Air Combat Tactics among the Fourth Generation Fighters

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***Abstract*—According to analysis of characteristics of the fourth generation fighter, airborne avionics system and airborne weapon system, weakness of the fourth generation fighter for air combat was found. Based on the weakness, air combat tactics among the fourth generation fighters with lower characteristics and the fourth generation fighter with higher characteristics was made. And mathematic model for air combat among the fourth generation fighters was established. The calculation and simulation show that the time of attacking window for the fighter and off-axis angle for missile launching are both satisfied, and the tactics is valid and effective.**

***Index Terms*—the fourth generation fighter, formation, air combat tactics, time of attacking window**

I. Introduction

With the development of communication, electronic radar and Air-to-Air missile technology, the fourth generation fighters which have the ability of stealth, super-maneuverability, super-sonic cruising, super avionics for battle awareness and effectiveness are made [1]. At present, almost all strong military countries are making researches on technology about the fourth generation fighters [2]-[3]. There is only one type of the fourth generation fighters being armed, which is raptor F22. There is only one type of the fourth generation fighters being tested armed, which is JSF F35. There are three types of the fourth generation fighters being flight-tested.

Since the fourth generation fighters join no battle for now, the air combat tactics among the fourth generation fighters is still being explored. Based on characteristics of the fourth generation fighters, airborne avionics system and airborne weapon system, this paper explored air combat tactics among the fourth generation fighters.

II. Characteristics of the Fourth Generation Fighters

Besides the characteristics of 4S, the fourth generation fighters utilize some new technology and have some new performance, which offer more options for possible battle modes.

The airborne avionics system utilizes integrated RF technology [4]-[5] and integrated EO technology [6]. By getting all RF sensors integrated, integrated RF technology implements electromagnetic signal being integrated managed with AESE radar, integrated EW, CNI and IFF system.

The integrated RF technology makes the fourth generation fighters using electron equipment flexible when executing mission, especially, AESE radar can cooperate with integrated EW system. For example, AESE radar in raptor F22 has capability of electronic jamming and IFF besides normal detecting.

Although radar is the main sensor for the fourth generation fighters, EO detecting system is also quite important. With the development of EO technology, detecting distance with EO system increases markedly, and EO detecting system can be a valid supplementary way when radar is limited. The integrated EO system in the fourth generation fighters includes EODAS and EOTS.

EODAS has passive detecting capability of EO system and omnidirectional detecting capability with distributed configuration. The main purpose of EODAS is detecting and tracking aerial objects, and it is supplementary with radar warning system and passive electronic detecting system. It also can detect ground-to-air missiles and other obvious infrared objects.

EOTS is an EO target indication system, and has the capability of long detecting distance, high detecting precision and narrow detecting visual angle. Since it is installed in glass cover below the head of fighter, the capability of detecting aerial objects is restricted, and it cannot detect frontal above objects. The main purpose of EOTS is detecting, tracking and indicating ground objects, and it can also detect aerial objects.

III. Analysis of Air Combat among the Fourth Generation Fighters

The fourth generation fighters have capability of stealth, and RCS of the fourth generation fighters decreases obviously relative to RCS of the third

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generation fighters. Since four times of detecting distance of radar is proportional to the RCS [7], detecting distance of radar to the fourth generation fighters with RCS 0.01m2 decreases to 30km while detecting distance of radar to the third generation fighters with RCS 1m2 is 100km. Therefore, it is difficult to detect the fourth generation fighters with traditional detecting methods, and the corresponding detecting distance is also much shorter. Since the small RCS of the fourth generation fighters, detecting distance of missile-borne radar of traditional active intermediate range missile to the fourth generation fighters decreases largely. Therefore, distant boundary of no escape kill zone of active intermediate range missile to the fourth generation fighters decreases largely. If launching missile at a large distance just like attacking the third generation fighters, the fourth generation fighters can get rid of the attacking of the active intermediate range missile easily because of its super cruse capability and super maneuverability. Also, since the fourth generation fighters have strong capability of situation awareness, it will detect enemy's information using its passive radar warning system as long as enemy turn on its radar. That makes the fourth generation keeping radio frequency silence, which can reduce its own detected probability.

Although the fourth generation fighters have strong capability, they still have weakness. By analyze characteristics of the fourth generation fighters, airborne avionics system and airborne weapon system, it is easy to find out their weakness. For example, although the fourth generation fighters have stealth, it cannot steal at all radio frequency, also its infrared stealth performance is quite poor [8]. Since the fourth generation fighters cannot steal at all radio frequency, they can be detected by meter-wave radar although the error might being several kilometers [9]. If fusing different information from different meter-wave radar, the sketchy track of the fourth generation fighters can be obtained. Considering the intensity of echo is four times proportional to the distance between the fourth generation fighters and meter-wave radar, it is possible to detect the fourth generation fighters at a long distance using single beam of AESA. Since the development of infrared stealth technology is not mature and the fourth generation fighters cruse with supersonic velocity, the fourth generation fighters might be detected at a long distance with infrared detector.

To restrain predominance of enemy's fourth generation fighter and utilize its weakness, this paper established one type of tactics: first detect the information of the enemy's fourth generation fighter with higher performance using meter-wave radar, then guide two fourth generation fighters formation with lower performance entering combat airspace. The vertical distance and horizontal distance between the two fourth generation fighters formation are both small. The formation first approaches enemy to intermediate distance, then the frontal fighter turns on its airborne-radar and entices the enemy, and at the same time, the other fighter detects the enemy using EO system, and attacks the enemy using infrared missiles. The whole attacking is radio silence.

IV. Air Combat Model among the Fourth Generation Fighters

Based on analysis of air combat among the fourth generation fighters, this paper established an air combat model among the fourth generation fighters. The red team uses two fourth generation fighters with lower performance while the blue team uses only one fourth generation fighter with higher performance, and the sketch of the air combat is shown in Fig. 1. Suppose the air combat occurs at height h. The blue fighter cruses with velocity v_b, and the two red fighters forming a formation with small horizontal and vertical distance cruse with velocity vr. In horizontal axis, the red fighter 1 is at front, and in vertical axis, the red fighter 1 is at down. The horizontal distance between two red fighters is d_0, and the vertical distance between two red fighters is h_0. When distance between the red fighter 1 and the blue fighter decreases to d, they both begin to turn. The turning radius of the red fighter 1 decided by its maximal acceleration G_r is r_1, and the turning radius of the blue fighter decided by its maximal acceleration G_b is r_b. At the same time, the red fighter 2 begins to climb with vertical velocity v_h, and then begins to turn after time t_h. The turning radius of the red fighter 2 decided by its maximal acceleration G_r is r_2. The purpose of the red fighter 1 is to entice the blue fighter and it flies away along line after turning π radian. Suppose the blue fighter chases the red fighter 1 and flies along the shortest path between it and the red fighter 1 after turning θ radian. The purpose of the red fighter 2 is to attack the blue fighter after turning α radian.

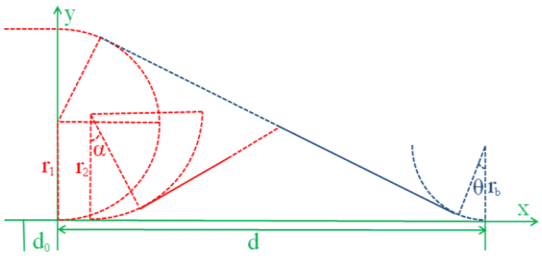

Figure 1. Sketch of plan form for air combat among the fourth generation fighters

The axis is shown in Fig. 1. At the beginning, t=0, the coordinate of the red fighter 1 is (0,0,h), the coordinate of the red fighter 2 is $(-d_0,0,h+h_0)$, and the coordinate of the blue fighter is (d,0,h). Since the turning velocity and turning radius of the red fighter 1 are v_r and r_1 respectively, it finishes its turning at time $\pi \cdot r_1/v_r$, and therefore its coordinate at time t is:

$$(r_1 \cdot \sin(v_r \cdot t/r_1),\ r_1 - r_1 \cdot \cos(v_r \cdot t/r_1),\ h), \quad t \le \pi \cdot r_1/v_r$$

$$(-v_r \cdot (t - \pi \cdot r_1/v_r),\ 2 \cdot r_1,\ h), \quad t > \pi \cdot r_1/v_r \qquad (1)$$

Since the blue fighter chases the red fighter 1 along the shortest path between them, the turning radian θ satisfies the following condition:

$$r_1/\tan(\theta/2) + r_b \cdot \tan(\theta/2) = d \qquad (2)$$

Since the turning velocity and turning radius of the blue fighter are v_b and r_b respectively, it finishes its turning at time $\theta \cdot r_b/v_b$, and therefore its coordinate at time t between 0 and $\theta \cdot r_b/v_b$ is:

$$(d-r_b \cdot \sin(v_b \cdot t/r_b), r_b \cdot \cos(v_b \cdot t/r_b), h) \quad (3)$$

The blue fighter then flies along line using time $(d-2 \cdot r_b \cdot \tan(\theta/2))/v_b$, therefore the coordinate at time t between $\theta \cdot r_b/v_b$ and $\theta \cdot r_b/v_b + (d-2 \cdot r_b \cdot \tan(\theta/2))/v_b$ is:

$$(d-r_b \cdot \sin\theta - v_b \cdot (t-(d-2 \cdot r_b \cdot \tan(\theta/2)/v_b) \cdot \cos\theta, r_b \cdot \cos\theta + v_b \cdot (t-(d-2 \cdot r_b \cdot \tan(\theta/2)/v_b) \cdot \sin\theta, h) \quad (4)$$

The height of the red fighter 2 after climbing time t_h is $h+h_0+v_h \cdot t_h$, and its velocity v_{r2} after climbing satisfies the following condition:

$$v_{r2}^2 = v_r^2 + (v_h \cdot t_h)^2 \quad (5)$$

Then the red fighter 2 begins to turn. After time $\alpha \cdot r_2/v_{r2}$, it swoops to attack the blue fighter. The corresponding swoop angel β and acceleration a satisfy the following conditions:

$$\beta = \operatorname{actan}((((d+d_0-v_r \cdot t_h - r_2 \cdot \tan(\alpha/2) - r_b \cdot \tan(\theta/2))/\sin(\pi-\alpha-\theta)) \cdot \sin\theta - r_2 \cdot \tan(\alpha/2))/(h_0+v_h \cdot t_h))$$

$$a = g \cdot \sin\beta \quad (6)$$

After swooping time t_a, the red fighter 2 launches an infrared missile to attack the blue fighter, and the coordinate of the red fighter 2 is:

$$(v_r \cdot t_h - d_0 + r2 \cdot \tan(\alpha/2) + ((v_{r2} \cdot t_a + a \cdot t_a^2/2) \cdot \cos\beta + r_2 \cdot \tan(\alpha/2)) \cdot \cos\alpha$$

$$((v_{r2} \cdot t_a + a \cdot t_a^2/2) \cdot \cos\beta + r_2 \cdot \tan(\alpha/2)) \cdot \sin\alpha, h_0 + v_h \cdot t_h - (v_{r2} \cdot t_a + a \cdot t_a^2/2) \cdot \sin\beta) \quad (7)$$

From the above equations, the distance between the red fighter 1 and the blue fighter and the distance between the red fighter 2 and the blue fighter at any time can be calculated. When the red fighter 2 can attack the blue fighter while the blue fighter cannot attack the red fighter 1, the blue fighter is damaged and the formation finishes the air combat.

V. Simulation and Analysis

Suppose the blue fighter cruses with velocity v_b being1.6Ma, maximal acceleration G_b being 6g, RCS being $0.01m^2$, launching distance of the air-borne infrared missile being 14.5km. The red fighters cruse with velocity vr being 1.5Ma, maximal acceleration G_r being 5g, RCS being $0.01m^2$, launching distance of the air-borne infrared missile being 13km, the horizontal distance between two red fighters d0 being 100m, vertical distance h_0 being 150m. When distance between red fighter 1 and blue fighter d is 30km, the two fighters begin to turn. The red fighter 2 climb with vertical velocity v_h being 150m/s, and begin to turn after climbing time t_h being 8s.

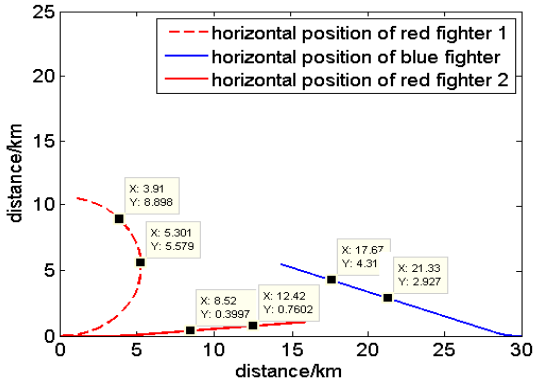

Figure 2. Positions of fighters.

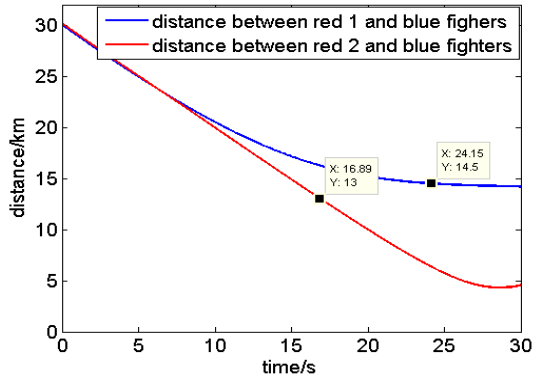

Figure 3. Distances among fighters.

Using the above data and equations established by air combat model, the positions of the fighters is calculated and shown in Fig. 2, the distance between the red fighter 1 and the blue fighter, the distance between the red fighter 2 and the blue fighter are calculated and shown in Fig. 3, off-axis angle of missile when launching are calculated and shown in Fig. 4. The simulation shows that the red fighter 2 can launches infrared missile to attack blue fighter from time 16.09s, and off-axis angle of missile is 5.9 degree. The blue fighter can launches infrared missile to attack red fighter 1from time 24.15s, which means red fighter 2 should destroy blue fighter before time 24.15s. Therefore, launching window time for red fighter 2 is 8.06s, and in that period, red fighter 2 can finish the process of attacking.

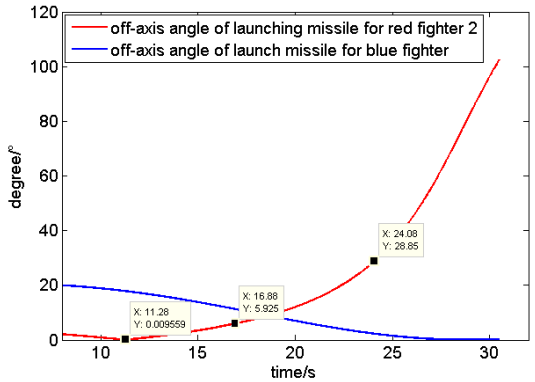

Figure 4. Off-axis angle of launching missile.

VI. Conclusion

This paper constructed and computed the model of air combat among the fourth generation fighters. The tactics that the frontal fourth generation fighter with lower performance turns on its airborne-radar and entices the fourth generation fighter with higher performance, and the other fourth generation fighter with lower performance detects the enemy using EO system, and attacks the enemy using infrared missiles is valid.

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