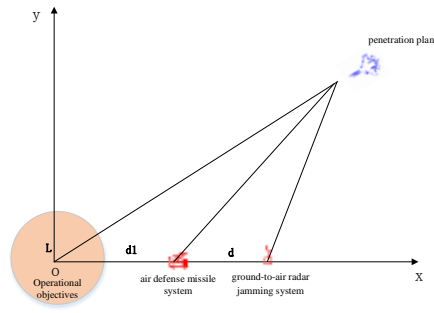
Figure 1. Finite Ground projection of each combat entity

Ground to air radar jamming equipment position (D, 0), air defense missile weapon system guidance radar position (d+d1, 0), target equivalent radius is L, and the radar cross section is σ_0, when the airborne radar antenna beam pointing to the ground target edge, the ratio of P_r and P_{rj} is Eq. 1 [9]. $G_t(\varphi)$ for airborne radar antenna in ground to air radar jamming equipment interference in the direction of the gain, calculated by Eq. 2. When $\frac{P_{rj}}{P_r}$ =Kj, we can find the relationship Dt and α in Eq. 3.

$$\frac{P_{rj}}{P_r} = \frac{P_j G_j}{P_t G_t} \cdot \frac{4\pi\gamma_j}{\sigma_0} \cdot \frac{R_t^4}{R_j^2} \cdot \frac{G_t(\varphi)}{G_t} \cdot \frac{\Delta f_r}{\Delta f_j}$$

(1)

$$G_t(\varphi) = \begin{cases} G_t & 0 \leq \varphi \leq \dfrac{\theta_{0.5}}{2} \\ \\ K\left(\dfrac{\theta_{0.5}}{\theta}\right)^2 G_t & \dfrac{\theta_{0.5}}{2} \leq \varphi \leq 90° \end{cases}$$

(2)

$$\frac{(D_t^2 + H^2)^2}{D_t^2 + H^2 + d^2 - 2D_t d \cos\alpha} = \frac{P_t G_t}{P_j G_j} \cdot \frac{\sigma_0 K_j}{4\pi\gamma_j} \cdot \frac{1}{K\theta_{0.5}^2} \cdot \frac{\Delta f_j}{\Delta f_r} \cdot \left[\arcsin\frac{L}{D_t} + \arctan\frac{d\sin\alpha}{D_t - d\cos\alpha}\right]^2$$

(3)

Assuming that the penetration of the aircraft into the target along the X axis, according to the formula to achieve the ground target as the center, with Dt and α as the variable of the effective interference area graphics, as shown in Fig. 2.
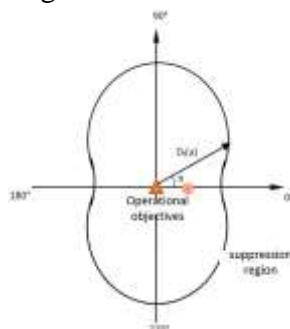

Figure 2. Finite The effective suppression area of ground to Air Radar Jamming

The Calculation of the Effective Suppression Area of Air Defense Radar. When the aircraft is self defense,, $R_t = R_j$, $\varphi = 0$, $G_t(\varphi) = G_t$, R0 is   Eq. 4,D0 is Eq. 5.At this point, the air defense missile system radar coverage area is the radius of D0.

$$R_0 = \left(\frac{K_j P_t G_t \sigma_0 \Delta f_j}{4\pi \gamma_j P_j G_j \Delta f_r} \right)^{\frac{1}{2}}$$

(4)

$$D_0 = \sqrt{R_0^2 - H^2}$$

(5)

Probability Calculation of Ground Target Falling into Penetration Radar. The projection of the plane's distance from the target to the horizontal plane is Eq.6.[10], and the probability density function of the lateral deviation from the target is Eq.7 .The projection of the airborne radar to the ground target is shown in fig 3.

$$\Delta z = \Delta\varepsilon \bullet R_L$$

(6)

$$f(\Delta z) = \frac{1}{\sqrt{2\pi}\sigma_\varepsilon R_L} \bullet e^{-\frac{\Delta z^2}{2(\sigma_\varepsilon R_L)^2}}$$
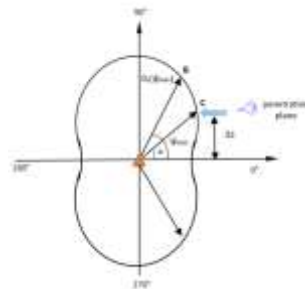
(7)

Figure 3.   Finite Penetration aircraft search ground target projection

In the penetration aircraft airborne radar detect probability region affected by airborne radar search angle target on the ground, the airborne radar is $\pm \varphi_{max}$ at the level of the maximum search angle, such as the figure B, C for the actual position of the penetration aircraft, to make the penetration aircraft can detect ground targets should meet $\alpha < \varphi_{max}$, see Eq. 8.Without considering the minimum launch range of airborne weapon Rmin and the threat of enemy air defense missile weapon system, the probability of the target falling into the effective detection area of the airborne radar of the penetration aircraft is shown in Eq. 9.

$$\Delta z < D_t(\varphi_{\max}) \bullet \sin \varphi_{\max}$$

(8)

$$P_L = 2\int_0^{D_t(\varphi_{\max})\bullet\sin\varphi_{\max}} f(\Delta z)d\Delta z = 2\int_0^{D_t(\varphi_{\max})\bullet\sin\varphi_{\max}} \frac{1}{\sqrt{2\pi}\sigma_\varepsilon R_L} \bullet e^{-\frac{\Delta z^2}{2(\sigma_\varepsilon R_L)^2}} d\Delta z$$

(9)

The Probability Model of Penetration Target Detection

Basic assumptions: first, the penetration of the aircraft into the effective range of airborne weapons after the start of the airborne radar; penetration of the aircraft once the enemy air defense missile system radar discovery is destroyed. Based on the above hypotheses, in considering the relationship between the position of the minimum distance of airborne weapon launch Rmin, the penetration aircraft target jamming exposure area radius D0 and the ground to air radar jamming target in the exposed area $D_t(\varphi_{\max})$ of the three radius (as shown in Table 1) under the condition that the target probability of Pf penetration under the condition of radar jamming aircraft.

Table 1   rmin,D0 and $D_t(\varphi_{\max})$ three position relation

Position relation	conclusion
rmin>Dt(ψmax)>D0	Penetration aircraft into the minimum range of airborne weapons can not find the target, Pf =0
rmin>D0>Dt(ψmax)	
D0>rmin>Dt(ψmax)	Penetration of the aircraft was destroyed by enemy air defense missile weap on systems, Pf =0
D0>Dt(ψmax)>rmin	
Dt(ψmax)>rmin>D0	The probability of finding the target is Pf
Dt(ψmax)>D0>rmin	

(1)Dt(ψmax)>rmin>D0.①If Dt(ψmax)>Dt(0)≥rmin>D0,the penetration aircraft found the target beyond the minimum range of airborne weapons, and is not to destroy enemy air defense missile weapon system, the penetration aircraft target detection probability Pf see Eq.10.②If Dt(ψmax)>rmin>Dt(0)≥D0 or Dt(ψmax)>rmin>D0≥Dt(0),this point the probability of penetration aircraft found Pf see Eq.11.The azimuth angle of the exposed area radius ω is equal to rmin.

$$p_f = 2(\int_0^{D_t(\varphi_{\max})\bullet\sin\varphi_{\max}} \frac{1}{\sqrt{2\pi}\sigma_\varepsilon R_L} \bullet e^{-\frac{\Delta z^2}{2(\sigma_\varepsilon R_L)^2}} d\Delta z - \frac{\pi r_{\min}^2 \varphi_{\max}}{360})$$

(10)

$$p_f = 2(\int_0^{D_t(\varphi_{\max})\bullet\sin\varphi_{\max}} \frac{1}{\sqrt{2\pi}\sigma_\varepsilon R_L} \bullet e^{-\frac{\Delta z^2}{2(\sigma_\varepsilon R_L)^2}} d\Delta z - \frac{\pi r_{\min}^2 (\varphi_{\max} - \omega)}{360})$$

(11)

(2)Dt(ψmax)>D0>rmin.①If   Dt(ψmax)>Dt(0)≥D0>rmin,penetration aircraft found target probability Pf see Eq.12②If Dt(ψmax)>D0>Dt(0)>rmin or Dt(ψmax)>D0>rmin>Dt(0),penetration aircraft found target probability Pf see Eq.13.The azimuth angle of the exposed area radius ω is

equal to rmin.

$$p_f = 2(\int_0^{D_t(\varphi_{max}) \bullet \sin\varphi_{max}} \frac{1}{\sqrt{2\pi}\sigma_\varepsilon R_L} \bullet e^{-\frac{\Delta z^2}{2(\sigma_\varepsilon R_L)^2}} d\Delta z - \frac{\pi D_0^2 \varphi_{max}}{360})$$

(12)

$$p_f = 2(\int_0^{D_t(\varphi_{max}) \bullet \sin\varphi_{max}} \frac{1}{\sqrt{2\pi}\sigma_\varepsilon R_L} \bullet e^{-\frac{\Delta z^2}{2(\sigma_\varepsilon R_L)^2}} d\Delta z - \frac{\pi D_0^2 (\varphi_{max} - \omega_1)}{360})$$

(13)

Simulation Analysis

D0 and $D_t(\varphi_{max})$ were mainly controlled by the penetration aircraft jamming equipment jamming power density Sz and the effects of enemy air radar jamming equipment jamming power density Sd, the penetration aircraft airborne radar at the level of the maximum search angle of φ_{max}, so the simulation analysis of major research Sz, Sd and φ_{max} on the effect that target probability Pf, simulation analysis of the parameters used in the process as shown in table 2.

Table 2 parameters used in the simulation

parameter	Parameter value	Explain
$\frac{P_t G_t}{\Delta f_r}$	1.5×105 W/MHz	Penetration of airborne radar power density
$\frac{P'_t G'_t}{\Delta f'_r}$	8×104 W/MHz	Power density of guidance radar for air defense missile weapon system
H	1.5 km	Penetration flight altitude
RL	250 km	The distance between the starting point of the bombing of the aircraft and the ground navigation station
σ_ε	0.02 rad	
σ_0	100 m2	Effective reflection area of ground target
σ_0	5 m2	Effective reflection area
d	0.5 km	The distance of ground to air radar jamming equipment from the ground target center
L	20 m	Equivalent radius of ground target
Kj	4	Airborne radar suppression factor
γ_j	0.5	Polarization loss of jamming signal to radar antenna
rmin	2 km	Minimum firing range of airborne weapon

The integrated use of Eq. 9 to Eq. 12, the PSI Max is 30 degrees and 60 degrees and 90 degrees, Sz, Sd and Pf, the simulation results shown in fig. 4 fig. 5 and fig. 6.
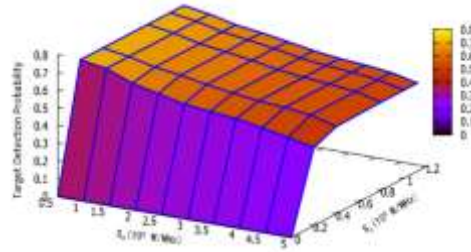
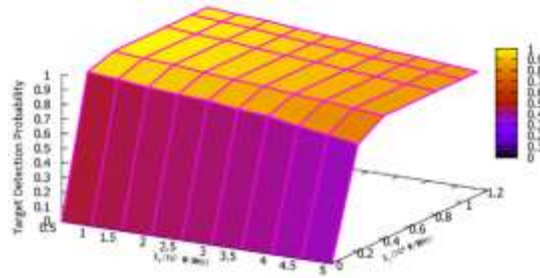Figure 4.   Finite ψmax=30°,the relationship of Sz,Sd and Pf

Figure 5.   Finite ψmax=60°,the relationship of Sz,Sd and Pf
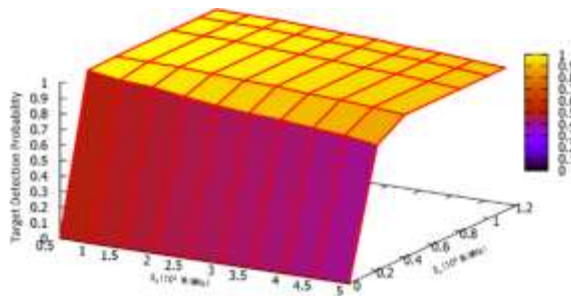

Figure 6.   Finite ψmax=90°,the relationship of Sz,Sd and Pf

The simulation results show that: when Sz=0, the air defense missile weapon system guidance radar without interference, D0=16km, at Sd value space, D0 is greater than Dt (or max), the aircraft penetration probability of target detection in Pf=0;When the 0<Sz is less than 0.4 * 105 W/MHz, 2.02km = D0<16km. The rmin<D0< Dt (or max), found that the influence of the penetration aircraft target probability Pf is mainly controlled by Sd and Sz, with the increase of Sz, D0 decreased, Pf increased gradually, and with the increase of Sd, Dt (or max) decreased gradually, fall into the penetration aircraft airborne radar effective detection area to reduce the probability of ground targets Pf decreased; When the 0.4 * 105 W/MHz<Sz 1.2 * 105 W/MHz, 0 at D0< = D0<2.02km, Rmin < Dt (or max), found that the influence of the penetration aircraft target probability Pf is mainly controlled by Sd and Rmin, with the increase of Sd, Dt (or max) gradually decreased, falling into the ground target penetration aircraft airborne radar effectively detecting probability measure the area decreased, Pf decreased gradually.

Conclusion

Based on the analysis of the influence of the enemy threat factors and the factors that restrict the penetration of the aircraft to the ground attack stage, this paper establishes the probability model. On this basis, through the simulation analysis to verify the main factors influencing the model,

obtained when only considering the incoming aircraft penetration in horizontal direction, the enemy ground to air radar jamming equipment jamming power density and airborne jamming equipment, airborne radar jamming power density factors in the horizontal plane angle of maximum search, found that the influence of curve of target probability, provides a new way for evaluating the penetration aircraft penetration effectiveness, but the two sides of the combat entity number is single, and the first deployment, the next step will focus on the research of the combat entity number is more than 1 and any deployment, discovery target probability model and calculation method of aircraft penetration.

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