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Combat capability evaluation method of surface warship considering impact of wind and waves

ZHANG Heng[1], *ZHU Jun*[2]

1 Naval Academy of Armament, Beijing 100161, China

2 Department of Naval Architecture Engineering, Naval University of Engineering, Wuhan 430033, China

Abstract: In order to evaluate the combat capability of surface warships while considering the impact of wind and waves, the impact on seagoing performance and weapon operation is analyzed, an evaluation index system for the combat capability evaluation of surface warships is determined, and an evaluation method is presented on the basis of the Analytic Hierarchy Process (AHP) and multi-attribute utility theory. Next, a typical example is used to validate the proposed method. It is found that the integrated combat capability of an evaluated destroyer in sea state 5 is approximate to 81.5% of that in calm water (sea state 0). The results show that the proposed method can quantitatively evaluate the actual combat capability of surface warships while considering the impact of wind and waves, which provides technical support for new ship demonstration and development.

Key words: combat capability evaluation; wind and waves; surface warship

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0 Introduction

Adaptability in wind and waves refers to the adaptability of surface warship platform to the natural environment such as wind and waves during navigation and implementing combat mission in the actual high sea states. Its advantages and disadvantages concern the indexes such as seagoing performance of warship, safety, survivability, combat effectiveness of shipborne weapon. Combat capability is a measure of the degree of completing a given combat mission by surface warships. It is the basic for planning, development, configuration and deploy, as well as the most important integrated index to evaluate the advantages and disadvantages of surface warships. In addition to the performance of shipborne weapon itself, surface warship's combat capability in wind and waves is also directly related to the adaptability of platform in wind and waves, and it is an important factor to measure the integrated combat capability of surface warship in the real sea environment. Therefore, research on the influence factors and relevance of adaptability in wind and waves on surface warship's combat capability, and further considering its impact on the combat capability evaluation, can more truly and objectively reflect the surface warship's actual combat capability, and provide technical support for the demonstration and design of project and analysis of combat operation, which plays an important role in improving the combat capability of surface warship in the actual sea environment [1-2].

At present, research on adaptability of surface warship in wind and waves in China is still in the initial stage. There are mainly the analytical method, the statistical method, the index method and computer simulation method of combat for the combat capability evaluation [3-4], but the in-depth research considering the impact of wind and waves has not been carried out in the combat capability evaluation. Therefore, the correlation research will be carried out on

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Author(s): ZHANG Heng (Corresponding author), male, born in 1981, Ph.D., engineer. Research interests: overall demonstration and overall performance of warship. E-mail: zhanghenghb@163.com

ZHU Jun, male, born in 1959, Ph.D., professor. Research interest: ship manoeuverability. E-mail: zhjun101@sina.com

the environmental adaptability and actual combat capability of surface warship in this paper, and evaluation method and evaluation model for the combat capability of surface warship were established considering wind and waves, which can be used for the evaluation of surface warship's actual combat capability, so as to provide technical support for the demonstration and development of surface warship type.

1 Influence of wind and waves on the combat operation of surface warships

1.1 Influence of wind and waves on the overall performance of warship platform

1) Rapidity. The maximum speed and endurance index are generally designed in accordance with the relatively calm wind and wave conditions below sea state 2, and when a warship navigates in the real sea environment, the effect of wind, wave and current will cause the maximum speed and endurance to be decreased or increased compared with the designed index value. Navigation against the wind or current will increase the resistance of the hull, reducing the maximum speed and endurance; and navigation following the wind and current will reduce the navigational resistance, increasing the maximum speed and endurance; in the meantime, too large pitching and heaving motions may cause emergence (racing) or water absorption of propeller, reducing the operating efficiency of propeller, as well as the maximum speed and endurance of the warships.

2) Maneuverability. The maneuvering parameters of surface warship are designed for the state of calm water, but the wind, waves and current in the actual sea environment will increase the difficulty maneuvering the warships. The sea environment has great influence on ship maneuvering, which is mainly reflected in three aspects: course keeping, maneuvering turning, and environment effect of crossing strong shear flow.

3) Seaworthiness. Seaworthiness mainly considers from the point of view of combat operation that the warships should have a certain capability of resistance to waves and ensuring ship operations at sea. Environmental effects of seaworthiness refer to changes of the technical parameters caused by the difference between the input sea state of warship design and actual sea states, which can make the warship sway enhance, and may also make the sway slow down. The platform's environmental adaptability to wind and waves directly affects the effectiveness of shipborne weapon equipment and working efficiency of the crew. When large sway motions occur in severe sea states, the general practice is to slow down the warship sway by reducing the speed or changing the course.

4) Stability. Surface warship stability is an important index of warship's navigation safety. The environmental effect has two aspects: one is the environmental effects of wind and wave resistance, that is, there are differences between the wind and wave conditions in actual navigation and design conditions, causing the increase or decrease of capsizing risk of warship due to wind and waves; the other is the phenomenon of abnormal increase of warship transverse sway due to the effect of waves, such as the parametric excitation rolling and broaching. Therefore, the stability environment effects of surface warship include pure loss of stability, anti-wind and wave capsizing effect, parametric excitation rolling and broaching.

1.2 Influence of wind and waves on shipborne weapon equipment

1) The impact on the radar systems. The waves make the radar antenna and the target sway in different degrees. The relative motion between the two will make the target deviate from the main axis of antenna beam, which reduces the directional coefficient of antenna, resulting in the shortened maximum operating range of radar. Meanwhile, the fluctuation of sea surface will produce a lot of sea clutter on the radar screen. The brightness of the sea clutter increases with the increase of the wind and waves. When the wind and waves are large, the clutter will appear in patches, which can cause the target echo to be submerged in a certain range.

2) The impact on the sonar system. The changes of static pressure of sea water caused by motion of the waves will interfere with the pressure-sensitive hydrophone. Because the change amplitude caused by the static pressure of sea water decreases rapidly with the increasing depth, noise generated in shallow water is the main noise source of low frequency of pressure-sensitive hydrophone. The noise produced by sea surface roughness is the noise source of high frequency of natural noise, and the natural noise level is directly related to the sea state.

3) The impact on missile weapons. The wind af-

fects the missile's range, causing missile yaw. When the wind is downwind, the missile airspeed becomes smaller, the corresponding air resistance decreases and the missile's range increases, when the wind is upwind, the missile range is reduced. The influence of waves is mainly the impact of wave height, wave direction, wave scale and phase on the exceeding water gesture of missile. Longitudinal waves affect the pitch attitude of a missile, whereas lateral waves cause the missile to yaw and affect its roll attitude.

4) The impact on torpedo weapons. A clear track of torpedo is formed on the sea surface due to the exhaust air escaping from the water in the navigation, so when the sea surface is calm, the torpedo track is more obvious and easier to be detected early. When the sea surface has white patches of sea spray, the torpedo tracks will blend with white sea spray, which will help to cover the torpedo tracks, difficult to be detected by enemy. The visibility of the sea surface directly affects the detection distance of torpedo.

5) The impact on naval mine weapons. The sea current has an effect of pressure on the anchored mine body, making the mine-mooring cable in inclined bending state downstream. The sea current can make the ground mine roll, and the sound from rolling can make the acoustic fuze of ground mine act until explode. Ground mine rolling may also change the action direction of mine fuze, so as to reduce the action distance of the naval mine, reducing the operation effects. Tide causes the periodic fluctuation of sea level. The bigger the tidal range, the greater the effect on the depth of mine. For non-trigger ground mine, its damage radius is a fixed value, therefore, change of tidal range caused by tide directly influences the damage radius on water surface.

6) The impact on shipborne helicopter. Downwind is the largest disadvantage for shipborne helicopter to take off, and beam wind has not much impact in general, but it cannot beyond a certain limit. If the warship's space is large, the helicopter can turn to be windward before taking off or at least to a more favorable direction. Turbulence is also a common interference factor affecting the take-off and landing of helicopters. Sometimes, although there is suitable deck wind, the helicopter cannot take off or land because of the presence of turbulence. The warship swaying and heaving caused by the wind and waves make the scheduled landing point of the helicopter in random motion. If there is no accurate guidance, it is very difficult for accurate landing of helicopter on warship.

2 Method for combat capability evaluation considering impact of wind and waves

2.1 Evaluation method based on AHP and multi-attribute utility theory

Method for combat capability evaluation considering wind and waves has the following characteristics: first, there are multiple subordinate indexes, including adaptability of seagoing performance, adaptability of weapon equipment operation and other attribute indexes. Secondly, there are many hierarchies of indexes. For example, the subordinate of combat capability includes indexes to anti-air, anti-surface and anti-submarine warfares. The indexes to anti-air, anti-surface and anti-submarine warfares also include subordinate indexes. Thirdly, the indexes are incommensurable, that is, the indexes do not have a unified dimension. For example, unit of speed is knot, and unit of endurance is nautical mile, which cannot be evaluated with a unified standard.

First of all, for the evaluation of this kind of multi-objective, multi-hierarchy and multi-attribute complex problems, we should follow the hierarchical decomposition to construct the index system, so as to ensure that the evaluation indexes include the main aspects of integrated performance and have feasibility.

Then, the integrated evaluation method is determined. One is to determine the measurement method of single index at the bottom level. For the indexes such as integrated performance, the pros and cons of the indexes at the bottom level are directly related to the combat operation. There is no fixed and standardized processing method, therefore, in combat operation, according to the different requirements of mission and operation demand, each index at the bottom can be quantified according to the utility function method, and the second is to determine the index weight. For this kind of multi-index and multi-hierarchy system, Analytic Hierarchy Process (AHP) is a valid method to determine the weights of the indexes, the third is the index integrated method. If the correlation between various layers of indexes is considered small, according to the multi-attribute utility theory, the total utility value can be obtained by weighting through the hierarchies. Therefore, AHP method and multi-attribute utility theory are combined to form an integrated evaluation method with mature theory, and the evaluation method and model are simple and easy to operate. The evaluation result is the total utility value, and the physical meaning is clear.

Therefore, in the integrated performance evaluation, the evaluation index system can be established first. Then, the integrated evaluation method and evaluation model based on AHP method and multi-attribute utility theory are adopted to evaluate the system comprehensively.

The combat capability evaluation considering the wind and waves is equal to the product of the combat capability evaluation without considering the influence of the wind and waves and the environmental adaptability effect.

2.2 Evaluation process

Combined with the advantages of multi-attribute utility theory and AHP method, the integrated evaluation process was established in the combat capability evaluation of surface warship considering the impact of wind and waves, as shown in Fig. 1.

Step 1: According to the hierarchical decomposition, the evaluation index system of combat capability and the index system of environmental adaptability effect were established.

Step 2: The value function of each bottom index of combat capability was established, and the environmental adaptability utility function was determined.

Step 3: The pairwise comparison method was used to determine the weight of each index.

Step 4: Each bottom index value and utility value of combat capability were analyzed and determined.

Step 5: Multi-attribute utility theory was used to calculate the total utility value of combat capability considering the influence of wind and waves.

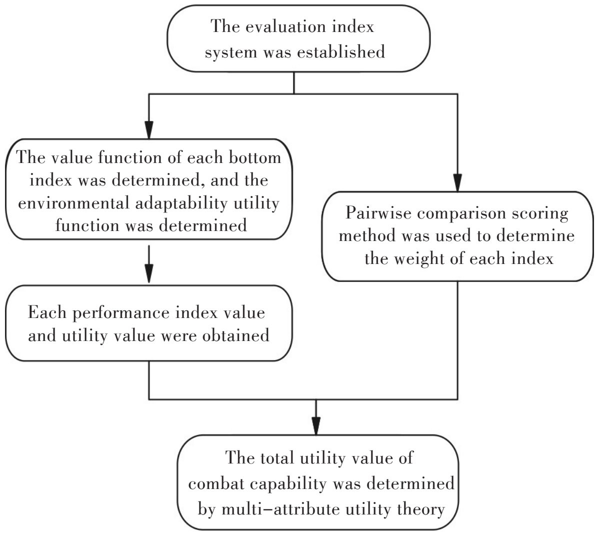

Fig.1 The evaluation process of integrated combat capability of warships

2.3 Index system of integrated combat capability evaluation considering wind and waves

The index system of integrated combat capability evaluation considering wind and waves includes the index system of integrated combat capability evaluation of surface warship (Fig. 2) and the adaptability index system of surface warship in wind and waves (Fig. 3).

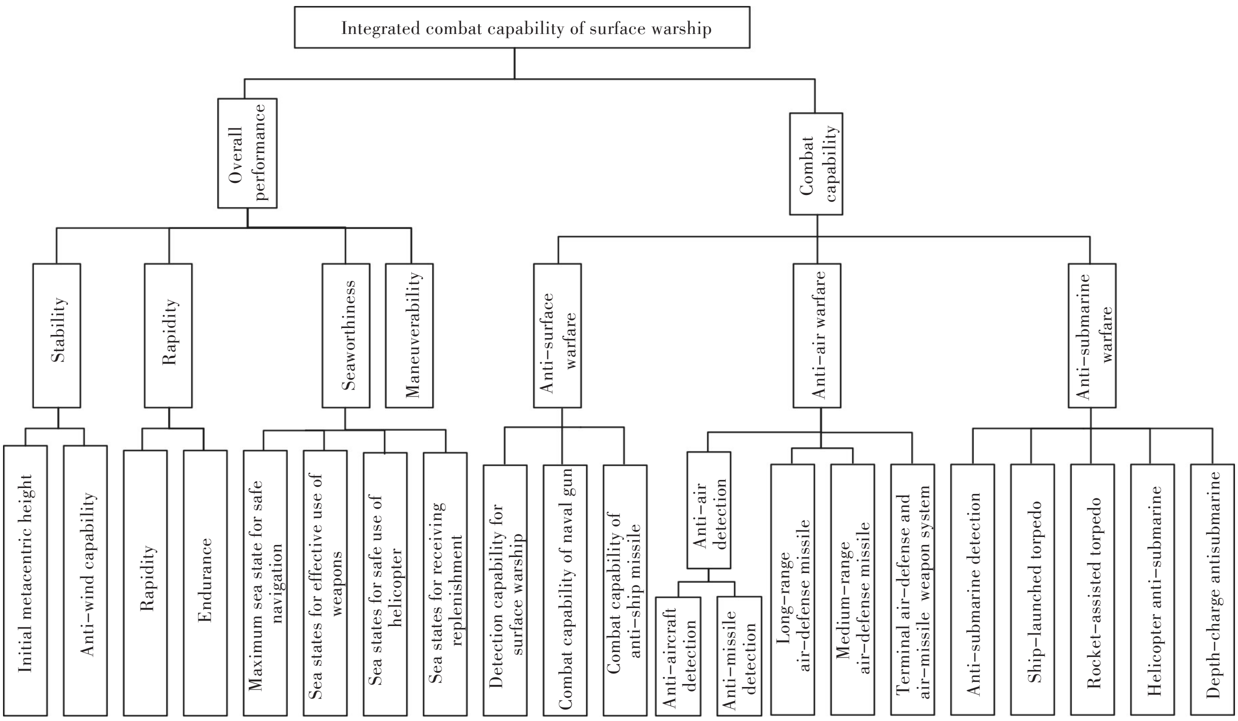

Fig.2 The index system of integrated combat capability evaluation

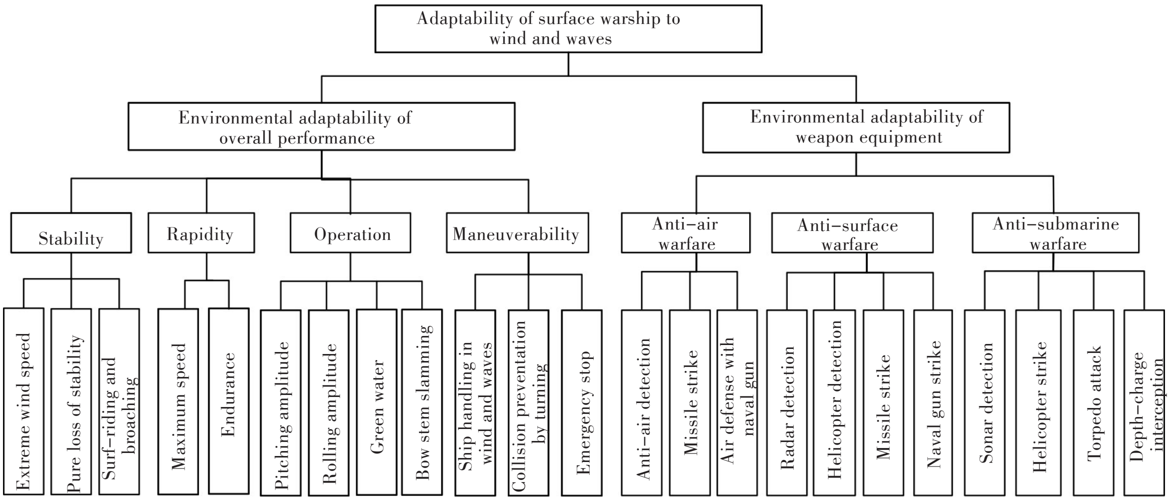

Fig.3 The index system for evaluating impact of wind and waves on integrated combat capability

2.3.1 Index system of integrated combat capability evaluation

The index system of integrated combat capability of surface warship includes the two parts of overall performance and combat capability: the former includes stability, rapidity, seaworthiness and maneuverability, the latter includes anti-surface combat capability, anti-air combat capability and anti-submarine combat capability.

2.3.2 Adaptability index system in wind and waves

The adaptability index system of warships in wind and waves consists of two environmental adaptability capabilities, i.e., environmental adaptability capability of the overall performance, and environmental adaptability of weapon equipment operation. The environmental adaptability of the overall performance is expressed according to stability, rapidity, operation and maneuverability, the environmental adaptability capability of weapon equipment operation refers to the difference of the tactical indexes between that in the real sea environment and that under the condition of testing (design), which is expressed according to environmental adaptability of the anti-air , anti-surface and anti-submarine warfares.

2.4 Method for integrated combat capability evaluation considering wind and waves

2.4.1 Method for integrated combat capability evaluation

1) Determination method for index weight .

According to the AHP method, the weights of the evaluation indexes were determined by pairwise comparison, and the relative importance of indexes was determined by pairwise comparison according to the nine-interval scale method, as shown in Table 1.

Table 1 Definitions of the nine interval scale

Scale	Definition
1	The row factor is as important as the column factor
3	The row factor is slightly more important than the column factor
5	The row factor is more important than the column factor
7	The row factor is much more important than the column factor
9	The row factor absolutely more important than the column factor
2,4,6,8	The median value of the two adjacent judgments
The reciprocal of the above scales	The judgment value comparing factors i with j is b_{ij} , then the judgment value comparing factors j with i is $1/b_{ij}$

The impacts of n elements of $x_1, x_2, \cdots, x_n$ on the standards were compared to determine their weights in the standards. Each time two elements of x_i and x_j were taken. a_{ij} is the ratio of the importance of x_i to that of x_j relative to the standards, and all the comparison results can be represented by the matrix $\boldsymbol{A}$

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

The matrix is the judgment matrix. The assignment a_{ij} in the judgment matrix represents the assignment of the importance of x_i relative to x_j . Each eigen value of the judgment matrix was calculated, where the eigenvector corresponding to the largest real eigenvalue was the relative weight, which generally would be normalized to obtain the final weight.

2) Establishment method of value function .

For the quantified indexes at the bottom, the value function method was adopted to determine the evaluation scores. The specific method is as follows: the value function of each quantified index is determined according to the main performance requirements in combat operation and relevant regulation of warship. First, the threshold value of each index was determined, that is, the minimum acceptable value meeting the operation requirements, and then the target value was determined, which was the ideal value or technical limit value. Then, the form of the value function was determined according to the combat operation requirement (which can be divided into linear type, S type, convex type and concave type). For curve shape function, after determining the threshold value, the target value and some intermediate points' score values, utility function was formed using the spline curve fitting [5-7]. For example:

The selection of the threshold value of the maximum speed was the basic value of main performance requirements in combat operation, which was 29 kn, corresponding to the utility value of 60. Considering the combat operation requirements and the current level of technology, the median value was 30 kn, and the corresponding utility value was 90. Considering the technical limit that the current ship form and power level can reach, or the maximum value of the same level of ship, the target value was taken as 32 kn, and the corresponding utility value was 100. The value function took the convex curve, and the value function curve was obtained by fitting the utility values under the determined typical speed, as shown in Fig. 4.

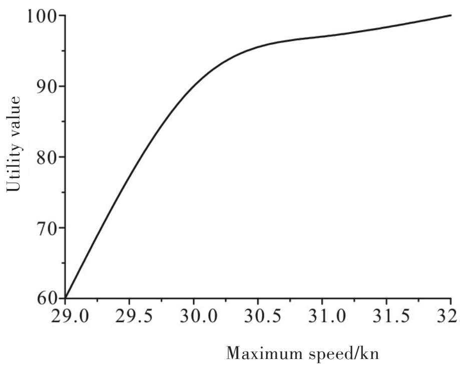

Fig.4 The value function of the maximum speed

2.4.2 Evaluation method for environmental adaptability effect

In the environmental adaptability evaluation system, the bottom indexes have their own dimensions. In order to transform the different dimensions into unified capability that can be evaluated, Multi-Attribute Utility Theory (MAUT) was used to transform the target attribute function into 0-1 capacity values in accordance with transfer function. Referring to GJB 4000-2000, the level of sea state (0-9 sea states) was regarded as the input condition of sea environment, and each adaptability attribute value was determined by Sigmoid function. The specific form of the S function (Fig. 5) is

$$S = 1 - \frac{1}{1 + e^{(A - B \times ST)}} \tag{1}$$

where ST is the sea state level, and the range is 0-9; A and B are constants and their values are shown in Table 2; S is the value of evaluation attribute.

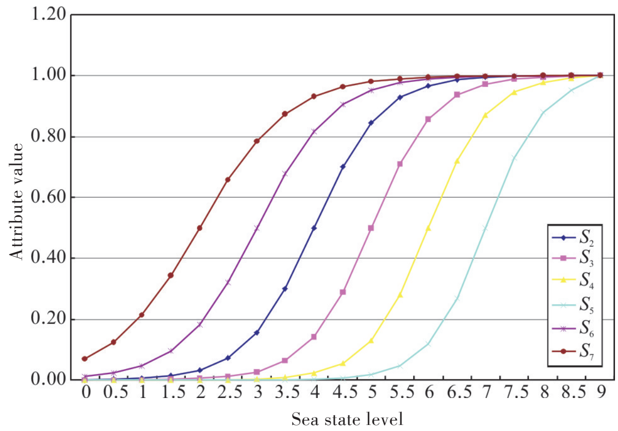

Fig.5 The S function

Table 2 The values of constant coefficient A and B in the S function

	Sea state level					
	2	3	4	5	6	7
Coefficients A	2.6	4.5	6.8	9	11.4	14
Coefficients B	1.3	1.5	1.7	1.8	1.9	2
Function	S_2	S_3	S_4	S_5	S_6	S_7

2.4.3 Method for integrated combat capability evaluation considering wind and waves

The calculation formula of integrated combat capability considering wind and waves is shown in Formula (2).

$$U(K) = \sum_{i=1}^{n} K_i U(x_i) \cdot R(x_i) \tag{2}$$

where K_i is the weight of i^{th} index x_i; $U(x_i)$ is the utility value of i^{th} index x_i; $R(x_i)$ is the environmental adaptability effect value of i^{th} index x_i.

3 Typical cases

Taking a foreign destroyer as an example, the combat capability evaluation considering wind and waves adaptability was carried out.

3.1 Index weight calculation

Firstly, the AHP method was used to determine the index weights of the index system of integrated combat capability evaluation and the index system of environmental adaptability evaluation shown in Figs. 2 and 3.

3.2 Calculation of utility value of integrated combat capability

According to the establishment method of value function, the value function of each index in the index system of integrated combat capability evaluation was established. For example, first, the forms of the value functions of the initial metacentric height and safe operation of helicopters were determined. Then, the threshold value, the target value and the intermediate value as well as the corresponding utility values were determined. Finally, the value function curves are fitted as shown in Figs. 6 and 7.

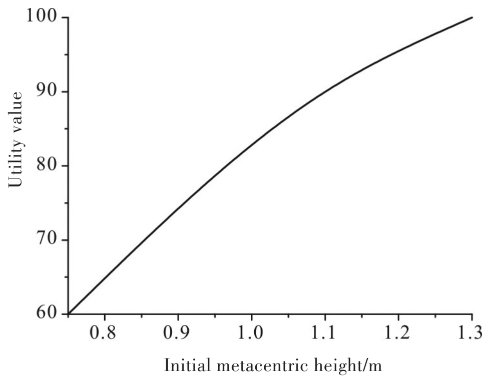

Fig.6 The value function of initial metacentric height

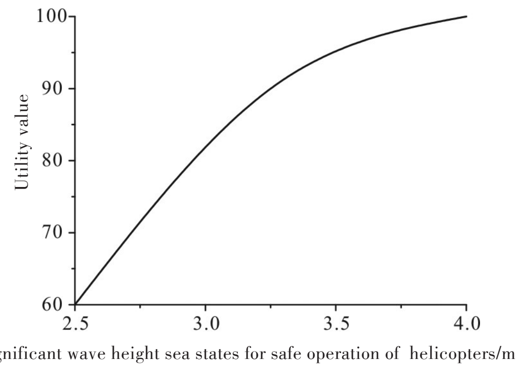

Fig.7 The value function of sea states for safe operation of helicopters

According to each bottom index value of integrated combat capability, the utility value of each index can be calculated according to the established value function, as shown in Table 3.

3.3 Environmental adaptability effect

1) Environmental adaptability effect of overall performance. According to Formula (1), the attribute values of environmental adaptability of overall performance in sea states 0–9 were obtained, as shown in Table 4.

Table 3 The utility values of indexes

Index item	Utility value	Index item	Utility value
Initial metacentric height (standard displacement)	80	Capability of anti-missile detection	60
Anti-wind capability (normal displacement)	100	Missile strike capability	80
Maximum speed (under full load displacement)	90	Capability of close-in anti-missile system	100
Endurance	47	Capability of anti-sea detection for radar	62
Maximum sea state for safe navigation (significant wave height)	60	Capability of anti-sea strike for missile	90
Sea state for effective operation of weapons (significant wave height)	90	Capability of anti-sea strike for naval gun	66.7
Sea state for safe operation of helicopter (significant wave height)	60	Sonar detection capability	60.6
Sea state for receiving replenishment(significant wave height)	80	Helicopter strike capability	100
Constant turning diameter (normal displacement and maximum speed)	60	Ship-launched torpedo capability	85
Capability of anti-aircraft detection	60	Rocket-assisted torpedo capability	45

2) Environmental adaptability effect of weapon equipment. According to Formula (1), the calculation results of attribute value of adaptability capability of weapon equipment operation in sea states 0–9 were obtained as shown in Table 5.

3) Combat capability evaluation of typical destroyer considering wind and waves. According to Formula (2), the calculation results of the combat capability in sea states 0–5 considering the impact of wind and waves were obtained as shown in Table 6.

Table 6 shows that, in sea state 5, the integrated combat capability of the warship was about 81.5% of that in calm water (sea state 0) considering wind and waves, and the quantitative evaluation results were consistent with the qualitative evaluation results of experts.

4 Conclusion

In the combat capability evaluation of surface warship in the past, integrated evaluation of the combat capability was carried out mainly according to the performance index of weapon system itself, but many performance indexes of surface warship platform and weapon system were proposed mainly for the applica-

Table 4 The environmental adaptability values of seagoing performance

Index	Sea state level									
	0	1	2	3	4	5	6	7	8	9
Extreme wind speed	1.000	1.000	1.000	1.000	0.998	0.982	0.881	0.500	0.119	0.000
Pure loss of stability	1.000	0.994	0.968	0.846	0.500	0.154	0.032	0.006	0.001	0.000
Surf-riding and broaching	1.000	0.994	0.968	0.846	0.500	0.154	0.032	0.006	0.001	0.000
Pitching amplitude	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Rolling amplitude	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Green water	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Bow stem slamming	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Ship handling in wind and waves	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Collision preventation by turning	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Emergency stop	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Maximum speed	1.000	0.994	0.968	0.846	0.500	0.154	0.032	0.006	0.001	0.000
Endurance	1.000	0.994	0.968	0.846	0.500	0.154	0.032	0.006	0.001	0.000

Table 5 The environmental adaptability values of weapons

Index	Sea state level									
	0	1	2	3	4	5	6	7	8	9
Anti-air detection	1.000	1.000	1.000	1.000	0.998	0.982	0.881	0.500	0.119	0.000
Anti-air missile strike	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Naval gun air defense	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Radar detection	1.000	1.000	1.000	1.000	0.998	0.982	0.881	0.500	0.119	0.000
Anti-surface missile strike	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Naval gun strike	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Sonar detection	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Helicopter strike	1.000	0.999	0.996	0.973	0.858	0.500	0.142	0.027	0.004	0.000
Torpedo attack	1.000	1.000	0.999	0.997	0.978	0.870	0.500	0.130	0.022	0.000
Depth-charge interception	1.000	1.000	1.000	1.000	0.998	0.982	0.881	0.500	0.119	0.000

Table 6 The computational results of integrated combat capability of the evaluated destroyer

	Sea state level					
	0	1	2	3	4	5
Integrated combat capability	74.29	74.23	73.95	72.78	68.80	60.57

tion in calm water and smaller sea states. Therefore, in the actual sea environment, especially navigating and using the weapon system in high sea, integrated combat capability of warships will be affected, and the actual combat capability cannot be fully reflected by the evaluation results of integrated combat capability based on performance index of platform and weapon system. In this paper, the impact of wind and waves on seagoing performance of platform and weapon system application was analyzed. Evaluation index systems of integrated combat capability and environmental adaptability were established. An integrated evaluation method was proposed based on AHP method and multi-attribute utility theory. Results for a foreign destroyer show that the established quantitative evaluation method is fairly scientific. In view of the complexity of the impact of wind and waves on the seagoing performance and weapon system of surface warship platforms, further research should be carried out on the influence function of environmental adaptability in wind and waves.

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计及风浪环境影响的水面舰船作战能力评估方法

张恒[1]，朱军[2]
1 海军装备研究院，北京 100161
2 海军工程大学 舰船工程系，湖北 武汉 430033

摘　要：[**目的**]为在水面舰船作战能力评估中计入海洋风浪环境影响，[**方法**]在分析风浪环境对水面舰船平台航行性能和武器系统使用影响的基础上，分别建立水面舰船综合作战能力评估指标体系和水面舰船风浪环境适应性评估指标体系，提出基于多属性效用理论和层次分析法（AHP）建立计及风浪环境影响的水面舰船作战能力综合评估方法，并选取国外某驱逐舰为典型算例进行验证。[**结果**]结果表明，在5级海况下计及风浪环境影响时该舰的综合作战能力约为静水中（0级海况）作战能力的81.5%，量化评估结果与专家定性评估结果趋势一致。[**结论**]该方法可以较合理地量化评估考虑风浪环境影响的水面舰船综合作战能力，为水面舰船型号论证与研制工作提供技术支持。

关键词：作战能力评估；风浪环境；水面舰船

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基于NURBS的球艏构型参数优化与分析

张文山，卢晓平，王中
海军工程大学 舰船工程系，湖北 武汉 430033

摘　要：[**目的**]设计优良的球艏构型能够改变船舶在水中航行时的船艏兴波，对阻力产生影响来改善整个船体的阻力性能，为此需对球艏构型参数进行优化。[**方法**]基于球艏参数化表达和NURBS理论，对母型球艏构型进行数据点网格生成和定义点反算，根据参数优化需要，利用优化算法对定义点进行优化调整后，给出优化船型球艏，并利用CFD软件进行仿真计算，与母型构型进行阻力和波形对比，将以球艏重心为代表的球艏参数阻力特征直接体现到构型优化结果中。[**结果**]结果表明，借助于NURBS曲线可有效将球艏参数优化特征体现出来，方法形象直观，可显著提高球艏构型表示和优化的效率。[**结论**]该方法简化了整个优化过程，并取得预期的减阻效果。

关键词：NURBS；兴波阻力；球艏构型参数；优化；CFD