UAV inlet plasma stealth performance numerical simulation

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Abstract. Plasma stealth is a new concept and principle of stealth technology. Firstly, WKB analysis method is used to analyse the attenuation of electromagnetic wave under the action of plasma. Then, a certain UAV inlet was selected to establish a model, and the inner wall was covered with a ring of closed cavity. Plasma was generated by discharge, and the stealth performance of the inlet was numerically simulated for the L-band electromagnetic wave and its stealth effect was analyzed. This method verifies the feasibility of applying plasma stealth technology to the L-band radar wave for inlet stealth.

1. Introduction

In late 1989, the U.S. military used the first F-117 stealth fighters to attack Panama during the Panama Canal War. Later in the Gulf War and the Kosovo War, the U.S. military carried out air strikes against Iraq and Yugoslavia by using f-117, B-2 and other stealth aircraft. UAVs(Unmanned aerial vehicles) are widely used in modern high-tech warfare due to their advantages such as flexibility, strong survivability and avoiding casualties. Due to the increasing threat of ground air defense firepower and the disadvantages of UAV, such as poor combat capability and easy detection, stealth technology is imperative to be applied to UAV. Plasma stealth technology has many advantages, such as no change of aircraft shape, wide wave absorption band, high absorption efficiency, easy to use and maintain, low price, etc [1]. Therefore, it has high academic value and application value in military and space technology fields. Strong reflection area of the UAV engine inlet nozzle, engine, machine first mirror radar antenna, the cockpit/wing leading edge, etc., due to the inlet of conventional stealth technology of L-band (1GHz~2GHz) radar wave effect is not obvious, in this paper, analytical method validation by WKB plasma display can be used in stealth technology, and through the simulation of plasma stealth technique for L-band radar wave, is applied to the feasibility of the inlet stealth [2].

2. WEB method of electromagnetic wave propagation in plasma

Wentzel-kramer-brillouin method (WKB method) is a very mature method for solving electromagnetic wave propagation in slow-varying media, and it is the most frequently used analytical method in plasma stealth technology. To facilitate the study of the relationship between plasma and electromagnetic wave, the plasma is assumed to be an uniform cold plasma [3].

Influence of non-magnetized non-uniform plasma on vertical Incident Electromagnetic Wave

In the one-dimensional state, the wave equation of electromagnetic wave propagation in the non-uniform and non-magnetized cold plasma (collision plasma) as [4]:

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\[
\frac{d^2E(z)}{dz^2} + k^2(z)E(z) = 0
\]

(1)

In the case of two-way attenuation, the solution of WKB as:

\[
E_y = E_{y0}exp\left[-j\int_{z_0}^{z} k(z')dz'\right]
\]

(2)

The electromagnetic wave enters into the plasma and is absorbed by collision. The electromagnetic wave energy attenuates for the first time, \(z=z_0\) is reflected back, and the energy attenuates for the second time. When \(z=0\), the energy expression as [5]:

\[
P(z_0) = P_0exp\left[-4Im\left(\int_{0}^{z_0} k(z')dz\right)\right]
\]

(3)

\(P_0\) represents the energy at the first arrival of the electromagnetic wave (i.e., the energy of the incident electromagnetic wave).

Two-way attenuation of electromagnetic wave is as follows:

\[
\text{Att} = \left|10\log\frac{P(z_0)}{P_0}\right| = \left|17.37m\left(\int_{0}^{z_0} k(z)dz\right)\right|
\]

(4)

By type 4, the electromagnetic wave energy attenuation \(\text{Att}\) is proportional to the vector \(k(z)\) of propagation of electromagnetic waves, electromagnetic wave propagation vector is affected by coefficient \(r\) and \(\Phi\), and the coefficient \(r\) and \(\Phi\) are decided by the plasma frequency \(\omega_p\) and the frequency of electromagnetic wave \(\omega_0\) and the collision frequency of plasma internal electronic and gas \(\nu\), so the analysis of available energy attenuation of electromagnetic wave is incident electromagnetic wave frequency and plasma frequency and collision frequency.

**Influence of non-magnetized non-uniform plasma on Oblique incident Electromagnetic Wave**

Because the incoming electromagnetic waves skew into the plasma, so the two-way attenuation is introduced by refraction law analysis, WKB solution as [6]:

\[
\left|\frac{3}{4}\left(\frac{1}{\omega^2} \frac{d\omega}{dz}\right)^2 - \frac{1}{2\omega^3} \frac{d^2\omega}{dz^2}\right| \leq 1
\]

(5)

In the place of \(z=d\), incident electromagnetic wave into plasma, then the first collision absorption, so the electromagnetic wave energy attenuation, in the place of \(z=0\), electromagnetic wave is reflected, enters into the plasma for the second time and is absorbed by collision, which attenuates the energy of electromagnetic wave, that is, the two-way attenuation of electromagnetic wave in the plasma with oblique incidence, and its attenuating energy is:

\[
P(z_0) = P_0exp\left[-4Im\left(\int_{0}^{z_0} \sqrt{k^2(z)} - k_0^2\sin^2\theta_n dz\right)\right]
\]

(6)

Two-way attenuation of electromagnetic wave as:

\[
\text{Att} = \left|10\log\frac{P(z_0)}{P_0}\right| = \left|17.37m\left(\int_{0}^{z_0} \sqrt{k^2(z)} - k_0^2\sin^2\theta_n dz\right)\right|
\]

(7)

This formula is used to study the electromagnetic wave in plasma with oblique incidence. When \(\theta_i = \theta_n = 0\), the two-way attenuation of the electromagnetic wave is the same as that of the electromagnetic wave in a plasma with vertical incidence.

3. **Numerical simulation of inlet plasma stealth**

The inlet model was established. The plasma thickness was assumed to be 25mm, the inlet radius was 450mm, the length was 1200mm, and the inlet wall thickness was 10mm. The finite element method was used for electromagnetic wave analysis.

The attenuation performance of plasma to radar wave is explored by measuring RCS. In actual working conditions, there are two cases of single-station scattering and double-station scattering. Single-station scattering means that the radiation source and the receiving location are located at the
same place. Double station scattering means that the radiation source and the receiving location are located at different locations. In the case of single-station scattering, it is easier to explore the energy attenuation of the inlet with electromagnetic wave incident at different frequencies, and in the case of double-station scattering, it is easier to explore the energy attenuation of the inlet with electromagnetic wave incident at different angles [7].

3.1. The absorption contrast of forward irradiation with different frequencies of electromagnetic waves scattered by two stations

In order to analyze the forward irradiation inlet with dual-station scattering electromagnetic waves of different frequencies, plasma relative dielectric constant and tangent of dielectric loss Angle should be set to explore the effect between electromagnetic waves of different frequencies and the plasma generated by high-frequency discharge. The relative dielectric constant of the unmagnetized plasma and the tangent of the dielectric loss Angle are respectively expressed as:

\[ \varepsilon_r = \varepsilon' + j\varepsilon'' \]  
\[ \frac{\varepsilon''}{\varepsilon'} = \frac{\nu_0^2}{\omega(\omega^2 + \nu^2 - \omega_p^2)} \]  

Corresponding to the electromagnetic frequency of L-band, the plasma density is \(1.24 \times 10^{10} \text{cm}^{-3}\). The incident electromagnetic wave frequencies of 1.00GHz, 1.25GHz, 1.50GHz, 1.75GHz and 2.00GHz were respectively selected to be vertically incident inside the inlet. Because of the double-station scattering, the electromagnetic wave energy attenuation at all angles in the inlet could be explored. After running simulation analysis, the following results are obtained [8].

FIG. 1 compares the energy attenuation of five incident electromagnetic waves of different frequencies. It can be seen that with the increase of the frequency of the electromagnetic wave, the energy attenuation of the electromagnetic wave is larger under the influence of plasma. In the case of the incident electromagnetic wave at 2.00GHz, the attenuation energy of about 25dB is detected from the side, so it can be proved that the plasma has a very significant attenuation effect on the energy of the L-band electromagnetic wave. However, it is obvious that based on the XOZ plane, the electromagnetic energy of 0 degrees and 180 degrees has no obvious attenuation, so it can be seen that the stealth effect is not very significant if it is only the case of single-station scattering.

![XY Plot 1](image)

(a) 1.00GHz incident electromagnetic wave
(b) 1.25GHz incident electromagnetic wave

(c) 1.50GHz incident electromagnetic wave

(d) 1.75GHz incident electromagnetic wave
3.2. Absorption contrast of electromagnetic wave irradiation from different angles scattered by a single station

Through the two-station scattering, we know that the stealth effect of plasma on the horizontal incident electromagnetic wave is not very ideal, so the single-station scattering is used to explore the electromagnetic wave incident inlet from different angles, and the energy attenuation value of the electromagnetic wave is simulated and calculated. For L-band electromagnetic waves of 1.00GHz, 1.25GHz and 1.50GHz, 0degree, 15degree, 30degree and 45degree were selected to explore the influence of different incidence angles of electromagnetic waves on the plasma stealth effect.

It can be seen from Figure 2 that with the increase of incident Angle, the stealth effect of the plasma is gradually enhanced, and the two conclusions in the previous section can be verified: First, the energy attenuation effect of the electromagnetic wave perpendicular to the incident is not obvious; Secondly, with the increase of incident electromagnetic wave frequency, the attenuation effect of plasma to electromagnetic wave energy is better.
Figure 2. RCS of incident electromagnetic waves at different angles

(a) 1.00GHz incident electromagnetic wave

(b) 1.25GHz incident electromagnetic wave

(c) 1.50GHz incident electromagnetic wave
4. Conclusion
This paper mainly studied the plasma stealth technology was applied to L-band the feasibility of the electromagnetic wave (1GHz~2GHz) by parsing methods WKB method to explore the relationship between the plasma and electromagnetic wave interaction, selection of UAV inlet model and numerical simulation of the plasma stealth technology analysis of the inlet to the incident electromagnetic wave of different frequency and the influence of different angles of incidence of electromagnetic wave. With the increase of incident electromagnetic wave frequency, the stealth effect of plasma is enhanced gradually. With the increase of the incident Angle of the electromagnetic wave, the plasma stealth effect of the inlet is enhanced gradually. The application of plasma stealth technology in the inlet can achieve the stealth of L-band electromagnetic wave (1GHz~2GHz), and the stealth effect is good.

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