Air Combat Command and Guidance Situation Assessment Based on Attack Area

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Abstract. Aiming at the problem that the situation function in traditional air combat command and guidance situation assessment lacks comprehensive consideration of advantages and threats, an air combat command and guidance situation assessment method based on attack area is proposed. In this method, combined with a certain type of air-to-air missile attack area, aiming at the comprehensive situation of advantages and threats, the best angle, distance, speed and height are proposed, a new situation function is constructed, and the air combat command and guidance situation evaluation model is improved. Through case analysis and comparison with traditional methods, the accuracy and effectiveness of the method are verified.

1. Introduction
With the progress of science and technology, military equipment will certainly develop towards unmanned and intelligent direction[1]. However, the ground command post has incomparable information advantages, computing advantages, data fusion and processing capabilities than airborne equipment, and the information carrying capacity of flight personnel is limited, so command and guidance still plays an irreplaceable role in air combat. Air-to-air missile is the final resting point of air combat damage. Studying the ballistic characteristics of air-to-air missile is of great significance to the hit probability of air combat. Accurately mastering the ballistic characteristics of air-to-air missiles is of great significance for accurate prediction, early decision-making and winning time for the rapidly changing battlefield environment[2]. Based on the study of an air-to-air missile attack area, this paper improves the traditional situation function to make the results more realistic, which has certain positive significance for improving the level of air combat command and guidance situation assessment.

2. Air-to-air Missile Attack Area
Air-to-air missile attack zone refers to the space range that the missile can hit under certain launch conditions. It is related to our air-to-air missile's launch inclination, initial velocity, launch altitude, missile entry angle, enemy target's position, heading and velocity characteristics, as well as mid-course guidance, terminal guidance, seeker search and capture, fuze characteristics, etc. Document [3] describes the attack area mathematical model as:

$$\begin{align*}
D_{\text{max}} &= f(h, h_z, v_z, n_z, q) \\
D_{\text{min}} &= f(h, h_z, v_z, n_z, q)
\end{align*}$$

(1)
Where: $D_{M_{\text{max}}}$ is the far boundary of the missile attack area and $D_{M_{\text{min}}}$ is the near boundary of the missile attack area; $h$ is the carrier altitude, $h_m$ is the target altitude; $v$ is the carrier speed and $v_m$ is the target speed; $n_y$ is target maneuver overload; $q$ is the entrance angle.

Among them, the theoretical attack range of the missile centered on the carrier is shown in Fig 1.

![Figure 1. Air-to-air missile attack area theoretical attack area range](image1)

**Figure 1.** Air-to-air missile attack area theoretical attack area range

In the figure, $D_{M_{\text{max}}}$ and $D_{M_{\text{min}}}$ represent the far and near bounds of the missile's theoretical attack.

At the same time, the factors that affect the attack area are\[^1\]: relative altitude ($H$), relative velocity ($\dot{D}$), target azimuth ($\varphi$), and missile initial velocity ($V$). $\dot{D}$ is expressed as:

$$\dot{D} = V_w \cos \varphi - V_m \cos q$$  \(2\)
The laboratory team conducted a systematic study on the trajectory simulation and attack area calculation model of a certain type of air-to-air missile in the early stage. The actual attack area of this type of missile centering on the target is calculated as shown in fig. 2.

3. Command and Guidance Situation Index Based on Missile Attack Area

3.1 Angle Situation Function

The angle situation is mainly determined by the target azimuth angle $\varphi$ and the entry angle $q$. Combined with the actual command and guidance, firstly, the target is located in the detection angle of our radar through guidance, and secondly, the target is ensured to be located in the off-axis launching angle of our air-to-air missile, so as to achieve the first enemy attack. In over-the-horizon air combat, the selection of command and guidance strategy usually focuses on head-to-head and oblique head-to-head attacks. Through simulation, it is found that the smaller the $|q|$ value, the larger the missile attack area and the larger the angle situation. The larger $|q|$, the larger the missile attack area and the larger the angle situation.

However, most literatures only consider their own advantages and ignore the threat of targets. In modern air combat, the greater the advantages, the greater the threat they will suffer. Therefore, based on the unified consideration of advantages and threats, this paper takes radar detection angle, missile launch angle and non-escape angle as important indicators for evaluating advantages and disadvantages, and constructs an angle situation function, as shown in formula 3, wherein the larger the situation value, the better for us.

\[
S_A \begin{cases}
0.9 - 0.1e^{\frac{(\theta_1 - \theta_{\text{max}}) - (\theta_2 - \theta_{\text{max}})}{20}} & 0 \leq \varphi < \varphi_{\text{MK max}}, \theta_{\text{max}} \leq \varphi \\
0.8 - 0.15e^{\frac{(\theta_1 - \theta_{\text{max}}) - (\theta_2 - \theta_{\text{max}})}{20}} & \varphi < \varphi_1, \theta_1 \leq \varphi < \varphi_2, \\
0.65 - 0.15e^{\frac{(\theta_1 - \theta_{\text{max}}) - (\theta_2 - \theta_{\text{max}})}{20}} & \varphi < \varphi_1, \theta_1 \leq \varphi < \varphi_2, \\
0.5 - 0.1e^{\frac{(\theta_1 - \theta_{\text{max}}) - (\theta_2 - \theta_{\text{max}})}{20}} & \varphi < \varphi_{\text{MK max}}, \theta_{\text{max}} \leq \varphi < \varphi_{\text{MK max}}, \theta_{\text{max}} \leq \varphi, \theta_{\text{max}} \leq \varphi \\
0.35 + 0.15e^{\frac{(\theta_1 - \theta_{\text{max}}) - (\theta_2 - \theta_{\text{max}})}{20}} & \varphi < \varphi_1, \theta_1 \leq \varphi < \varphi_2, \\
0.2 + 0.15e^{\frac{(\theta_1 - \theta_{\text{max}}) - (\theta_2 - \theta_{\text{max}})}{20}} & \varphi < \varphi_1, \theta_1 \leq \varphi < \varphi_2, \\
0.1 + 0.1e^{\frac{(\theta_1 - \theta_{\text{max}}) - (\theta_2 - \theta_{\text{max}})}{20}} & \varphi_{\text{MK max}} \leq \varphi, 0 \leq \varphi < \theta_{\text{MK max}}
\end{cases}
\]
Type 3: $\theta_{\text{max}}(\varphi_{\text{max}})$ is the enemy (Friend) radar search azimuth angle, $\theta_{\text{Mmax}}(\varphi_{\text{Mmax}})$ is the maximum off-axis launch angle of the enemy (Friend) air-to-air missile, and $\theta_{\text{MKmax}}(\varphi_{\text{MKmax}})$ is the maximum deflection angle of the enemy (Friend) air-to-air missile's non-escape zone.

The simulation results of angle situation function in Matlab are shown in fig. 3.

![Angle situation function simulation diagram](image1)

**Figure 3.** Simulation diagram of angle advantage

As can be seen from fig. 3, when the target heading angle is constant and the target azimuth angle $\varphi = 0^\circ$ (i.e. the nose of our aircraft points to the target), the angle situation is the best. Similarly, when the target azimuth angle is fixed and the target heading angle $\theta = 0^\circ (q = 180^\circ)$ (the nose of the target plane points to our plane), the threat to one's own side is the greatest, that is, the angle situation is the worst. However, if the two planes are attacking each other head-on, the two sides have equal advantages and disadvantages in terms of angle. At this time, the one with superior equipment performance will occupy more favorable positions. The purpose of command and guidance is to guide our planes to occupy absolute advantages.

3.2 Distance Situation Function

The distance situation is reflected in the relationship between the relative distance $D$ between the enemy and the enemy, the missile kill distance and the radar detection distance: the smaller $D$, the greater the probability that our aircraft will find and kill enemy aircraft, and the greater the threat from enemy aircraft. Similarly, the distance situation (taking our aircraft's performance superior to that of enemy aircraft as an example) is divided as shown in Table 1.
### Table 1. Division of distance advantage and its corresponding relationship

| Good and bad relations | Distance relation | describe |
|------------------------|-------------------|----------|
| Absolute posture       | $D_{MK,\text{max}} < D \leq D_{WK,\text{max}}$ | The target is located within the non-escape boundary of our aircraft, and our aircraft is located outside the non-escape boundary of the target. |
| Obvious dominance      | $D_{MK,\text{max}} < D \leq D_{MK,\text{max}}$ | The target is located within the boundary of our attack area, and our aircraft is located outside the boundary of our attack area. |
| Slightly superior      | $D_{MK,\text{max}} < D$ | Our plane is located outside the target radar detection range. |
| Obvious disadvantage   | $D_{MK,\text{min}} \leq D < D_{MK,\text{min}}$ | Our plane is located within the non-escape boundary of the target, and the target is located outside the non-escape boundary of our plane. |
| Slight disadvantage    | $D_{MK,\text{min}} < D \leq D_{MK,\text{min}}$ | Our plane is located within the boundary of the target attack area and the target is located outside the boundary of our attack area. |
|                        | $D_{MK,\text{min}} \leq D \leq D_{MK,\text{min}}$ | Both the enemy and ourselves are within the non-escape boundary of each other's missiles. Both the enemy and ourselves are within the boundaries of the other's attack area. Both sides are within the radar detection range of the other side. |

At the same time, considering the influence of carrier height on the range of air-to-air missiles, the influence coefficient $m = \frac{H - 6500}{6500}$ is introduced. The construction distance situation function is shown in equation 4, wherein the larger the situation value, the better for our machine.

Where: $D_{\text{max}}$ is the maximum radar detection distance, $D_{MK,\text{max}}$ and $D_{MK,\text{min}}$ are the far and near bounds of the missile attack area, $D_{MK,\text{max}}$ and $D_{MK,\text{min}}$ are the far and near bounds of the inescapable area. The simulation results of distance situation function in Matlab are shown in fig. 4. As can be seen from fig. 4, the distance situation function established in this paper is different from that in previous air combat situation assessments. the closer the distance, the greater the advantage. However, considering the threat the target poses to me, the corresponding situation values are expressed at different distances. The optimal distance situation of our aircraft is concentrated in [30km, 40km] and [60km, 70km] in the figure. At the same time, as the distance between the two planes increases, both sides cannot form favorable attacks outside the radar detection range, and the distance situation tends to be equal.

#### 3.3 Velocity Situation Function

Literature [5-6] believes that the greater the speed, the greater the advantage. However, from the perspective of command and guidance, the higher the speed, the shorter the attack occupation time and the shorter the "follow-up shooting" time, the lower the hit rate. Based on this, the best air combat
speed $V_{\text{max}}$ is introduced, and $S_V = 1$ at $V_W = V_{\text{max}}$ is specified, with other conditions $S_V \leq 1$. $V_{\text{max}}$ is affected by the relative distance between the two planes: $V_{\text{max}}$ is large when the distance is far, which is convenient to pick up the enemy quickly; $V_{\text{max}}$ is small when the distance is close, which is convenient for occupying and shooting. The situation function of Design Speed is shown in Equation (5)(6):

$$S_V = \begin{cases} 
\frac{V_W - V_{\text{max}}}{V_{\text{max}}}, & V_{\text{max}} < V_W \\
1.5V_M < V_W \leq V_{\text{max}} \\
-0.5 + \frac{V_W}{V_T}, 0.6V_W < V_W \leq 1.5V_M \\
0.1V_W \leq 0.6V_W 
\end{cases}$$  \hspace{1cm} (5)  

$$S_V = \begin{cases} 
\frac{V_W - V_{\text{max}}}{V_{\text{max}}}, & V_W \leq V_{\text{max}} \leq V_W \\
3 \left( \frac{V_W}{V_{\text{max}}} + \frac{V_{\text{max}}}{V_W} \right) - 0.6V_W < V_W \leq 1.5V_M \\
0.1V_W \leq 0.6V_W 
\end{cases}$$  \hspace{1cm} (6)$$

Where: $V_W$ is the speed of our machine; $V_M$ is the target speed.

The simulation results of velocity situation function in Matlab are shown in fig. 5.

**Figure 5.** Speed advantage simulation diagram

**Figure 6.** Height advantage simulation diagram

As can be seen from fig. 5, within a certain range ($V_W \leq V_{\text{max}}$), the speed situation is directly proportional to the speed of our machine, but when $V_W > V_{\text{max}}$, the speed situation decreases with the increase of speed. The higher the speed of the target, the smaller the speed situation of our aircraft, which also shows the speed relationship between the enemy and ourselves in air combat: the speed of the target is higher than that of our aircraft, which is beneficial for the target to attack/evade our aircraft.

### 3.4 Height Situation Function

Previous studies have shown that the higher the altitude, the larger the missile kill zone, and the greater the advantage from the attack point of view. However, too high a flight altitude will not only affect the carrier's own performance, but also affect the air-to-air missile's own performance. And the height difference with the target is too large, which will cause the missile to greatly increase its maneuver in the vertical plane when attacking the target, thus affecting the hit rate of the missile. Based on the above analysis, not the higher the altitude, the more obvious the advantage, so the best air combat altitude $H_{\text{max}}$ is introduced.

Construct the altitude situation function, as shown in equation (7):
In formula (7): $H_W$ is the height of our machine; $H_M$ is the altitude of enemy planes.

The simulation results of altitude situation function in MATLAB are shown in fig. 6.

As can be seen from fig. 6, when the target height is constant, the higher the aircraft height is within a certain range ($H_M \leq H_{\max}$), the better the situation is. At $H_M > H_{\max}$, the situation becomes worse with the increase of height. At the same time, the higher the target altitude, the worse the situation.

3.5 Air Combat Capability Index

Air combat capability assessment is an important component of command and guidance effectiveness assessment. The main research methods can be divided into three categories [7]: parameter calculation method, probability analysis method and requirement assessment method. Among them, the parameter calculation method is the most commonly used method for air combat capability evaluation, and the most typical methods are mainly logarithmic method and comprehensive index model.

Among them, the logarithmic method has weight determination, influencing factors and their correlations, so the comprehensive index method is selected in this paper.

The comprehensive index model is:

$$E = \omega_1 \left( \omega_{F_1} E_F^S + \omega_{F_2} E_F^M \right) E_C + \omega_{SA} E_{SA} + \omega_{F_1} E_F + \omega_{CM} E_{CM}. \quad (8)$$

In formula (8): $E_F^S$, $E_F^M$, $E_C$, $E_{SA}$, $E_{SA}$, $E_F$, $E_{CM}$ respectively represent the aircraft's stable flight performance, maneuvering flight performance, operational performance, situational awareness capability, fire performance, survivability and electronic countermeasures capability; $\omega_1$, $\omega_2$, $\omega_3$, $\omega_{F_1}$, $\omega_{F_2}$ respectively represent corresponding weight coefficients.

3.6 Air Combat Command and Guidance Situation Assessment Model

Integrated command and guidance situation index and fighter air combat capability index, both of which are indispensable influencing factors for establishing a command and guidance situation assessment model. Considering that the missile attack area is an arc-shaped killing range formed by off-axis launching angle (angle) and attack far boundary (distance), both are equally indispensable, so they are aggregated according to the weighted product method. The available command and guidance situation assessment model is:

$$X = M \left( m_1 S_1 \cdot n_1 S_1 + m_2 S_2 + m_3 S_3 \right)$$

$$n_1 + n_2 = 1$$

$$m_1 + m_2 + m_3 = 1 \quad (9)$$

Where $X$ is the command and guidance situation value, $n_1$, $n_2$ and $m_1$, $m_2$ and $m_3$ are the weight coefficients.

The weight obtained by analytic hierarchy process is shown in table 2.
Table 2. Calculation value of weight coefficient

| Parameter | Long distance | mid-range |
|-----------|---------------|-----------|
| $n_1$     | 0.72          | 0.26      |
| $n_2$     | 0.28          | 0.74      |
| $m_1$     | 0.76          | 0.76      |
| $m_2$     | 0.14          | 0.14      |
| $m_3$     | 0.1           | 0.1       |

4. Analysis of Examples

In order to verify the validity of the established model, the model in this paper is compared with the reference [10]. Two representative three-generation aircrafts Su-27 and F-15C are selected for example analysis. The initial relative positions of the two aircrafts and the relative positions and maintaining the current situation after continuing the flight time $t$ are shown in fig. 7.

The coordinates of our plane are (20km, 20km, 6500m) and the coordinates of the target plane are (60km, 60km, 8000m). The initial air situation parameters of the two aircrafts are shown in Table 3.

Figure 7. Air combat situation

Figure 8. Command and guidance advantage change curve
Table 3. Initial situation parameters of air combat

| Parameter     | Speed | Heading | the pitching angle |
|---------------|-------|---------|-------------------|
| my aircraft   | 220   | 15°     | 30°               |
| enemy aircraft| 200   | 270°    | 0°                |

Assume that the performance parameters of enemy and friend weapons are shown in Table 4. According to the model proposed in document [10], the results are shown in table 5. Using the improved model, the calculation results are shown in Table 6.

Table 4. Per formation parameters of weapon equipment

| Variable | Indicators | Variable | Indicators |
|----------|------------|----------|------------|
| $\theta_{\text{max}}(\varphi_{\text{max}})$ | 70°(80°) | $D_{\text{MMmax}}(D_{W\text{MMmax}})$ | 40km(60km) |
| $\theta_{\text{Mfmax}}(\varphi_{\text{Mfmax}})$ | 40°(50°) | $D_{\text{MKmin}}(D_{W\text{MKmin}})$ | 2km(5km) |
| $\theta_{\text{MKmax}}(\varphi_{\text{MKmax}})$ | 20°(30°) | $D_{\text{MKmax}}(D_{W\text{MKmax}})$ | 20km(30km) |
| $V_{\text{max}}$ | 240m/s | $D_{\text{MMmax}}(D_{W\text{MMmax}})$ | 100km(120km) |
| $H_{\text{max}}$ | 8000m |                      |           |

Table 5. Calculation results of traditional model

| Parameter | $S_A$ | $S_D$ | $S_Y$ | $S_H$ | $X$ |
|-----------|-------|-------|-------|-------|-----|
| Initial time | 0.643 | 0.569 | 0.605 | 0.312 | 0.543 |
| Time t    | 0.612 | 0.687 | 0.404 | 0.480 | 0.545 |

Table 6. Calculation results of this model

| Parameter | $M$ | $S_A$ | $S_D$ | $S_Y$ | $S_H$ | $X$ |
|-----------|-----|-------|-------|-------|-------|-----|
| Initial time | 0.503 | 0.551 | 0.633 | 0.605 | 0.312 | 0.335 |
| Time t    | 0.503 | 0.514 | 0.598 | 0.404 | 0.480 | 0.310 |

The simulation results are shown in fig. 8.

As can be seen from table 4, according to the situation values obtained from the model in document [10], keep the initial situation and continue to meet the enemy. as the target azimuth angle becomes larger, the target entry angle becomes smaller and the angle situation becomes smaller. As the distance decreases, the target is closer to my attack area and the distance situation becomes larger. As the speed decreases (less than the optimal air combat speed) and the altitude increases (close to the optimal air combat altitude), the speed situation of our aircraft becomes smaller and the altitude situation becomes larger. The change trend of speed situation and altitude situation objectively reflects the air situation. However, the traditional model lacks analysis of the performance of weapons and equipment, and cannot reflect the differences of different combat models. At the same time, it lacks analysis of the target threat, and does not consider that the greater the threat to continue to receive the enemy. As can be seen from table 5 and fig. 8, in the initial state, our plane is inclined to meet the enemy head-to-head, which is a typical mid-range command and guidance method, and is conducive to a better occupation of the enemy, thus occupying a certain situation in terms of angle. Due to $D_{\text{MMmax}} < D < D_{W\text{MMmax}}$ in the initial situation, our machine is slightly superior. However, as the distance decreases, our plane gradually approaches the boundary of the enemy attack area, and the distance situation decreases. If the current situation is maintained to receive the enemy, once entering the target missile attack range, the distance situation value will obviously decrease. Therefore, compared with
the traditional model, the model built in this paper can better reflect the actual situation of air combat and is more reasonable.

5. Conclusion
(1) In air combat confrontation, the greater our advantage, the greater the threat we will often face. This paper comprehensively considers our advantage and threat, which is more in line with the objective situation.

(2) The missile attack area is added to the air combat command and guidance situation assessment function, and the best angle, distance, speed and height are introduced to make the command and guidance process clearer. The situation function is improved to make the air combat command and guidance situation assessment model closer to actual combat.

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