Electromagnetic Stealth
: The Fight Against Radar

2011142159 Jang Yune-seok
2012142168 Lee Jun-hyuk
- How Radars locate targets?

: in angle and distance.
• How to avoid detection

: Minimizing visual signature, infrared heat signature, acoustic signature, radio transmission signature and radar echo signature using a variety of advanced technologies.

• The goal of stealth technology

: Invisible to radar using principle of reflection.

  i) Shaped so that any radar signals are reflected away from the radar equipment.

  ii) Covered in electromagnetic absorbing materials.
[Radar Cross Section]
• **RCS (Radar Cross Section)**

  Measure of how detectable an object. A large RCS indicates that an object is more easily detected.

  - **The RCS depends on**
    - Shape of the target
    - Absolute size of the target
    - Material of the target
    - The incident and reflected angle
**How to calculate RCS**

$$\text{RCS } \sigma = 4 \cdot \pi \cdot r^2 \frac{s_r}{s_t}$$

- $s_t$: power density that is intercepted by target
- $s_r$: scattered power density in the range

<table>
<thead>
<tr>
<th>RCS of Various Flying Objects</th>
<th>RCS[m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object</td>
<td></td>
</tr>
<tr>
<td>F-15 Eagle</td>
<td>405</td>
</tr>
<tr>
<td>B-1A</td>
<td>10</td>
</tr>
<tr>
<td>SR-71 Blackbird</td>
<td>0.014</td>
</tr>
<tr>
<td>Birds</td>
<td>0.01</td>
</tr>
<tr>
<td>F-117</td>
<td>0.003</td>
</tr>
<tr>
<td>B-2 Sprit</td>
<td>0.0014</td>
</tr>
<tr>
<td>Insects</td>
<td>0.001</td>
</tr>
</tbody>
</table>
• **How to calculate RCS**

\[
\text{RCS } \sigma = 4\cdot\pi\cdot r^2 \frac{s_r}{s_t}
\]

- \(s_t\): power density that is intercepted by target
- \(s_r\): scattered power density in the range

---

### RCS of Various Flying Objects

<table>
<thead>
<tr>
<th>Object</th>
<th>RCS [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-15 Eagle</td>
<td>405</td>
</tr>
<tr>
<td>B-1A</td>
<td>10</td>
</tr>
<tr>
<td>SR-71 Blackbird</td>
<td>0.014</td>
</tr>
<tr>
<td>Birds</td>
<td>0.01</td>
</tr>
<tr>
<td>F-117</td>
<td>0.003</td>
</tr>
<tr>
<td>B-2 Sprit</td>
<td>0.0014</td>
</tr>
<tr>
<td>Insects</td>
<td>0.001</td>
</tr>
</tbody>
</table>
[Design of stealth]
Shape
And
Material
Shape

And

Material
The past

The present

The future
The curved shape

Diamond shape

The diamond shape

Normal Aircraft Surface

Stealth Aircraft Surface
Diamond shape

The curved shape

The diamond shape
- **Engine inlet design**: Buried engine
- Disadvantage of diamond shape

1. Poor aerodynamics.
2. Poorly reducing RCS of bistatic radar system.
Shape
And
Material
Non-conductive material

<table>
<thead>
<tr>
<th>Reflection coefficient</th>
<th>Reflected power</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Gamma_p = \frac{n_{2p} - n_{1p}}{n_{2p} + n_{1p}} )</td>
<td>( \frac{P_r}{P_{inc}} =</td>
</tr>
<tr>
<td>( \Gamma_s = \frac{n_{2s} - n_{1s}}{n_{2s} + n_{1s}} )</td>
<td>( \frac{P_t}{P_{inc}} = 1 -</td>
</tr>
</tbody>
</table>

\( n_1 = n_2 \Rightarrow \Gamma_p = 0, \Gamma_s = 0 \)
- Radar Absorbing Material (RAM)

: Absorption the energy of the radio waves transmitted by the radar antenna.

[Carbonyl iron ferrite]
- **Frequency selective surface (FSS)**

  FSS is designed to improve the wideband stealth performance of RAM.

  ![The structure sketch map of RAM containing FSS](image1)

  ![The equivalent circuit model](image2)

  Reflection coefficient of RAM:

  \[
  \Gamma = \frac{Z_{in(i)} - Z_0}{Z_{in(i)} + Z_0}
  \]

  \[
  Z_{i(FSS)} = \frac{1}{2} \sqrt{\frac{\mu}{\varepsilon}} \left[ \frac{Q_0}{Q} - 1 + jQ_0 \left( \frac{f \text{Re}\sqrt{\varepsilon\mu}}{f_0} - \frac{f_0}{f \text{Re}\sqrt{\varepsilon\mu}} \right) \right]
  \]

  \[
  Q = \frac{Q_0 Q_L}{Q + Q_L}
  \]

  \[
  Q_L = \frac{\varepsilon'\mu'}{\varepsilon''\mu'' + \varepsilon'\mu'}
  \]
We optimize the FSS element design based on the electromagnetic parameter of RAM.
The reflection is calculated as

\[ \Gamma = \frac{Z_{in}^N - Z_0}{Z_{in}^N + Z_0} \]

The reflection coefficient of RAM is a multi-variable function.

\[ \Gamma = f(f_0, \varepsilon_1 \cdots \varepsilon_n, \mu_1 \cdots \mu_n, d_1 \cdots d_n, R_1 \cdots R_n) \]

The optimal variables of the parameters only be obtained by optimized algorithms.
[Plasma stealth]
[Plasma stealth]
Why stealth make plasma?

1. The absorption take place when EM wave encounter a charged particle.
2. Electromagnetic wave tend to bend around the cloud and pass aircraft.
3. Frequency oscillation of a plasma changes frequency of incoming radar waves which makes radar waves to become useless.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Radar Absorption Material is not needed.</td>
<td>1. Making plasma cloud around aircraft require huge power.</td>
</tr>
<tr>
<td>2. Plasma will provide heat shield which separate plane from hot air.</td>
<td>2. Plasma layer can also block pilot’s radar.</td>
</tr>
<tr>
<td>3. Plasma could soften airflow across the aircraft so aircraft could be more aerodynamic.</td>
<td>3. When ion is neutralized it will give off light It will create visual path of aircraft</td>
</tr>
</tbody>
</table>
- Absorption of Electromagnetic wave by plasma

[Plasma stealth]
In collisional plasma electron under EM-wave can express by:

\[ m \frac{dv}{dt} = -eE - \nu mv \]

If we consider \( E \) as exponential form, collision frequency is:

\[ \nu = -\frac{eE}{m} \frac{(\nu - i\omega)}{(\omega^2 + \nu^2)} \]

By maxwell equation we can get wave equation as:

\[ (\omega^2 - c^2k^2)E - i\frac{\omega}{\varepsilon_0}J = 0 \]

We can get dispersion equation by \( J = nev \):

\[ k = \frac{\omega}{c} \sqrt{1 - \frac{\omega_p^2(\omega + iv)}{\omega(\omega^2 + \nu^2)}} = k_r - ik_i \]

If plasma is collisional \( \nu \) is not zero and \( ki \) is positive, E-field is absorbed by plasma.

\[ k_i = \frac{\omega}{\sqrt{2}c} \sqrt{-\left(1 - \frac{\omega_p^2}{\omega^2 + \nu^2}\right) + \sqrt{1 - \frac{2\omega_p^2}{\omega^2 + \nu^2} + \frac{\omega_p^4}{\omega^2(\omega^2 + \nu^2)}}} = \frac{\omega}{\sqrt{2}c} \sqrt{-\left(1 - \frac{\omega_p^2}{\omega^2 + \nu^2}\right) + \sqrt{1 - \frac{\omega_p^2}{\omega^2 + \nu^2}}^2 + \left(\frac{\nu}{\omega} \frac{\omega_p^2}{\omega^2 + \nu^2}\right)^2} \]
- Refraction of Electromagnetic wave by plasma
When plasma collision is omitted, it's refraction index is

\[ n_p^2 = \varepsilon_{pr} = 1 - \frac{\omega_p^2}{\omega^2} \]

If plasma density changes with R,

\[ n(R) = \frac{(R)^m}{R_0^m} \]

We combine two equation. We can get EV-wave's R and θ.

\[ \theta_1 = -\text{arc sec}(\sqrt{C_1R^{m+1}}) / (m+1) + C_2 \quad \theta_3 = -\text{arc sec}(\sqrt{C_1R^{m+1}}) / (m+1) - C_2 \]

\[ \theta_2 = \text{arc sec}(\sqrt{C_1R^{m+1}}) / (m+1) + C_2 \quad \theta_4 = \text{arc sec}(\sqrt{C_1R^{m+1}}) / (m+1) - C_2 \]

We can get \( C_1, C_2 \) by substitute \( R_0 \) and EM-wave's incident angle.

\[ C_1 = \frac{\cot^2 \theta_0 + 1}{R_0^{2m+2}} \quad C_2 = \text{arc sec}(\sqrt{C_1R^{m+1}}) / (m+1) + \theta_0 \]

Based on Snell's law, we can get

\[ R_0^m \sin \theta_0 = R^m \sin \theta = r_d^m \sin (\pi/2) = r_d^m \]
[Radar] vs [Stealth]
Thank you!