Influence of Double Stealth Aircraft Approach Forward Support Cooperative Jamming on Radar Detection Performance

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ABSTRACT Aiming at the single stealth aircraft approaching support jamming, the support jamming suppression ability is insufficient, and if the jamming power is too large, it will be tracked and located. With the increase of hazard coefficient, a model of double stealth aircraft cooperative proximity support jamming is proposed. Based on solving the attitude angle of two aircraft, comparing with the static RCS database in the whole airspace and simulating the time-varying RCS of two aircraft, the influence degree of detection distance of monostatic radar is analyzed and verified by simulation using power co-suppression method. The results show that when the formation of two aircraft is 1 km, the suppression effect of the cooperative suppression and shielding task aircraft is better, which can effectively reduce its RCS, reduce the radar detection distance, improve the cooperative jamming effect and enhance the overall conduct operations level.

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1. INTRODUCTION
With the increasing number of modern ground air defense weapons and equipment and the increasing performance and support system, the electromagnetic environment of the battlefield is becoming more and more complex, and the form of cooperative air support jamming and shielding operations is becoming increasingly prominent. It is the inevitable result of the internal development law of system
and system confrontation. E.E. Foreman and Rafael A. Acevedo analyzed the advantages of cooperative operations in depth. In the aspects of multi-aircraft cooperative tactics, cooperative target allocation and cooperative detection, Lan Weihua and others [1-2] have studied, deepened the research content and expanded the concept of cooperative air combat. Zhang Yangrui et al [3-4]. Aiming at the key technology of multi-aircraft concomitant cooperative jamming radar network, this paper analyzes the different cooperative suppression/deception modes and jamming effects, and determines the strategy of multi-aircraft concomitant cooperative jamming against radar network. However, these researches mainly focus on the decision-making of cooperative air combat and the design of cooperative jamming modes, the optimization of jamming resource allocation and the evaluation model of various jamming effects. The practical application of tactical scenarios in specific air combat is less involved, and the precise coordination of how the double stealth aircraft is arranged to approach the guidance radar defense and control area. There is no research on the operational style requirement of precise cooperative support for jamming carrier to break through enemy air defense zone and the evaluation of detection performance of guidance radar in this method. In view of this, this paper proposes a new method for double stealth aircraft formation detection, which is provided in literature [3-4], identification and successful penetration of aircraft in proximity support cooperative jamming shield, which relieves single aircraft due to suppression power limitation and passive passivity determination. Position tracking can increase the self-threat coefficient, realize joint electronic warfare operations and effectively improve operational effectiveness.

2. DOUBLE AIRCRAFT COOPERATIVE INTERFERENCE SUPPORT MODEL

2.1 Scene Design

![Figure 1. The escort-support jamming scenario of double stealth aircraft.](image)

Figure 1. The escort-support jamming scenario of double stealth aircraft.

Figure one is the scene of approaching the anti-jamming zone. The mission plane refers to the group of aircraft carrying out the attack to break through the enemy air defense zone, and the main lobe beam of the ground air defense radar searches the target. At this time, the double stealth aircraft keeps the distance of 1 km to reach the support flight, and the main lobe of jamming equipment is aimed at the side lobe or main lobe of ground air defense radar to suppress jamming to cover the successful penetration of Mission Aircraft formation. $R_{\text{max}}$ is the maximum distance of guidance radar to the enemy aircraft in the airspace. $\theta$ is the angle between the direction of support jamming and the direction of radar main lobe detection when the stealth aircraft approaches the guidance radar. $R_i$ is the stealth aircraft approaching the support jamming distance. $d_s$ is the burning distance to support...
interference\cite{5}, AJ-1 and AJ-2 are the immediate spatial locations of stealth aircraft 1 and stealth aircraft 2 respectively. T is the immediate spatial location of the task machine. $D_{tr}$ is the immediate spatial location of the task machine. $(x_{tr}(t), y_{tr}(t), z_{tr}(t))$ is the instant location of task machine. $(x_{AJ}(t), y_{AJ}(t), z_{AJ}(t))$ is the immediate position of stealth aircraft. $(0,0,0)$ indicates that radar is at the origin of the coordinate system. In the triangle composed of the real-time space position of the mission plane, stealth aircraft and guidance radar, the three sides respectively are $|D_{tr}|$, $|D_{AJ}|$ and $|D_{AR}|$.

2.2 Analysis of Stealth Aircraft Performance

2.2.1 Calculation of dynamic RCS

(1) Parameter setting of double aircraft setting

| Track parameter | Numerical value |
|-----------------|-----------------|
| Stealth aircraft AJ-1 and AJ-2 endurance speed $v/\text{Ma}$ | 1.4 |
| Mission aircraft speed $v/\text{Ma}$ | 1.4 |
| Flight height of stealth aircraft AJ-1 and AJ-2 $H/\text{km}$ | 8 |
| Mission machine penetration height $H/\text{km}$ | 10 |
| Stealth aircraft AJ-1 flying radius $R/\text{km}$ | 20 |
| Stealth aircraft AJ-2 flying radius $R/\text{km}$ | 19 |
| Mission machine turning radius $R/\text{km}$ | 40 |
| Flight attitude elevation of double aircraft $\phi < 5^\circ$ | |
| Rolling angle of aircraft circling $\eta = 30^\circ$ | |

(2) Instant attitude calculation

1) The definition of coordinate system

In Figure 2, the stealth aircraft coordinate system $(O-X_{AJ}, Y_{AJ}, Z_{AJ})$ and the radar coordinate system $(O-X, Y, Z)$. $\theta$, $\phi$ and $\eta$ are the azimuth, pitch and roll angles of the aircraft.

2) Coordinate system conversion
Figure 3 shows the solution process for understanding the line of sight azimuth and line of sight pitch. The conversion relationship between the radar coordinate system and the body coordinate system \([6-9]\) is

\[
\begin{bmatrix}
 x_{RA-1}(t) \\
 y_{RA-1}(t) \\
 z_{RA-1}(t)
\end{bmatrix} = Q
\begin{bmatrix}
 x(t) \\
 y(t) \\
 z(t)
\end{bmatrix}
\]

\((x(t), y(t), z(t))\) is the position of any point in the Radar coordinate system. The coordinates in the airframe coordinate system of stealth aircraft is

\[
(x_{A-1}(t), y_{A-1}(t), z_{A-1}(t)) = (x_A(t), y_A(t), z_A(t))
\]

\(Q\) is the transformation matrix from the mission coordinate system to the radar coordinate system. Conversion matrix \(Q\):

\[
Q = \begin{bmatrix}
 \cos \theta(t) \cos \phi(t) & \sin \phi(t) & -\sin \theta(t) \cos \phi(t) \\
 -\sin \theta(t) \sin \eta(t) - \sin \phi(t) \cos \theta(t) & \cos \phi(t) \cos \eta(t) & \sin \theta(t) \sin \phi(t) \cos \eta(t) + \sin \eta(t) \cos \theta(t) \\
 \sin \theta(t) \cos \eta(t) & -\sin \eta(t) \cos \phi(t) & \cos \theta(t) \sin \eta(t)
\end{bmatrix}
\]

When the radar coordinate origin is substituted into the formula (3), the time-varying attitude angle of sight \([12]\) is expressed as

\[
\begin{align*}
\theta(t) &= \arctan \frac{y_{A-1}(t)}{x_{A-1}(t)} \\
\phi(t) &= \arctan \frac{z_{A-1}(t)}{\sqrt{x_{A-1}^2(t) + y_{A-1}^2(t)}}
\end{align*}
\]

(3) Static database extraction time variant RCS

The FEKO platform is equipped with simulation conditions to calculate the static RCS data of a stealth aircraft (service frequency: 5.8GHz; polarization mode: HH; azimuth range: 0\(^\circ\) ~ 360\(^\circ\); pitch range: -30\(^\circ\) ~ 10\(^\circ\); step angle: 1\(^\circ\)). In the static RCS two-dimensional database, extract the instantaneous RCS of the line of sight angle. Programming in MATLAB for data processing, drawing dynamic RCS sequence of time-varying graphics.

Figure 4 describes the time-varying dynamic RCS sequence of a single stealth aircraft in the approach forward supports jamming.
Figure 4. Dynamic RCS sequence of single stealth aircraft

Figure 5 shows the time-varying dynamic RCS sequence of double stealth aircraft during the jamming process.

The dynamic RCS sequence generated by a single aircraft approaching support interference fluctuates between(-26.813~22.511dB). The dynamic RCS sequence generated by two machine cooperation approaches support interference, and the fluctuation range is between -44.889~12.016dB. It shows that the stealth performance of the two aircraft stealth aircraft is stronger than that of the single aircraft.

3. ANALYSIS OF RADAR DETECTION PERFORMANCE

3.1 Radar detection distance

1) Radar detection distance without interference

Under the premise of setting detection threshold and giving false alarm probability, the detection range of time-varying radar without jamming state is

\[ R_{T_{\text{max}}} (t) = \left[ \frac{DI}{(4\pi)^{3/2}} \frac{G_i \lambda^2}{k \tau f T_B F_\gamma L_\sigma} \frac{P_{\text{av}} \sigma}{\xi_{\min}} \right]^{1/4} \] (4)

In formula (4), average transmitting power: \( P_{\text{av}} = P_r f \); radar transmit peak power: \( P_r \); pulse width: \( \tau \); PRF: \( f \); transmit antenna gain and receiving antenna gain: \( G_i = G_r \); wavelength: \( \lambda \); RCS value of aircraft: \( \sigma \); Boltzmann constant: \( k \); effective noise temperature: \( T_B \); Receiver bandwidth: \( B_r \); Receiver noise figure: \( F_\gamma \); Radar system loss: \( L_r \); coherent accumulation gain: \( I \); Echo target pulse pressure gain: \( D \); minimum detection signal-to-noise ratio: \( \xi_{\min} \).

2) Radar detection distance of single aircraft jamming

The time variant radar detection range of single stealth aircraft under the condition of jamming support is

\[ R_{T_{\text{max}}} (t) = \left[ \frac{DI}{D_j f_j} \frac{P_{\text{av}}^2 (t)}{P_j} \frac{G_i G_r}{G_i (\phi) G_r (\phi)} \frac{\gamma L_\sigma \xi_j}{4\pi L_r} \xi_{\min}^{1/4} \right]^{1/4} \] (5)
In formula (5), noise signal pulse pressure gain and Coherent accumulation gain: \( \gamma_D, \gamma_I \); transmitter power of jammer: \( P_j \); transmit antenna gain: \( G_j(\phi) \); receiving antenna gain: \( G_r(\phi) \); signal interference loss: \( L \); polarization adaptation: \( \gamma \); signal to noise ratio after signal processing: \( \xi \).

3) Radar detection distance under the condition of double aircraft cooperative jamming \[^3\]

\[
R_{T-jam}(t) = T \left[ \frac{G_jG_r \sum_{m=0}^{M} s_m}{\xi} \left\{ \frac{G_j(\phi)G_r(\phi)}{R_j(t)} + \frac{G_j(\phi)G_r(\phi)}{R_r(t)} \right\} \right]^{1/4}
\]

(6)

In formula (6), \( T = \frac{DP_jr_jL_j}{4\pi J/L} \), The transmit antenna gain of stealth aircraft AJ-1 is \( G_{j1}(\phi) \); The transmit antenna gain of stealth aircraft AJ-2 is \( G_{j2}(\phi) \). Jamming distance of stealth aircraft AJ-1: \( R_j(t) \), Jamming distance of stealth aircraft AJ-2: \( R_r(t) \).

Burn-through distance must be taken into account when approaching support interference. For single base radar, it has transceiver antenna. Therefore, the signal power \[^5\] received by the receiver is

\[
R_r = P_j + G_j + G_r - 103 - 20\log(T_j)
\]

\[-40\log(ID_j) + 10\log(\sigma)\]

(7)

In equation (7), \( R_r \) is the signal power at the receiver input, the unit is dB; \( T_j \) is the transmitted signal frequency, the unit is MHz. Interference distance is \( ID_j \).

The interference power \[^5\] entering the receiver input is

\[
I_j = P_j + G_j + G_r - 32 - 20\log(T_j)
\]

\[-20\log(R_j) - 10\log(\sigma)\]

(8)

In the formula (8), \( I_j \) is the interference power of the receiver at the receiver, and the unit is dB. According to the set scenario, the \( J/S = I_j / R_r \) to letter is expressed as

\[
I_j / R_r = 71 + G_j + G_r + 40\log(ID_j) + P_j - P_r - G_r - G_j
\]

\[-20\log(R_j) - 10\log(\sigma)\]

(9)

After finishing:

\[
40\log(ID_j) = P_j + G_j + 10\log(\sigma) + 20\log(R_j)
\]

\[+ J/S - 71 - P_j - G_j + G_r - G_r\]

(10)

The firing distance is \[^7\]:

\[
id_{j} = 10^{\left[\frac{40\log(ID_j)}{40}\right]}
\]

When \( id_j < R_r \), stealth aircraft can effectively release noise and suppress interference. The gain of radar antenna can be obtained from the following empirical formula \[^{10}\]:

\[
G_r' = \begin{cases} 
G_r |\theta| \leq \theta_{0.5}/2 \\
K(\theta_{0.5}/\theta)^2 G_j, \theta_{0.5}/2 < |\theta| \leq 90^\circ \\
K(\theta_{0.5}/90^\circ)^2 G_j, 90^\circ < |\theta| \leq 180^\circ 
\end{cases}
\]

(11)

In the above formula, \( \theta_{0.5} \) is the main lobe width of the radar antenna; \( K = 0.04 \pm 0.1 \) is a constant related to the characteristics of the radar antenna; \( \theta \) is the angle between the main lobe direction of the radar and the connecting direction of the radar to the jammer.
4. SIMULATION ANALYSIS
The average dynamic RCS of stealth aircraft in jamming is only -5.4dBsm. At present, mission fleet is an aircraft with strong scattering characteristics. Therefore, the radar cross section parameter of the mission aircraft is set to 10dBsm in the simulation analysis.

4.1 Detection distance
(1) Simulation conditions
Radar parameter setting:
Transmitting power /kw: 100; Pohl Seidman constant /K:1.38×10-23; Internal noise temperature /K:290; Transmit antenna gain /dB:35; Receiving antenna gain / dB:35; Receiver bandwidth /MHz:5; Noise figure / dB:4; System wastage / dB:5; Minimum detectable SNR / dB:20; Coherent accumulation gain $D=BT$; Signal pulse width/ $\mu$s:10; Cumulative number of pulses /:64; false-alarm probability: $P_a=1e-6$.

Interference parameter setting:
Jamming device AJ-1=AJ-2 power /w( $P_j=P_j$):100; Jamming antenna gain /dB:10; Interference bandwidth /MHz:12; Polarization loss:0.5; Total cost of jamming equipment / dB:6; Radar receiving bandwidth /MHz:5; Noise coherent accumulation gain $J$/dB:0; Only considering random noise interference, the pulse pressure gain is $J_D=0$dB.

Effective release of random noise suppression from single stealth aircraft under proximity support jamming. The time-varying burn through distance is as follows:

Figure 6. Instant burn distance under single machine interference

Double stealth aircraft can effectively release random noise and suppress interference under close support jamming. The time-varying burn through distance is as follows:

Figure 7. Instant burn distance based on two aircraft cooperative jamming

Comparative analysis is shown in figures 6 to 7. Under the support jamming of single stealth aircraft, the time varying burn through distance is $id_j<0.95km$, Under the support jamming of double stealth aircraft, the time varying burn through distance is $id_j<0.01km$. The instant support jamming distance of stealth aircraft is $R_j>19km$. It can be seen that the suppress distance of stealth aircraft is
far greater than the burning distance. Therefore, we can get the real-time distance of radar detection mission aircraft under the support interference.

(2) Instantaneous detection distance between mission aircraft and radar.

Figure 8. The mission machine is detected by radar Without jamming.

Instantaneous detection distance of radar detection mission under support jamming cover of single stealth aircraft.

Figure 9. Radar detection distance with standalone support

The radar detect the real time distance of mission aircraft based on cooperative jamming of double stealth aircraft.

Figure 10. Radar detection distance with two aircraft support jamming

Comparative analysis is shown in figures 8 to 10. If the stealth aircraft does not support jamming, the detection distance of the radar is larger than the real distance of the aircraft. Under support jamming, radar detection performance decreases, and mission aircraft penetration is safer.

5. CONCLUSION

In this paper, based on the background of penetration of double-aircraft approach support jamming shield mission aircraft, the advantages of double-stealth aircraft cooperative approach combat in power cooperative suppression distance are studied, and the corresponding simulation and comparative analysis are made. The simulation results show that the advantages of system-based countermeasure in joint operations are more obvious than that of single-aircraft. It provides a new way for stealth aircraft to cooperate in penetration support operations.

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