Analysis of Radar and Infrared Stealth Compatibility Design for Surface Ships

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Abstract. The stealth problem of surface ships is no longer a problem of a single physical field in a single frequency band. Under the severe threat of mutual coordination of enemy's radar and infrared composite guidance mode, it is necessary to pay enough attention to the compatibility of radar and infrared stealth for surface ships. First, we analyzed the composite guidance threat of radar and infrared detection faced by surface ships at sea. Second, we analyzed compatibility design of radar and infrared stealth from ship hull outer board inclination, chimney parts and stealth coatings used by ships, separately. Finally, we clarified the direction for the subsequent research and development of stealth technology for surface ships.

1. Introduction
As the main technical and tactical indicators, radar and infrared stealth design is one of the important symbols of the modernization of surface ships. In the early years, radar and infrared stealth were independently designed separately. However, with the increasing complexity of the guidance threat faced by surface ships, the radar and infrared stealth design of surface ships are also required to evolve from a single design to a compatible design. First, we analyzed the composite guidance threat of radar and infrared detection faced by surface ships at sea. Second, we analyzed compatibility design of radar and infrared stealth from ship hull outer board inclination, chimney parts and stealth coatings used by ships. In the end, we clarified the direction for the development of stealth technology for surface ships.

2. Radar and infrared composite guidance threat
Modern sea battle are dominated by missile attack and defense. Anti-ship missile guidance is mainly based on radar guidance, supplemented by infrared. In the early years, the single radar guided anti-ship missile is easier to be interfered and deceived. In fact, it is difficult to track targets accurately under complex background and strong interference and hit the ship.

In the recent years, it is gradually turning to radar and infrared (here after referred to as Radar-Infrared) composite guidance mode (see Table 1). From the trend of anti-ship missiles, composite guidance has become the mainstream guidance mode of anti-ship missiles in the future. This trend has been reflected in several models of anti-ship missiles in service and under development (See Table 1). Radar and infrared composite guidance has the advantages of radar working all weather, long working distance. Moreover, it has the advantages of infrared guidance system such as good concealment, strong target recognition ability and not easy to be interfered by electronic. It obtains better anti-
interference ability and guidance performance than single-mode radar guidance. Therefore, it is one of the mainstream trends in the future development of anti-ship missile composite guidance.

The evolution of anti-ship guidance threat from single radar guidance to Radar-Infrared composite guidance were clearly show in Table 1. This evolution requires surface ship stealth should not only meet the requirements of radar and infrared stealth separately, but also meet the mutual coordination between them.

### Table 1. Typical Radar-Infrared composite guided missiles

| Model or code of anti-ship missile | Area           | Guidance mode                                                                 | Service status                                                                 |
|-----------------------------------|----------------|-------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| SS-N-9                            | Russia         | Autopilot plus relay modified midcourse guidance, active radar seeker (10GHz) terminal guidance and infrared seeker is used as supplementary terminal guidance system. | Started service in 1969                                                       |
| Harpoon                           | United States  | Full-range inertial, GPS midcourse guidance plus active radar terminal guidance. In recent years, infrared imaging seekers have been developed for this type of missile. The two seekers are interchangeable. | Equipped in 1971, the infrared imaging seeker was successfully tested in 2003. |
| LRASM                             | United States  | Weapon data link, enhanced digital anti-interference GPS, radar/infrared/photoelectric multi-mode seeker. | Newly developed, and the third flight test was completed in February 2015.     |
| RIM-116                           | United States  | Passive radar and infrared composite guidance seeker                           | Equipped in 1992                                                              |
| NSM modified version              | Norway         | Various schemes, such as dual-band passive intelligent infrared imaging, millimeter wave, semi-active laser, active radar and infrared laser composite seeker. | Initial operational capacity was available in 2010                           |
| Penguin IV                        | Norway         | Millimeter wave radar, laser and infrared composite guidance                  | Under development                                                             |
| NGASM                             | Italy          | Infrared imaging/X-band active radar dual-mode guidance                        | In 2001, replaced Teseo III anti-ship missile                                |
| Hsiung Feng II                    | Taiwan, China  | Active radar and infrared guidance                                             | The design was finalized in 1988                                              |
| Hsiung Feng III                   | Taiwan, China  | Active radar and infrared imaging dual-mode composite guidance                | The first test flight in 1998                                                  |
| RBS-15BK III                      | Sweden         | Active radar / infrared imaging dual-mode composite guidance                  | Served in 1979                                                               |
| ASM-3                             | Japan          | Passive radar / infrared imaging composite guidance                           | Developed in 2000                                                            |

### 3. Analysis of the Radar-Infrared composite guidance compatibility design of the surface ship's hull outer board part

In view of the early anti-ship missile, it is guided mainly by radar. Radar stealth technology is one of the earliest developed technologies of modern stealth technology for surface ships. It mainly uses the
external and inward tilt the ship hull outer board (as shown in Figure 1). In addition, it uses a large area of flat plate structure to shield the complex shipboard weapons and equipment. As a result, the ship forms a concise and plate structure in appearance. This makes the radar detected by the enemy deflect to the non-incident direction. It reduces the radar cross section (RCS) received by the enemy radar, thereby realizes the radar stealth of the ship.

However, the outer surface is heated up because of the solar irradiation, and a larger inward inclination angle will increase the area perpendicular to the solar irradiation, thus raising the temperature of the outer surface to some extent. The infrared radiation ability of the target is proportional to the fourth power of its surface temperature. The increase of the inward inclination angle will not be conducive to the infrared stealth of the target.

In reference[1], in order to clarify the influence of the change of the inclination angle of the ship hull outer board on the infrared radiation of the target, a section of typical outer surface (flat plate) of the target is taken for analysis. The result shows that: the infrared contrast between the target and the background will increase with the increase of the inclination angle when the ocean background is unchanged. The time, which the outer surface of the target reaches heat equilibrium with the water spray cooling (i.e. cooling time) increases, as the inclination angle increases. The target outer surface inclination shall be designed to realize radar stealth. Nevertheless, the design should decrease the inclination angle of the outer surface of the target as much as possible, reduces the infrared contrast between the target and the background. Moreover, it shortens the cooling time of the outer surface, so that it is much easier to reach the infrared stealth purpose.

![Figure 1. The outer surface of the Swedish Visby stealth battleship is a plate-shaped radar stealth structure.](image)

Generally speaking, the radar is deflected by more than 4 degrees, and its reflected energy peak is shifted out from its main lobe. If the reflection residual angle of the enemy detection radar is less than 3 degrees, the ship hull plate inclination of 7 degrees can deflect the reflected wave of the enemy radar. Which means making the reflected echo of the target it receives very weak, and effectively realizing the stealth of radar. However, the inclination of 7 degrees is not conducive to infrared stealth compared with the vertical one. 7 degree increases the infrared contrast [1] by about 0.7% than 0 degree (vertical one). Moreover, the cooling time of infrared water spray increases by about 7 seconds. However, infrared stealth is still acceptable by opening the water spray in advance.

4. Analysis of radar and infrared stealth compatibility design for surface ship chimney part
The chimney part of surface ship is different from other hull parts. It is located at the upper surface of the ship's midship. It has large area and can't be covered. It has high exhaust temperature and obvious outline contour features. It is a part with strong radar and infrared target features. The chimney part of surface ships is the key point of radar and infrared stealth compatibility design.

The US surface ship attaches great importance to the radar and infrared stealth compatibility design of its chimney part. In its early surface ship models, such as the Arleigh Burke class destroyer (before
the DDG88), infrared suppressor was installed at the chimney part to reduce the intensity of infrared radiation (as shown in Figure 2). However, it was found that the portion of the infrared suppressor that protruded from the chimney trap had a large radar scattering area due to its irregular shape. Therefore, on its subsequent improved Arleigh Burke Class Destroyers (starting from DDG89), the infrared suppressor was installed at lower height, and the infrared suppressor diffuser ring is no longer exposed (as shown in Figure 2). Therefore, the good performance of radar stealth can be guaranteed. This successful design of radar and infrared stealth compatibility causes that the chimney parts in terms of the later new U.S. surface ships are all designed with radar and infrared stealth compatibility, such as DDG1000 (shown below in Figure 3).

In addition that chimneys are designed with radar and infrared stealth compatibility, the main power exhaust port is set near the water line, and even the vent is hidden inside the two plates of the catamaran so that the high temperature vent cannot be seen by the infrared guidance detector. This design can fundamentally eliminate the radar scattering caused by the complex structure of chimney parts so as to solve the problem of radar and infrared stealth compatibility of chimney parts once and for all [2]. Representatives of this design are Sweden's Visby (see Figure 1), Germany's Meko, U.S. LCS (shown in the top of Figure 3) and China's catamaran missile speedboat.

Figure 2. Position change of infrared suppressors at chimney parts of the U.S. Arleigh Burke Class Destroyers DDG88 (left) and DDG89 (right)
Note: after DDG89, chimneys of all Arleigh Burke Class Destroyers are designed with radar infrared stealth compatibility

Figure 3. The chimney part of DDG1000 is designed with radar and infrared stealth compatibility

5. Analysis of radar and infrared stealth compatibility design for surface ship surface coating
It’s relatively common that modern surface ships adopts the radar stealth coating, while the application of infrared stealth coating lags far behind that of radar stealth coating. For a relatively new material (infrared stealth coating), when relatively mature ship radar stealth coating has been applied, the problem of compatibility of radar and infrared stealth coating is inevitable due to the similarity of the applied parts.
The overall requirements of radar and infrared compatible stealth material are: for infrared light, it is necessary to reduce absorption and increase reflection, while for radar, it is necessary to reduce reflection and increase absorption. At present, the compatible stealth coating can be divided into dual-layer compatible stealth coating and single-layer stealth coating.

The dual-layer compatible stealth coating, that is, the applying of a layer of infrared stealth coating on the radar stealth coating. As the infrared stealth coating on the top layer, it shall not only realize infrared stealth, but also enable the radar to pass through the layer and reach the radar stealth coating on the bottom layer smoothly, so that the radar can be absorbed, and the infrared and radar compatible stealth can be finally achieved. The feasibility of the dual-layer compatible stealth depends on the transmission performance of the infrared stealth coating. Common coating, such as polyurethane, epoxy resin and EPDM rubber commonly used in projects, has good transmission performance due to its low dielectric constant and extremely low conductivity. Therefore, the radar and infrared stealth compatibility design can be achieved through a dual-layer or even multiple-layer structure.

It is much more difficult for the single-layer compatible stealth coating to achieve compatibility than the dual-layer compatible stealth coating. In general, materials are required to be frequency selective. The frequency selective surface is a hot research field at present. It can be seen from reports [3, 4] and feedback of multiple information channels that it is also possible to achieve the radar and infrared compatible design by using frequency selective materials.

6. Conclusion
The stealth problem of surface ships is no longer a problem of a single physical field in a single frequency band. Under the severe threat of mutual coordination of enemy's radar and infrared composite guidance mode, it is necessary to pay enough attention to the compatibility of radar and infrared stealth for surface ships. Moreover, it is avoided the method of adopting one kind of stealth by sacrificing another kind of stealth. Through the analysis of this paper, we can see that the problem of mutual restriction of radar and infrared stealth exists in the inclined outer board of surface ship, the high-temperature chimney part and the radar and infrared stealth coating adopted. Some of these problems can be solved by changing the overall structural design, such as adopting the method of exhausting near the water line; some of them can be solved through microscopic material structure, such as using infrared transmission stealth materials; some of them can only be solved by additional methods under the premise of ensuring one kind of stealth. For example, the infrared stealth needs to be solved by using the water spray after the outer board is inclined. This shows that the surface ship stealth technology is developing towards the compatibility of radar and infrared stealth.

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