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

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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 A4 is also the position of a single short-range ship-to-air missile ship, and A4 circle is also the horizontal fire circle of single short-range ship-to-air missile ship, which is a circle with point A4 as the center and radius E4.

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

The intersection of Y1 circle tangent to line OJ is point C1. Rj is the distance between point O and point A4, which is given in (1).

\[ R_j = \sqrt{E^2 + E_j^2} \]  

Point A4 is also the position of another short-range ship-to-air missile ship, and Y2 circle is also the horizontal fire circle of another short-range ship-to-air missile ship, which is a circle with point A4 as the center and radius E4. The Y2 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 A1 to the point A2 with the point O as the center and the radius R, which constitutes the shielding horizontal closed area formed by the line segment OC, 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 Fgd of a single short-range ship-to-air missile ship covering U ship. Take the point O as the starting point for the ray OD. The ray OD is tangent to the Y1 circle, and the tangent point is the point D1. The maximum horizontal azimuth range angle Fgd for a single short-range ship-to-air missile ship to cover U ship, which is given in (2).
The distance of ships in the formation and determine the location of the short-range ship-to-air missile ships. There are three situations.

In case 1, when \( H \leq F_{zd} \), \( N_j = 1 \). The position of the one short-range ship-to-air missile ship is position point \( A_1 \). The distance of point \( A_1 \) from point \( O \) is \( R_s \), and the relative horizontal angle \( \angle A_1 O J_1 \) is given in (3).

\[
\angle A_1 O J_1 = B + \arctan\left(\frac{E_j}{R_j}\right)
\]  

(2)

In case 2, when \( F_{zd} < H \leq 2F_{zd} \), \( N_j = 2 \). The positions of the two short-range ship-to-air missile ships are point \( A_1 \) and point \( A_2 \). The distance of point \( A_1 \) from point \( O \) is \( R_s \), and the relative horizontal angle is \( \angle A_1 O J_1 \). The distance between point \( A_2 \) and point \( O \) is \( R_s \), and the relative horizontal angle \( \angle A_2 O J_1 \) is given in (4).

\[
\angle A_1 O J_1 = B + H - \arctan\left(\frac{E_j}{E_i}\right)
\]

(3)

In case 3, when \( 2F_{zd} < H \), \( N_j \) is given in (5).

\[
N_j = \left[\frac{H}{2F_{zd}}\right]
\]

(4)

The positions of the \( N_j \) short-range ship-to-air missile ships are position points \( A_1, A_2, \ldots, A_{N_j-2} \). The positions of the \( N_j-2 \) ships are, the distance between the \( i \)th ship and the relative point \( O \) is \( R_s \), and the relative horizontal angle \( \angle A_{1j} O J_1 \) is given in equation (6). \( 1 \leq i \leq N_j-2. \)

\[
\angle A_{1j} O J_1 = \angle A_{1j} O J_1 + \frac{H - 2F_{zd}}{N_j - 2} i
\]

(5)

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 \( S_1 \). The intersection of the arc line \( S_1 \) and the straight line \( OJ_2 \) is the point \( C_2 \), the intersection of the arc line \( S_1 \) and the straight line \( OJ_3 \) is the point \( C_3 \), the point \( A_3 \) is also the position of a single medium-range ship-to-air missile ship, and the \( Y_{st} \) circle is also the horizontal fire circle of a single medium-range ship-to-air missile ship, which is a circle with the point \( A_{st} \) as the center and the radius \( R_z \). The \( Y_{st} \) circle is tangent to the straight line \( OJ_3 \), and the tangent intersection point is point \( C_3 \).

\[
F_{zd} = 2\arcsin\left(\frac{E_j}{R_j}\right)
\]

(6)

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

In case 4, when \( H \leq F_{zd} \), \( N_z = 1 \). The position of the one medium-range ship-to-air missile ship is point \( A_{st} \), the distance between point \( A_{st} \) and point \( O \) is \( R_s \), and the relative horizontal angle is \( \angle A_{st} O J_1 \) is given in (7).

\[
\angle A_{st} O J_1 = B + \arctan\left(\frac{E_j}{R_j}\right)
\]

(7)

In case 5, when \( F_{zd} < H \leq 2F_{zd} \), \( N_z = 2 \). The positions of the two medium-range ship-to-air missile ships are point \( A_{st} \) and point \( A_{st} \). The distance of point \( A_{st} \) from point \( O \) is \( R_s \), and the relative horizontal angle is \( \angle A_{st} O J_1 \). The distance between point \( A_{st} \) and point \( O \) is \( R_s \), and the relative horizontal angle \( \angle A_{st} O J_1 \) is given in (8).

\[
F_{zd} = 2\arcsin\left(\frac{E_j}{R_j}\right)
\]

(8)

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

In case 6, when \( 2F_{zd} < H \), \( N_z \) is given in (9).

\[
N_z = \left[\frac{H}{2F_{zd}}\right]
\]

(9)
The positions of the \( N_2 \) medium-range ship-to-air missile ships are position points \( A_{i1}, A_{i2}, \) and \( A_{N2-2} \) ships. The positions of the \( N_2-2 \) ships are, the distance between the \( j \)th ship and the relative point \( O \) is \( R_y \), and the relative horizontal angle \( \angle A_{j1}O \) is given in (12), where \( 1 \leq j \leq N_2-2 \).

\[
\angle A_{j1}O = \angle A_{j1}O + \frac{H-2F_{y\text{d}}}{N_2-2} j
\] (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 \( S_2 \) of the medium-range ship-to-air missile ship configuration. The intersection of the arc line \( S_2 \) and the straight line \( OJ_2 \) is point \( C_3 \), the intersection of the arc line \( S_2 \) and the straight line \( OJ_3 \) is point \( C_6 \), the point \( A_3 \) is also the position of a single long-range ship-to-air missile ship, and the \( Y_3 \) circle is also the horizontal fire circle of a single long-range ship-to-air missile ship, which is a circle with the point \( A_3 \) as the center and the radius \( E_3 \). The intersection of the circle \( Y_3 \) tangent to the straight line \( OJ_2 \) is the point \( C_3 \), and \( R_y \) is the distance between the point \( O \) and the point \( A_{31}, R_y \) is given in equation (13).

\[
R_y = \sqrt{E_3^2 + R_2^2}
\] (13)

Point \( A_{22} \) is also the position of another long-range ship-to-air missile ship, and the \( Y_2 \) circle is also the horizontal fire circle of another long-range ship-to-air missile ship, which is a circle with point \( A_{22} \) as the center and radius \( E_2 \). The circle \( Y_2 \) tangent to the straight line \( OJ_2 \) and the tangent intersection point is point \( C_6 \).

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 \( S_3 \) with the point \( O \) as the center and the radius \( R_3 \). The horizontal arrangement range is the arc segment from the point \( A_{31} \) to the point \( A_{22} \) with the point \( O \) as the center and the radius \( R_3 \), which constitutes the shielding horizontal closed area formed by the line segment \( OC_3 \), the line segment \( OC_6 \) 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 \( F_{y\text{d}} \) of a single long-range ship-to-air missile ship covering \( U \) ship. Take point \( O \) as the starting point for the ray \( OD_3 \). The ray \( OD_3 \) is tangent to the \( Y_1 \) circle, and the tangent point is the point \( D_3 \). The maximum horizontal azimuth range angle of a single long-range ship-to-air missile ship covering \( U \) ship is \( F_{y\text{d}} \), which is given in (14).

\[
F_{y\text{d}} = 2\arcsin\left(\frac{E_y}{R_y}\right)
\] (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 \( H < F_{y\text{d}} \), \( N_y = 1 \). The position of the one long-range ship-to-air missile ship is point \( A_{31} \). The distance of point \( A_{31} \) from point \( O \) is \( R_y \), and the relative horizontal angle \( \angle A_{31}O \) is given in (15).

\[
\angle A_{31}O = B + \arctan\left(\frac{E_y}{R_y}\right)
\] (15)

In case 8, when \( F_{y\text{d}} < H < 2F_{y\text{d}} \), \( N_y = 2 \). The positions of the two long-range ship-to-air missile ships are point \( A_{31} \) and point \( A_{22} \). The distance of point \( A_{31} \) from point \( O \) is \( R_y \), and the relative horizontal angle is \( \angle A_{31}O \). The distance between point \( A_{22} \) and point \( O \) is \( R_y \), and the relative horizontal angle \( \angle A_{22}O \) is given in (16).

\[
\angle A_{22}O = B + H - \arctan\left(\frac{E_y}{R_y}\right)
\] (16)

In case 9, when \( 2F_{y\text{d}} < H \), \( N_y \) is given in (17).

\[
N_y = \left\lceil \frac{H}{F_{y\text{d}}} \right\rceil
\] (17)

The positions of the \( N_y \) medium-range ship-to-air missile ships are points \( A_{31}, A_{22}, \) and \( A_{N2-2} \) ships. The positions of the \( N_2-2 \) ships are, the distance between the \( k \)th ship and the relative point \( O \) is \( R_y = \sqrt{E_3^2 + R_2^2} \), and the relative horizontal angle \( \angle A_{yk}O \) is given in (18), where \( 1 \leq k \leq N_2-2 \).

\[
\angle A_{yk}O = \angle A_{yk}O + \frac{H-2F_{y\text{d}}}{N_2-2} k
\] (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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