Research on Combat Composition of Ship-to-Air Missile Formation

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Abstract — In view of the quantitative determination of the combat composition number and relative positions of ship-to-air missile formation, the factor of the horizontal required azimuth range of the ship-to-air missile formation to cover a single ship, and the factors of the horizontal fire circle of short-range ship-to-air missile ships, medium-range ship-to-air missile ships, long-range ship-to-air missile ships were considered. A combat composition model of ship-to-air missile formation was proposed, which can quantitatively determine the number and relative positions of short-range, medium-range, and long-range ship-to-air missile ships, and provide a model basis for the combat composition of ship-to-air missile formation.

Keywords — Combat Composition, Formation, Ship-To-Air Missile.

I. INTRODUCTION

Combat composition of ship-to-air missile formation includes the number and relative positions of ship-to-air missile ships. The ship-to-air missile weapons are usually classified from near to long distance, including short-range ship-to-air missiles, medium-range ship-to-air missiles, and long-range ship-to-air missile weapons.

When the ship-to-air missile formation covers a single ship, under the condition that the ship-to-air missile formation covers a single ship with the horizontal required azimuth range, the ship-to-air missile combat composition needs to determine the number and relative positions of short-range, medium-range, and long-range ship-to-air missile ships to cover a single ship.

At present, the relevant research is mainly as follows: The multi-attribute decision-making method of fuzzy set theory was used to evaluate the air defense combat composition of an aircraft carrier formation. The quantitative static and dynamic models, the multi-objective decision-making, and a parallel simulation method were used to assess combat composition. The anti-ship combat composition scheme of the warship formation was optimized. The mathematical description of the task-based force composition cutting problem was constructed. The fuzzy comprehensive evaluation and effectiveness evaluation of the formation of the island and reef warning force was constructed. The composition optimization model based on a multi-attribute decision was constructed. The formation and command relationship of the amphibious combat force was qualitatively analyzed. The test analysis method was used to study the composition problem. The multi-objective decision-making method was used to study the aircraft carrier formation problem. The clustering algorithm was used to study the composition problem.

The above-mentioned research results are scattered, and no research has been conducted on the combat composition of ship-to-air missile formations, and factors such as the horizontal required azimuth range of a ship-to-air missile formation to cover a single ship, as well as factors such as the horizontal fire circle of a short-range ship-to-air missile, medium-range ship-to-air missile, long-range ship-to-air missile ships, have not been taken into account. Therefore, a combat composition model of ship-to-air missile formation is proposed in this paper, which can quantitatively determine the number and relative positions of short-range ship-to-air missile ships to cover a single ship, the number and relative positions of medium-range ship-to-air missile ships to cover a single ship, and the number and relative positions of long-range ship-to-air missile ships to cover a single ship, and provide a composition model basis for ship-to-air missile formation.

II. COMBAT COMPOSITION PROCESS OF SHIP-TO-AIR MISSILE SHIP FORMATION

Assume that the ship-to-air missile combat composition of the ship-to-air missile formation covers a single ship. The steps of the composition process of ship-to-air missile formation are as follows.

A. Step 1

Determining the position of a single ship covered by the ship-to-air missile formation, and the horizontal required azimuth range of the ship-to-air missile formation to cover a single ship.

B. Step 2

According to the range of the ship-to-air missile, the formation ship-to-air missile weapons are classified into formation short-range ship-to-air missile, formation medium-range ship-to-air missile, and formation long-range ship-to-air missile weapons.

C. Step 3

Calculate the horizontal fire circle of the formation to cover
a single ship, based on the position of a single ship covered by the ship-to-air missile formation, and the maximum horizontal range of the ship-to-air missile weapon covering a single ship.

D. Step 4
Determine the horizontal fire circle of the formation short-range ship-to-air missile based on the horizontal fire circle of the covered single ship. The ship-to-air missile ship’s horizontal fire circle refers to a circle with the ship’s position as the center and the radius as the distance from the ship-to-air missile horizontal launch area. The far range of the horizontal launching area of the ship-to-air missile refers to the maximum horizontal distance of the ship-to-air missile intercepting aircraft and other air targets.

E. Step 5
Determine the horizontal fire circle of the formation medium-range ship-to-air missile based on the horizontal fire circle of the formation short-range ship-to-air missile.

F. Step 6
Determine the horizontal fire circle of the formation long-range ship-to-air missile based on the horizontal fire circle of the formation medium-range ship-to-air missile.

G. Step 7
Determine the ship-to-air missile combat composition based on the covered single ship's horizontal fire circle, the required azimuth range of the ship-to-air missile formation covering the single ship, the short-range ship-to-air missile's horizontal fire circle, the medium-range ship-to-air missile's horizontal fire circle, and the long-range ship-to-air missile's horizontal fire circle. The ship-to-air missile combat composition includes the number and relative positions of the formation's short-range ship-to-air missile ships, medium-range ship-to-air missile ships, and long-range ship-to-air missile ships.

III. DETERMINATION MODEL OF THE NUMBER AND POSITIONS OF THE FORMATION SHORT-RANGE SHIP-TO-AIR MISSILE SHIPS

The schematic diagram of the combat composition of a ship-to-air missile formation is shown in Fig. 1.

A. Determination of the Horizontal Fire Circle of the Formation Short-range Ship-to-air Missile

In Fig. 1, the single ship is a U ship. The horizontal fire circle of the short-range ship-to-air missile is determined on the basis of the ship-to-air missile horizontal fire circle of the U ship. The Y circle is the ship-to-air missile horizontal fire circle of a U ship, which is a circle with point O as the center and radius E. E is the distance from the ship-to-air missile horizontal launching area of the U ship. The intersections of the Y circle and the Y1 circle are point C1 and point C4. Point A1 is also the position of a single short-range ship-to-air missile ship, and A2 circle is also the horizontal fire circle of single short-range ship-to-air missile ship, which is a circle with point A1 as the center and radius E1.

The intersection of Y1 circle tangent to line OJ is point C1, Rj is the distance between point O and point A1, which is given in (1).

\[ R_j = \sqrt{E^2 + E_j^2} \]  \hspace{1cm} (1)

Point A12 is also the position of another short-range ship-to-air missile ship, and Y12 circle is also the horizontal fire circle of another short-range ship-to-air missile ship, which is a circle with point A12 as the center and radius Ej. The Y12 circle is tangent to the straight line OJ, and the tangent intersection point is point C4.

B. Determination of the Number and Positions of the Formation Short-range Ship-to-air Missile Ships

In Fig. 1, on the basis of the horizontal fire circle of the formation short-range ship-to-air missile, the number Nj of the formation short-range ship-to-air missile ships is determined, and the positions of the Nj short-range ship-to-air missile ships are determined.

When the formation of short-range ship-to-air missile ships covers the U ship, they need to be horizontally configured in Fig. 1. That is, the formation of short-range ship-to-air missile ships can be laterally arranged on the arc line Sj with the point O as the center and the radius Rj. The lateral arrangement range is the arc section from the point A1j to the point A2j with the point O as the center and the radius Rj, which constitutes the shielding horizontal closed area formed by the line segment OCj, the line segment OC1 and the horizontal fire circle of the short-range ship-to-air missile ships when the short-range ship-to-air missile ships cover the U ship in this arc segment. This shielding horizontal enclosed area is the horizontal enclosed area when the short-range ship-to-air missile ships cover the U ship in the horizontal required azimuth range angle H.

Calculation of the maximum horizontal azimuth range angle Fy of a single short-range ship-to-air missile ship covering U ship. Take the point O as the starting point for the ray OD1. The ray OD1 is tangent to the Y1 circle, and the tangent point is the point D1. The maximum horizontal azimuth range angle Fy for a single short-range ship-to-air missile ship to cover U ship, which is given in (2).
Calculate the number of short-range ship-to-air missile ships in the formation and determine the location of the Nj medium-range ship-to-air missile ships. There are three situations.

In case 1, when H≤Fzd, Nj=1. The position of the one short-range ship-to-air missile ship is position point A₁. The distance of point A₁ from point O is Rₒ, and the relative horizontal angle \( \angle A₁O₁ \) is given in (3).

\[
\angle A₁O₁ = B + \arctan \left( \frac{E_y}{E_x} \right)
\]  

(3)

In case 2, when Fzd<H≤2Fzd, Nj=2. The positions of the two short-range ship-to-air missile ships are point A₁ and point A₂. The distance of point A₁ from point O is Rₒ, and the relative horizontal angle is \( \angle A₁O₁ \). The distance between point A₂ and point O is Rₛ, and the relative horizontal angle \( \angle A₂O₁ \) is given in (4).

\[
\angle A₂O₁ = B + H - \arctan \left( \frac{E_y}{E_x} \right)
\]  

(4)

In case 3, when 2Fzd<H. Nj is given in (5).

\[
N_j = \left[ \frac{H}{Fzd} \right]
\]  

(5)

The positions of the Nj short-range ship-to-air missile ships are position points A₁, A₂, and Nj-2 ships. The positions of the Nj-2 ships are, the distance between the ith ship and the relative point O is Rₒ, and the relative horizontal angle \( \angle A_iO_1 \) is given in equation (6). \( 1 ≤ i ≤ N_j-2 \).

\[
\angle A_iO₁ = \angle A₁O₁ + \frac{H-2Fzd}{N_j-2} \times i
\]  

(6)

IV. DETERMINATION MODEL OF THE NUMBER AND POSITIONS OF THE FORMATION MEDIUM-RANGE SHIP-TO-AIR MISSILE SHIPS

A. Determination of the Horizontal Fire Circle of the Formation Medium-range Ship-to-air Missile

In Fig. 1, the horizontal fire circle of the formation medium-range ship-to-air missile is determined on the basis of the short-range ship-to-air missile ship configuration arc line S₁. The intersection of the arc line S₁ and the straight line OJ₁ is the point C₀, the intersection of the arc line S₁ and the straight line OJ₂ is the point C₂, the point A₀ is also the position of a single medium-range ship-to-air missile ship, and the Yₓ₁ circle is also the horizontal fire circle of a single medium-range ship-to-air missile ship, which is a circle with the point A₀ as the center and the radius Rₓ. The intersection of Yₓ₁ circle tangent to line OJ₂ is point C₂, and Rₓ is the distance between point O and point A₀ is given in (7).

\[
R_x = \sqrt{E_x^2 + R_y^2}
\]  

(7)

Point A₂ is also the position of another medium-range ship-to-air missile ship, and Yₓ₂ circle is also the horizontal fire circle of another medium-range ship-to-air missile ship, which is a circle with point A₂ as the center and radius Rₓ. The Yₓ₂ circle is tangent to the straight line OJ₂, and the tangent intersection point is point C₅.

B. Determination of the Number and Positions of the Formation Medium-range Ship-to-air Missile Ships

In Fig. 1, on the basis of the horizontal fire circle of the formation medium-range ship-to-air missile, the number Nₓ of the formation medium-range ship-to-air missile ships are determined, and the positions of the Nₓ medium-range ship-to-air missile ships are determined.

When the formation of medium-range ship-to-air missile ships cover the U ship, they need to be horizontally configured in Fig. 1. That is, the formation of medium-range ship-to-air missile ships can be horizontally arranged on the arc S₂ with the point O as the center and the radius Rₒ. The horizontal arrangement range is the arc segment from the point A₁ to the point A₂ with the point O as the center and the radius Rₒ, which constitutes the shielding horizontal closed area formed by the line segment OC₂, the line segment OC₃ and the horizontal fire circle of the medium-range ship-to-air missile ships when the medium-range ship-to-air missile ships cover the U ship in this arc segment. This cover horizontal closed area is the horizontal covered area when the medium-range ship-to-air missile ship can cover the U ship in the horizontal required azimuth range angle H.

Calculation of the maximum horizontal azimuth range angle Fzd of a single medium-range ship-to-air missile ship covering U ship. Take the point O as the starting point for the ray OD₂. The ray OD₂ is tangent to the Yₓ₁ circle, and the tangent point is the point D₂. The maximum horizontal azimuth range angle Fzd for a single medium-range ship-to-air missile ship to cover U ship is given in (8).

\[
Fzd = 2\arcsin \left( \frac{E_y}{R_x} \right)
\]  

(8)

Calculate the number of medium-range ship-to-air missile ships in the formation and determine the location of the Nₓ medium-range ship-to-air missile ships. There are three situations.

In case 4, when H≤Fzd, Nₓ=1. The position of the one medium-range ship-to-air missile is point A₁, the distance between point A₁ and point O is Rₒ, and the relative horizontal angle \( \angle A₁O₁ \) is given in (9).

\[
\angle A₁O₁ = B + \arctan \left( \frac{E_y}{E_x} \right)
\]  

(9)

In case 5, when Fzd<H≤2Fzd, Nₓ=2. The positions of the two medium-range ship-to-air missile ships are point A₁ and point A₂. The distance of point A₁ from point O is Rₒ, and the relative horizontal angle \( \angle A₁O₁ \) is given in (10).

\[
\angle A₂O₁ = B + H - \arctan \left( \frac{E_y}{E_x} \right)
\]  

(10)

In case 6, when 2Fzd<H. Nₓ is given in (11).

\[
N_x = \left[ \frac{H}{Fzd} \right]
\]  

(11)
The positions of the N₂ medium-range ship-to-air missile ships are position points A₁,₂, and N₂-2 ships. The positions of the N₂-2 ships are, the distance between the jth ship and the relative point O is Rₓ, and the relative horizontal angle \( \angle A_xOJ_1 \) is given in (12), where \( 1 \leq j \leq N₂-2 \).

\[
\angle A_xOJ_1 = \angle A_xOJ_1 + \frac{H-2F_{yd}}{N_y-2} \cdot j \quad (12)
\]

V. DETERMINATION MODEL OF THE NUMBER AND POSITIONS OF THE FORMATION LONG-RANGE SHIP-TO-AIR MISSILE SHIPS

A. Determination of the Horizontal Fire Circle of the Formation Long-range Ship-to-air Missile

In Fig. 1, the horizontal fire circle of the formation’s long-range ship-to-air missile is determined on the basis of the arc line S₂ of the medium-range ship-to-air missile ship configuration. The intersection of the arc line S₂ and the straight line OJ₂ is point C₃, the intersection of the arc line S₂ and the straight line OJ₃ is point C₄, the point A₁ is also the position of a single long-range ship-to-air missile ship, and the Y₁ circle is also the horizontal fire circle of a single long-range ship-to-air missile ship, which is a circle with the point A₁ as the center and radius E₁. The intersection of the circle Y₁, tangent to the straight line OJ₂ is the point C₃, and Rₓ is the distance between the point O and the point A₁, R₢ is given in equation (13).

\[
R_y = \sqrt{E_y^2 + R_x^2} \quad (13)
\]

Point A₂ is also the position of another long-range ship-to-air missile ship, and the Y₂ circle is also the horizontal fire circle of another long-range ship-to-air missile ship, which is a circle with point A₂ as the center and radius E₂. The circle Y₂ is tangent to the straight line OJ₁, and the tangent intersection point is point C₄.

B. Determination of the Number and Positions of the Formation Long-range Ship-to-air Missile Ships

In Fig. 1, based on the horizontal fire circle of the formation of long-range ship-to-air missiles, the number N_y of the formation of long-range ship-to-air missile ships is determined, and the positions of the N_y long-range ship-to-air missile ships are determined.

When the formation of long-range ship-to-air missile ships covers the U ship, they need to be laterally configured at the far side in Fig. 1. That is, the formation of long-range ship-to-air missile ships can be horizontally arranged on the arc S₃ with the point O as the center and the radius Rₚ. The horizontal arrangement range is the arc segment from the point A₁ to the point A₂ with the point O as the center and the radius Rₚ, which constitutes the shielding horizontal closed area formed by the line segment OC₃, the line segment OC₄ and the horizontal fire circle of the long-range ship-to-air missile ships when the long-range ship-to-air missile ships cover the U ship in this arc segment. This cover horizontal enclosed area is the horizontal enclosed area when the long-range ship-to-air missile ship can cover the U ship in the horizontal required azimuth range angle H.

Calculation of the maximum horizontal azimuth range angle F_{yd} of a single long-range ship-to-air missile ship covering U ship. Take point O as the starting point for the ray OD. The ray ODₚ is tangent to the Y₁ circle, and the tangent point is the point Dₚ. The maximum horizontal azimuth range angle of a single long-range ship-to-air missile ship covering U ship is F_{yd}, which is given in (14).

\[
F_{yd} = 2\arcsin\left(\frac{E_y}{R_y}\right) \quad (14)
\]

Calculate the number of long-range ship-to-air missile ships in the formation and determine the positions of N_y long-range ship-to-air missile ships. There are three situations.

In case 7, when H≤F_{yd}, N_y=1. The position of the one long-range ship-to-air missile ship is point A₁. The distance of point A₁ from point O is Rₓ, and the relative horizontal angle \( \angle A_1OJ_1 \) is given in (15).

\[
\angle A_1OJ_1 = B + \arctg\left(\frac{E_y}{R_x}\right) \quad (15)
\]

In case 8, when F_{yd}≤H≤2F_{yd}, N_y=2. The positions of the two long-range ship-to-air missile ships are point A₁ and point A₂. The distance of point A₂ from point O is Rₓ, and the relative horizontal angle is \( \angle A_2OJ_1 \). The distance between point A₂ and point O is R₢, and the relative horizontal angle \( \angle A_2OJ_1 \) is given in (16).

\[
\angle A_2OJ_1 = B + H - \arctg\left(\frac{E_y}{R_x}\right) \quad (16)
\]

In case 9, when 2F_{yd}<H, N_y is given in (17).

\[
N_y = \left[\frac{H}{F_{yd}}\right] \quad (17)
\]

The positions of the N_y medium-range ship-to-air missile ships are points A₁,₂, and N_y-2 ships. The positions of the N_y-2 ships are, the distance between the kth ship and the relative point O is R_y=\sqrt{E_y^2 + R_x^2}, and the relative horizontal angle \( \angle A_kOJ_1 \) is given in (18), where \( 1 \leq k \leq N_y-2 \).

\[
\angle A_kOJ_1 = \angle A_1OJ_1 + \frac{H-2F_{yd}}{N_y-2} \cdot k \quad (18)
\]

VI. CONCLUSION

The combat composition model of ship-to-air missile formation is proposed in this paper, which takes into account the factors of the horizontal required azimuth range of ship-to-air missile formation to cover a single ship and the factors of the horizontal firepower circle of short-range ship-to-air missile, medium-range ship-to-air missile, long-range ship-to-air missile ships, quantitatively determines the number and relative positions of short-range, medium-range, long-range ship-to-air missile ships for protecting a single ship, and provides a composition model basis for ship-to-air missile formation.
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