Proceedings of the 2nd International Conference on Mathematical Physics and Computational Simulation
DOI: 10.54254/2753-8818/42/20240650

Assessment of influencing factors on the flight performance of J-series fighter jets based on the entropy weight-TOPSIS model

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Abstract. To enhance the scientific approach to fighter jet design and improve performance in areas such as supersonic cruise, long-range strike, and high maneuverability, this paper first collects, organizes, and thoroughly analyzes relevant data on factors affecting the flight performance of existing J-series fighter jets, including indicators such as engine thrust, aspect ratio, root-to-tip ratio, and wing shape. Using the entropy weight-TOPSIS evaluation analysis model, the performance factors influencing J-series fighter jets are quantitatively analyzed and ranked, avoiding subjective assumptions. Ultimately, the flight performance scores of eight J-series fighter jets under ten influencing factors are obtained. The results show that the top four scoring fighter jets are J-31 > J-20 > J-10 > J-15. This outcome provides directional guidance for the future development of fighter jets, indicating that by selecting appropriate engines, root-to-tip ratios, aspect ratios, and tail fin types, fighter jets can achieve better flight performance. This has significant implications for enhancing national defense capabilities, promoting military technological progress, and fostering economic development.

Keywords: J-series aircraft, entropy weight, TOPSIS, evaluation.

1. Introduction

With the rapid advancement of global military technology, countries are striving to enhance their military capabilities. As an indispensable key equipment in modern warfare, the performance enhancement of fighter jets is of great significance to national security and military strategy. Among many fighter jets, the J-series jets are the main equipment of the Chinese Air Force. By thoroughly studying the factors influencing flight performance, targeted improvements can be made in fighter jet design, enhancing supersonic cruise, long-range strike, and high maneuverability, thus boosting the combat effectiveness of the Chinese Air Force, advancing Chinese fighter jet technology, strengthening national defense, and promoting economic development. Therefore, it is particularly important to analyze the factors affecting the performance of J-series fighter jets using scientific and effective methods.

Bao-rui Fang's discussion on the importance of wing design in aerodynamic layout design in "Aircraft Aerodynamic Layout Design" concludes that wing design is a critical factor influencing an aircraft's aerodynamic layout, thereby affecting flight performance[1]. The "Military Enthusiast World"

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article "Why Does the J-10 Fighter Jet Have a Pair of Canards" analyzes the J-10's force, showing that its canards and main wings work together to generate lift, improving flight performance and enhancing maneuverability[2]. Wencong Song et al. in "Research on the Aerodynamic Layout of a Small Aspect Ratio High Lift Aircraft" point out the core design principles of the J-20, adopting a small aspect ratio lifting body layout, using leading-edge extensions to enhance the canard layout, and employing small-area twin outward-canted full-moving vertical tails. This explains the J-20's excellent supersonic drag characteristics, high angle-of-attack lift characteristics, high angle-of-attack stability and control, and good stealth characteristics[3].

2. Data Collection and Analysis

To study the factors influencing the flight performance of J-series fighter jets and derive improvement directions for future fighter jets, the following aspects of several current Chinese J-series fighter jets were analyzed: engine thrust, aspect ratio, root-to-tip ratio, wing position, wing shape, aerodynamic layout, combat radius, tail fin type, thrust-to-weight ratio[4], and engine type.

By consulting relevant literature and using Microsoft Excel 2016 for data organization, the data presented in Table 1 were finally obtained:

Table 1. Ten Parameters of Eight J-Series Fighter Jets

	Engine thrust(KN)	Wing spanning ratio	Wing tip-root ratio	Wing position	Wing shape	Aerodynamic layout	Combat radius (kilometers)	Pndant tail	Engine thrust-to-weight ratio	Engine type
J-5	33.8	3.7	1.9	center wing (2)	rectangular wing (3)	General Layout (1)	425	single-leafed (1)	4.4	turbojet (1)
J-7	57.5	3.1	5.4	top wing (1)	triangle wing (2)	General Layout (1)	1759	single-leafed (1)	5.0	turbojet (1)
J-8	137.4	2.1	11.0	center wing (2)	triangle wing (2)	General Layout (1)	800	single-leafed (1)	7.5	turbofan (2)
J-10	145.15	2.9	10.7	center wing (2)	triangle wing (2)	Duck Layout (2)	1600	single-leafed (1)	7.9	turbofan (2)
J-11	245	3.5	2.1	center wing (2)	trapezoidal wing (1)	General Layout (1)	1500	double pendant tail (2)	6.4	turbofan (2)
J-15	264	3.6	3.2	top wing (1)	trapezoidal wing (1)	Duck Layout (2)	1200	double cambered drogue (3)	8.5	turbofan (2)
J-20	278	2.2	4.8	top wing (1)	trapezoidal wing (1)	Duck Layout (2)	2000	double cambered drogue (3)	9.0	turbofan (2)
J-31	204	3.3	7.6	center wing (2)	trapezoidal wing (1)	General Layout (1)	1350	double cambered drogue (3)	7.9	turbofan (2)

Note: In the table, (1), (2), and (3) represent different levels of evaluation for the influencing factors.

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3. Model Establishment

3.1. Establishment of the Entropy Weight-TOPSIS Aircraft Evaluation Model

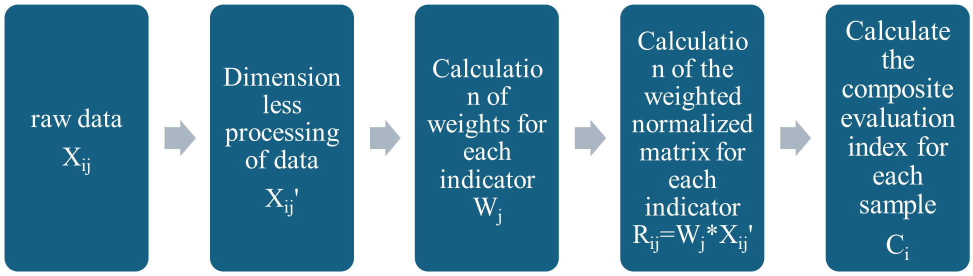

Figure 1. Process of Establishing the Entropy Weight-TOPSIS Evaluation Model

1) Establish a Comprehensive Performance Evaluation Index System

Using eight J-series fighter jets (n) as feasible options and ten influencing factors as target variables, the original matrix $R=[X_{ij}]_{n\times m}$ is constructed.

2) Determine the Weight of Each Indicator Using the Entropy Weight Method

The entropy weight method is a weight determination method based on the principle of information entropy. Its core lies in measuring the degree of variation in the information contained in each indicator, i.e., the information entropy, to calculate the entropy weight of each indicator. These entropy weights are then used to adjust and optimize the initially set indicator weights to achieve objectivity. In this process, the original data matrix $R=[X_{ij}]_{n\times m}$ is first dimensionless, resulting in a standardized matrix X'. Subsequently, based on the calculation principles of the entropy weight method, the final weights W_j of each indicator are determined.

$$X_{ij}' = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)}, j = 1,2,\dots,m$$

$$p_{ij} = \frac{X_{ij}'}{\sum_{i=1}^{n} X_{ij}'}$$

$$E_j = -\ln(n)^{-1} \sum_{i=1}^{n} p_{ij} \ln(p_{ij})$$

$$W_j = \frac{1 - E_j}{m - \sum E_j}$$

In the formula: p_{ij} is the proportion of the i-th evaluation object under the j-th indicator; E_j is the entropy value of the j-th indicator.

3) Benefit Evaluation and Screening of Influencing Factors of Flight Performance

Using the TOPSIS Method The basic idea of the TOPSIS method is to construct a decision-making framework by defining the ideal solution (optimal solution) and the negative ideal solution (worst solution) to evaluate a series of feasible options. Among these options, the one closest to the ideal solution and farthest from the negative ideal solution is sought, thus achieving the selection of the best option. First, the original data matrix $R=[X_{ij}]_{n\times m}$ is normalized to obtain the standardized matrix $R=[R_{ij}]_{n\times m}$. Subsequently, the weights calculated by the entropy weight method are used to weight the matrix B, forming a weighted matrix Z. Then, the Euclidean distances S_i^* and S_i^- between each option's target value and the ideal solution are calculated. Based on these distance values, the relative closeness C_i^* of each option is calculated, reflecting the proximity of the option to the ideal solution. Finally, the options are ranked based on the relative closeness to provide decision-makers with a basis for decision-making[5].

$$R_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X^2}}, j = 1,2,\dots,m$$

$$z_{ij} = W_j R_{ij}$$

$$S_i^* = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_j^*)^2}, i = 1,2,\dots,n$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_j^-)^2}, i = 1,2,\dots,n$$

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-}$$

3.2. Solving Weights Using the Entropy Weight Method

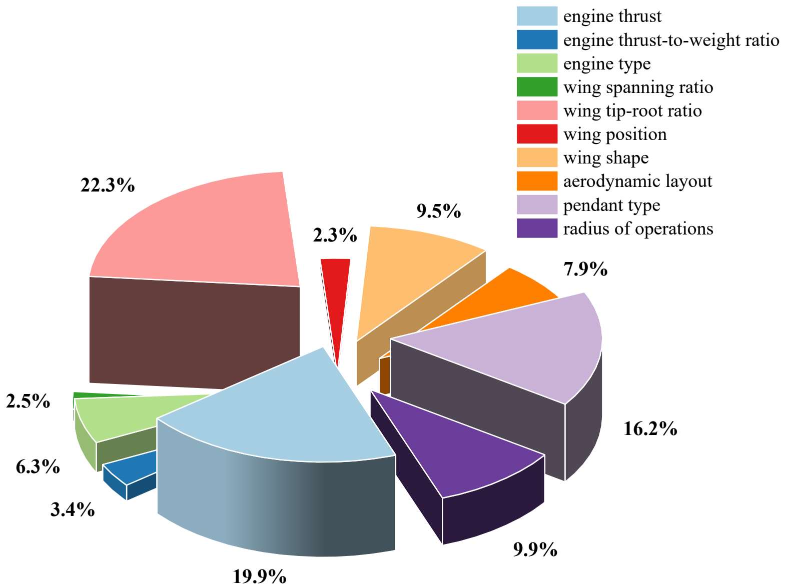

Figure 2. Solving the Weights of Ten Influencing Factors on Flight Performance Using the Entropy Weight Method

From the analysis of Figure 2, it can be seen that among the ten influencing factors, the root-to-tip ratio of the wing has the greatest impact on the flight performance of J-series fighter jets. The influence of the root-to-tip ratio on the flight performance of aircraft is reflected in multiple dimensions such as aerodynamic performance, structural strength, and control performance, which holds significant academic value. Specifically, the root-to-tip ratio directly determines the lift and drag distribution characteristics of the fighter jet. By optimizing the root-to-tip ratio in design, the cruising speed and economy of the fighter jet can be effectively improved, and its short takeoff and landing capabilities and overall flight stability can be significantly enhanced. Additionally, as the primary load-bearing structure of a fighter jet, the design of the wing's root-to-tip ratio is directly related to the structural strength of the wing. A reasonable root-to-tip ratio ensures that the wing maintains sufficient strength and rigidity under various flight load conditions, effectively avoiding potential structural damage and fracture risks. Furthermore, an appropriate root-to-tip ratio design also helps to improve the flexibility of the wing, thereby enhancing the maneuverability and controllability of the fighter jet, resulting in better stability during high-speed flight. These academic analyses hold important theoretical guidance and practical application value in the field of aircraft design.

Secondly, the engine thrust. In the field of aerospace engineering, engine thrust has a significant direct impact on various key performance indicators of aircraft. These performance indicators include the aircraft's acceleration capability, climb performance, maximum flight speed, and maneuverability. Specifically, when the engine thrust is sufficiently strong, the aircraft can achieve higher climb altitudes in a shorter period, which is particularly important for J-series fighter jets during high-altitude reconnaissance, strikes, or evasion of ground-based anti-aircraft fire. Moreover, during aerial combat or emergency maneuvers, strong thrust ensures that the aircraft can quickly adjust its flight state, such as making rapid turns, diving attacks, or emergency pull-ups, thereby greatly enhancing the combat effectiveness and survivability of the fighter jet in adverse environments[6].

Third is the tail fin type. One of the main functions of the tail fin is to provide aircraft stability and controllability. Different tail fin designs directly impact the stability and controllability of the aircraft. For example, twin vertical tails can achieve sufficient yaw stability and control during supersonic flight[7], which significantly affects the performance of fighter jets, giving J-series fighter jets better maneuverability and flexibility. This is also crucial for the survival and combat capability of modern fighter jets in air combat.

Fourth is the combat radius of the fighter jet. The combat radius is a core parameter for evaluating the mission execution capability of a fighter jet. This parameter directly defines the effective combat range that a fighter jet can cover. Its value significantly impacts the tactical mobility of J-series fighter jets. Specifically, fighter jets with a larger combat radius have greater freedom in selecting takeoff and landing airfields and combat routes, effectively avoiding the threat of enemy air defense systems. Additionally, a larger combat radius means that the fighter jet has higher autonomy and independence during missions, reducing reliance on aerial refueling. Under the same conditions, a fighter jet with a larger combat radius can cover a broader combat area, providing richer and more flexible operational choices.

Following are the wing shape, aerodynamic layout, engine type, engine thrust-to-weight ratio, wing aspect ratio, and wing position. Regarding wing shape, different wings affect the lift and drag characteristics of fighter jets. In the J-series, there are no short and thick wings, mostly flat and raised wings (such as delta wings), which are easier to maintain high-speed flight. Regarding aerodynamic layout, it largely determines the flight performance of fighter jets. For example, the canard layout, compared to the conventional layout, can generate vortices on the upper surface of the main wing after airflow passes, increasing the pressure difference between the upper and lower wing surfaces, thereby improving total lift; it also improves control and maneuverability during high-angle-of-attack maneuvers, enhancing combat performance.

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4. Results Analysis

4.1. Final Scores of the Eight J-Series Fighter Jets

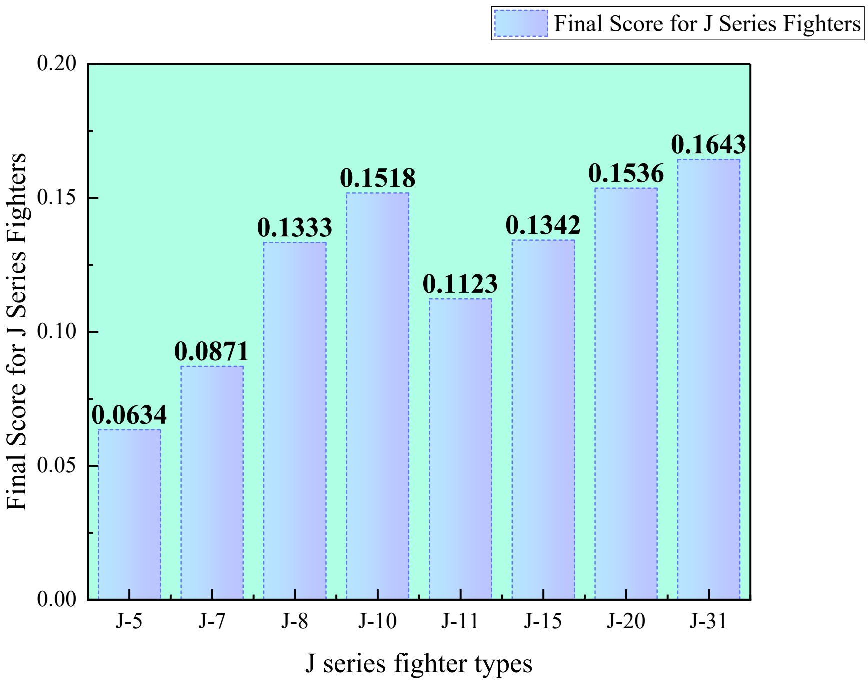

Figure 3. Final Scores of the Eight J-Series Fighter Jets

From the comprehensive analysis of Figure 3, the ranking of the eight J-series fighter jets is as follows: J-31 > J-20 > J-10 > J-15 > J-8 > J-11 > J-7 > J-5, with scores of 0.1643, 0.1536, 0.1518, 0.1342, 0.1333, 0.1123, 0.0871, and 0.0634 respectively. The fighter jet with the best overall flight performance is the J-31, followed by the J-20, J-10, and J-15.

Each generation of these jets has undergone a series of improvements and optimizations based on its predecessors.

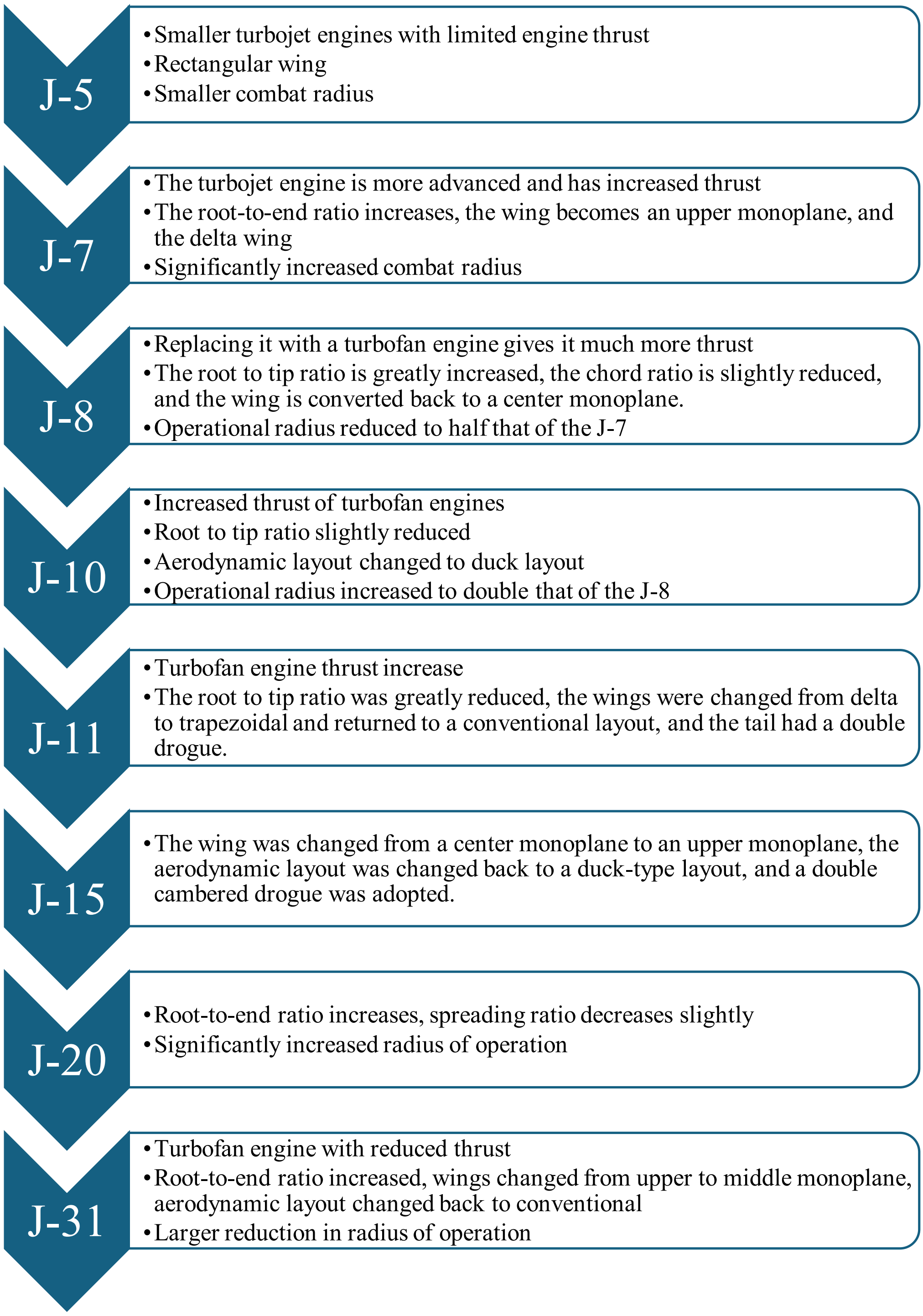

Figure 4. Improvements from J-5 to J-31

As the main equipment of the Chinese Air Force, the enhancement of flight performance in J-series fighter jets directly relates to the improvement of combat capabilities. By analyzing the flight performance of the J-series fighter jets, we can identify their strengths and weaknesses, which allows for targeted improvements and upgrades. Understanding these pros and cons helps to define the future

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direction of fighter jet development, aiming to design aircraft that better meet the needs of modern warfare.

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5. Conclusion

This study shows that among engine thrust, wing aspect ratio, wing root-to-tip ratio, wing position, wing shape, aerodynamic layout, combat radius, tail fin type, engine thrust-to-weight ratio, and engine type, the influencing factors are ranked in descending order of impact weight as follows: wing root-to-tip ratio > engine thrust > combat radius > tail fin type > wing shape > aerodynamic layout > engine type > engine thrust-to-weight ratio > wing aspect ratio > wing position. According to the comprehensive evaluation using the entropy weight-TOPSIS method, the top four fighter jets are ranked as J-31 > J-20 > J-10 > J-15[9]. Thus, in the future, by meeting aerodynamic requirements, structural integrity and minimum weight requirements, maintenance requirements, process requirements, and economic requirements, the selection of appropriate engines, root-to-tip ratios, and tail fin types can enable fighter jets to achieve better flight performance.

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