Research on the Air Combat Countermeasure Generation of Fighter Mid-range Turn

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Abstract. When a fighter implements air combat, the pilot maneuvers according to the acquired air situation and the guidance password of the ground commander, and combined with training experience. In order to make the pilot's mid-range turning maneuver more accurate and effective, this paper makes an in-depth study on the generation of countermeasures in air combat of fighter mid-range turning. Firstly, the influencing factors of the mid-range turning maneuvering countermeasures are analyzed, and the boundary function of the maximum attacking zone of the air-to-air missile and the fighter's comprehensive superiority function are obtained; Then, based on the main maneuvering action of the fighter, a medium-range turning maneuvering vector model is established, and the medium-range turning maneuver countermeasures of our aircraft are calculated; Finally, through simulation calculations, the validity of this model is analyzed and verified, which is of great significance for our fighter to constitute combat advantages and improve combat effectiveness.

1. Introduction
Generalized free air combat refers to that in air confrontation, both sides in air combat give full play to the limit performance of aircraft in three-dimensional space, reasonably use all kinds of airborne weapons, and flexibly and freely use tactical countermeasures according to the mastered air situation and combined with the guidance countermeasures of ground command post, so as to achieve attack conditions and attack. At present, great achievements have been made in the research of air combat maneuvering countermeasures at home and abroad. Main solving methods are: influence graph method [1], matrix game method [2], and artificial intelligence algorithm based on “IF-THEN” rule, risk decision [3], genetic algorithm [4], tactical immune maneuver system [5], etc. These methods mainly provide auxiliary decision-making for real-time confrontation in medium-short range free air combat, but seldom study the generation problem of turning maneuver countermeasures in medium-range air combat. In this paper, based on the boundary function of air-to-air missile attack zone and the superiority function of air combat situation, the medium-range turning maneuver vector model in free air combat is established, and the auxiliary guidance countermeasures are solved and generated, which can effectively solve the generation problem of medium-range turning maneuver countermeasures.

2. Analysis on influencing factors of middle-range turning maneuver countermeasures
In free air combat, the pilot will maneuver the fighter plane according to preset methods of warfare, combined with air combat situation and ground command and guidance strategy. The main factors that influence the generation of maneuver countermeasures of middle-range turning in our aircraft are the maximum attack area of missiles of IFF and the current situation of our aircraft.
2.1 Missile attack zone
The missile attack zone, also known as the kill envelope, refers to the space area that may hit the target determined by the missile performance under certain attack conditions, and it is possible to hit the target only when the missile is launched in the attack zone [6]. Document [7] describes the boundary function of the maximum attack zone of air-to-air missiles as follows:

\[ D_{M_{\text{max}}} = f(h, h_m, v, v_m, n_y, q) \]  

(1)

Where: \( D_{M_{\text{max}}} \) is the boundary of the missile's maximum attack zone, \( h \) is the altitude of the aircraft and \( h_m \) is the target altitude; \( v \) is the carrier speed and \( v_m \) target speed; \( n_y \) is the target maneuver overload; \( q \) is the entry angle.

In order to simplify the middle-range turning maneuver model, the boundary of the missile's maximum attack zone can be regarded as an ellipse when it is expressed schematically, and it can be solved by polar coordinate equation: \( L = L(\theta) \) Wherein, \( \theta \) represents the angle with the aircraft heading, and defines the right hemisphere as positive and the left hemisphere as negative; \( L \) is the boundary distance of the missile attack zone when the angle between the aircraft heading is \( \theta \), as shown in figure 1.

![Figure 1. Boundary of missile maximum attack zone](image)

2.2 Aircraft dominance function
The purpose of air combat countermeasures is to command fighter planes to fly according to predetermined altitude, course and speed, and the enemy constitutes favorable air situation and occupies favorable tactical position. Mathematically, according to the current air combat situation, it is our greatest air combat advantage to construct the corresponding aircraft superiority function and choose the corresponding aircraft maneuver. Literature [8] gives the angle, distance, speed and altitude superiority functions and weights them to get the air combat superiority comprehensive function:

\[ S = \omega_a S_a + \omega_r S_r + \omega_v S_v \]  

(2)

Where: \( \omega_a \), \( \omega_r \), \( \omega_v \) is the weight coefficient corresponding to the aircraft angle superiority function \( S_a \), distance superiority function \( S_r \) and speed superiority function \( S_v \) respectively, and \( \sum \omega_i = 1 \) \((i = a, r, v)\). In different air combat situations, the importance of each parameter of the aircraft superiority function is different, and the calculation formula of its weight coefficient [9] is as follows:
\[ \omega_i = \omega_{i0} + k_i e^{-\left(\frac{D}{1.5D_{\text{max}}} \right)^2} \]  

(3)

Where: \( \omega_{i0} \) is the initial weight coefficient value of each parameter, and \( k_i \) is the adjustment coefficient of the weight coefficient, and \( \sum k_i = 0, (i = a, r, v) \).

3. **Medium range turning maneuver vector model**

When modeling and studying the mid-range turning maneuver of fighter in free air combat, this paper, aiming at the difficulty of establishing aircraft coordinates in air combat, establishes a vector model, and expresses the relative relationship between enemy and aircraft through vector equations, which can optimize the computational complexity and improve the effectiveness of aircraft maneuver.

3.1 **Introduction to vector model**

In the agreed plane rectangular coordinate system, the situation between enemy and enemy aircraft can be measured by the relative distance and azimuth of the two aircraft. According to the rectangular coordinates and current heading of the two aircraft, through Euler equation transformation, the vector description of the IFF can be expressed by complex expressions, and then substituted into the vector equation, and the corresponding vector model can be established, thus solving unknown variables.

In this article, the units of physical quantities used are unified as international standard units. The basic units of distance, time and angle are meters, seconds and radians respectively.

Suppose the distance from \( A \) to \( B \) is \( S \), and direction is \( K \), then there are:

\[ \overline{AB} = S(\cos K + i \sin K) \]

Combined Euler formula: \( e^{iK} = \cos K + i \sin K \), Then: \( \overline{AB} = Se^{iK} \).

3.2 **Construction of medium range turning maneuver vector model**

At the initial moment, through the comprehensive superiority function of fighter aircraft, we calculate the course, speed and altitude that our aircraft should fly, and then adjust our aircraft to the enemy receiving state. According to the missile attack area range and angle superiority function of the enemy and mine, we calculate the turning time and turning elements in our aircraft, thus generating the guidance countermeasures of middle-range turning maneuver. The specific flow is shown in figure 2:

![Figure 2. Middle-range turning maneuver countermeasure generation flow](image-url)
At times \( t_0 \), our aircraft and the target aircraft are respectively located at \( W_0 \left( x_{w_0}, y_{w_0} \right) \), \( M_0 \left( x_{m_0}, y_{m_0} \right) \), \( V_W \cdot V_M \cdot H_W \cdot H_M \cdot K_W \cdot K_M \) are respectively the speed, height and course of the enemy aircraft and me. After time \( \Delta t \), our aircraft has passed \( W_1 \) and implemented medium-range turning maneuver to reach \( W_2 \), and the target aircraft has reached \( M_1 \). At this time, our aircraft is outside the maximum attack zone of the target aircraft missile, while the target aircraft is in mine, so our aircraft occupies an advantage. Launching missiles here or turning into close combat can effectively improve the operational efficiency of our aircraft. As is shown in figure 3.

\[ M \cdot W_2 = M \cdot W_0 + M_0 \cdot W_0 + W_0 \cdot O_1 + O_1 \cdot W_2 \]

\[ S_0 e^{i(K_w \cdot n_1 \cdot \rho)} = -V_M \cdot \Delta t e^{iK_w} + S_0 e^{iK_w} + V_W \cdot \Delta t e^{iK_w} + R_1 e^{i(K_w - \frac{\pi}{2} n_1)} + R_1 e^{i(K_w + \frac{\pi}{2} n_1)} \]

Where: \( S_0 \) refers to the distance between me and the enemy aircraft at the initial moment, \( n_1 \) refers to the turning direction, the turning radius is \( R_1 \), \( K_w \) refers to the course of our aircraft connecting with the enemy, and \( V_W \) refers to the speed of our aircraft in the period of turning and laying potential. Suppose the middle distance of our aircraft to turn, and the incoming angle of the enemy is \( X_C \).

Set up the time equation:

\[ \Delta t = \Delta t_1 + t_{ZW} = \Delta t_1 + \frac{n_1 \cdot (K_{wj} - K_W) \cdot R_1}{V_W} \]

Where: \( t_{ZW} \) represents the turning time

In conjunction with (4)(5), we can calculate the timing \( \Delta t_1 \) and the speed \( V_W \) of the aircraft in the middle of our machine. According to the variation of the maneuvering movement of our aircraft, we can get the mid-range turning maneuver countermeasures of our aircraft.

3.3 Generation of maneuver countermeasures for mid-range turning

In air combat, the ground command post can generate the maneuver countermeasures of mid-range turning in real time by using the advantages of strong computing power and the vector model of mid-range turning established above according to the information of IFF received, thus improving the operational efficiency of our aircraft. The maneuver countermeasures of mid-range turning mainly include our aircraft response course \( K_w \), response speed \( V_W \), maneuver, mid-range turning maneuver time \( \Delta t_1 \) and turning to change course.

Figure 3. Schematic diagram of pitch turning maneuver
4. Simulation analysis

In order to verify the validity of this model, simulation is made for an air combat method. At the initial moment, Enemy aircraft and mine is located at (10Km, 10Km) and (82.75Km, 4Km) respectively, and the flight parameters of enemy aircraft and mine are (8000, 800, 90) and (8000, 1100, 270) respectively. The gravity acceleration $g = 10m/s^2$ is specified, and the simulation step size is 3s. The simulation results are shown in figure 4.

![Flight path of our aircraft and target aircraft](image)

**Figure 4.** Flight path of our aircraft and target aircraft.

And the table 1 lists the maneuver strategy instructions of our aircraft at six special nodes, as follows:

| Position | Time(s) | Response speed | Response heading | Maneuver action | Maneuver timing(s) | Course of Maneuver to change |
|----------|---------|----------------|------------------|-----------------|--------------------|-------------------------------|
| A        | 0       | 1100           | 274              | accelerate, right turn | 83                | 287                           |
| B        | 45      | 1000           | 275              | uniform, right turn | 42                | 287                           |
| C        | 57      | 1000           | 356              | uniform, left turn  | 38                | 300                           |
| D        | 69      | 1000           | 354              | uniform, left turn  | 27                | 300                           |
| E        | 87      | 800            | -                | slow down, left turn | -                 | -                             |
| F        | 117     | 800            | 262              | uniform, left turn  | 5                 | 255                           |

So it can be preliminarily concluded that the course, speed and mid-range turning maneuver timing of our aircraft obtained by model calculation and simulation are more accurate, which can make our aircraft maneuver more effective, air combat advantage more obvious and pose a threat to the enemy. And it is that which proves the effectiveness of the model.

5. Conclusion

In free air combat, the automatic generation of middle-range turning maneuver countermeasures still plays a very important role. This paper combines the missile maximum attack area with the superiority function of fighter planes, analyzes the factors that affect the middle-range turning maneuver, and establishes the vector model of middle-range turning maneuver. through simulation analysis, it verifies the validity of the model, which is significant to improve the accuracy of middle-range turning maneuver countermeasures in free air combat.
References
[1] Kirtanen K, Karelahti J and Raivio T 2006 Journal of Guidance, Control and Dynamics vol 29 pp 1080-91
[2] Hui Y N Zhu H Y and Shen L C 2009 Ordnance Industry Automation vol 28 pp 4-7
[3] Zhou S Y Wu W H Zhang N and Zhang J 2012 Aeronautical Computing Technique vol 42 pp 27-31
[4] Guo H Zhou D Y and Zhang K 2010 Electronics Optics and Control vol 17 pp 28-32
[5] Krishna Kumar K and Kaneshige J 2003 Proc. of the 41st Aerospace Sciences Meeting & Exhibit pp 1-10
[6] Gu J J Liu W H and Jiang W Z 2015 Systems Engineering and Electronics vol 37 pp 1306-12
[7] Wang Y H Gao X G and Zhen J 2010 Fire Control and Command Control vol 35 pp 32-36
[8] Han Q S and Yu M J 2015 Journal of Air Force Engineering University vol 16 pp 12-15
[9] He X Jing X N and Feng C 2017 Journal of Air Force Engineering University vol 18 pp 36-41