A quick calculation method for flight radius of fighter aircraft

Hu Zhaohuia, Luo Jixunb and Yang Liuc
Aeronautics and astronautics engineering institute air force engineering university Xi'an, China
ahuzhaohui123@163.com, bLuojixun123456@163.com, cYangliu123456@163.com

Abstract

The flight radius is an important index to describe the performance of fighter aircraft. The size of flight radius is closely related to flight profile, engine state, external store and fuel quantity of aircraft. These factors make the flight radius difference. According to the characteristics of actual air fight, this paper builds up the flight radius digital models, the models can be used both for air fight mission planning and air fight effectiveness analysis.

Keywords: fighter aircraft; flight radius; calculation method; air fight mission planning; air fight effectiveness analysis

1. Introduction

The flight radius is an important parameter in air fight mission planning and air fight effectiveness analysis. But the size of flight radius varies considerably since the different aircraft characters; these characters mainly include flight profile, engine state, external store and fuel quantity. In some cases, the flight radius differs probably several times. In general, there are little flight radius data in the flight manual of fighter aircraft, and the definitions of flight radius vary. In most cases the definitions include maximum flight radius and the longest flight radius, and some manuals give the flight radius when the fighter aircraft equips a weapon. So the flight radius data in flight manuals only have reference value, it can't meet the demands of air fight mission planning and air fight effectiveness analysis [1,2].

This paper discuses how to evaluate the flight radius. Combining calculation accuracy and complexity, the flight radius digital models are built up, and by the flight radius data in the fighter aircraft flight manual, the model parameters are deduced, so the flight radius models can be solved the lack of flight data problem, and they can be used both for air fight mission planning and air fight effectiveness analysis.

2. Influencing Factors of Flight Radius

For the specific aircraft, flight character, profile, engine state, external store and fuel quantity are the main Flight Radius influence factors. These factors will be analyzed in more detail in the following chapters.

The plug-in type equipment configuration: Before the fighter aircraft takes off, it has equipped with different plug-in type equipments in order to complete the task. The plug-in type equipments change the mass, fuel and aerodynamic characteristics of the aircraft, so they affect the size of flight radius. The plug-in type equipments include weapons, some pods and fuel tanks, etc. Besides changing aircraft mass, the plug-in type equipment also changes the aerodynamic characteristics of aircraft. The fuel tanks can also change the fuel quantity of the aircraft. So the size of flight radius varies considerably because of different weapons equipped in aircraft[3].

The flight profile: The flight profile of fighter aircraft prescribes the flight altitude, velocity and attitude in flight phases. In general, the flight phases are composed of take-off phase, climb phase, speeding up phase, air combat phase, return phase and landing phase. Apparently, the size of flight radius varies considerably because of these parameters.

The control plan of engine: There are two principal types of military aircraft engines: turbojet engine and turbofan engine. When the engine type is known, the engine operating state, aircraft flight speed and height determine the fuel consumption rate of fighter aircraft, so the control plan of engine determines the flight radius of aircraft.

The aircraft fuel quantity: The fuel quantity which the aircraft carried is different in different tasks. Generally the fuel tanks are full while the fighter aircraft takes off. When external fuel tanks are installed on the fighter aircraft or the fighter aircraft has the in-flight refueling capability, the flight radius becomes large than normal.

3. Planed Flight Radius

According to the demand of mission planning, the flight radius of the fighter aircraft is calculated using the parameters of weapon, flight profile, engine operating state, external store and fuel quantity.

3.1 The engine control demand

According to the actual requirements for flight, the engine control model is designed according to fight missile, the typical engine control demand is shown in Table 1:

Table 1 the engine operating state in different flight phase

Flight Phase	Engine Operating State
take-off	full afterburner or maximum thrust
climb	afterburner or maximum thrust
speeding up	maximum or cruise thrust
combat	afterburner or maximum thrust

return	cruise thrust
landing	idle

3.2 The fuel quantity calculation models

The aircraft fuel quantity determines the flight time and flight radius of fighter aircraft. The fuel quantity is defined in blow:

(1) Total fuel quantity

$$Q = Q_1 + Q_2 \tag{1}$$

In the Eq.(1), the variable Q is the total fuel quantity which the aircraft carried; the variable Q_1 is the fuel quantity in the internal fuel tanks of fighter aircraft; the variable Q_2 is the fuel quantity in the external fuel tanks of fighter aircraft.

(2) Usable fuel quantity

$$Q_4 = Q - Q_3 - Q_7 \tag{2}$$

In the Eq.(2), the variable Q_4 is fuel the fighter aircraft can consume in flight; the variable Q_3 is the fuel quantity in fuel tanks which can't be used by aircraft; the variable Q_7 is the remaining fuel quantity in the fuel tanks, this is secure fuel.

(3) Level flight fuel quantity

$$Q_8 = Q_4 - Q_5 - Q_6 \tag{3}$$

In the Eq.(3), the variable Q_8 is the fuel the fighter aircraft consumes in Level flight; the variable Q_5 is the fuel consumption in climb phase; the variable Q_6 is fuel consumption in landing phase.

3.3 Fuel consumption rate models

Generally the engine operating state, flight speed and height of the aircraft determine the fuel consumption rate, the fuel consumption rate can be gained by interpolation calculation.

$$\begin{cases} C_{e1} = \mathrm{f}(H, M_a, \phi_1) \\ C_{e2} = \mathrm{f}(H, M_a, \phi_2) \\ C_{e3} = \mathrm{f}(H, M_a, \phi_3) \end{cases} \tag{4}$$

In the Eq.(4), the function **f(.)** is fuel consumption rate function; the variable C_{e1} is fuel consumption rate when engine is in full afterburner; the variable C_{e2} is fuel consumption rate when engine is in maximum thrust, the variable C_{e3} is fuel consumption rate when engine is in cruise thrust; Φ_1 is the engine operating state of full afterburner; Φ_2 is the engine operating state of maximum thrust; Φ_3 is the engine operating state of cruise thrust; the variable H is flight height of fighter aircraft; the variable Ma is fighter aircraft speed in mach.

3.4 The flight radius models

The typical flight radius is the furthest level flight range of fighter aircraft. In order to calculate the flight radius quickly, the flight phase of fighter aircraft is divided into four phases: climb phase, long-distance navigation phase, return phase and landing phase.

So the flight radius can be defined in (5).

$$R_D = D_1 + D_3 = D_2 + D_4$$

(5)

In the Eq. (5), the variable D1is the level flight distance in climb phase; the variable D_3 is the level distance in long-distance navigation phase; the variable D_2 is the level distance in landing phase; the variable D_4 is the level distance in return phase.

Because the level flight fuel quantity is $Q_8 = Q_4 - Q_5 - Q_6$, so the variable Q_8 can be deduced into below:

$$Q_8 = C_{e2} \cdot t_1 + C_{e3} \cdot t_2$$

(6)

In the Eq. (6), the variable t_1 is the long-distance navigation time of fighter aircraft; the variable t_2 is the return time of fighter aircraft, the variable D_3 and the variable D_4 is the product of flight speed and time:

$$\begin{cases} D_3 = M_{a1} \cdot a \cdot t_1 / 1000 \\ D_4 = M_{a2} \cdot a \cdot t_2 / 1000 \end{cases}$$

(7)

In the Eq. (7), the variable M_{a1} is long-distance navigation speed in mach; the variable M_{a2} is return speed in mach; the variable a is the sonic speed. The speed in mach convert units sonic experience formula is:

$$a = \begin{cases} 20\sqrt{288 - 6.5H} & H < 11km \\ 295 & H \geq 11km \end{cases}$$

(8)

So the Eq. (5) can be transformed into:

$$D_3 = D_2 + D_4 - D_1$$

(9)

Plug the Eq. (7) into Eq. (9), then:

$$D_3 = D_2 + M_{a2} \cdot a \cdot t_2 / 1000 - D_1 = M_{a1} \cdot a \cdot t_1 / 1000$$

(10)

So the flight radius of fighter aircraft can be deduced into Eq. (11).

$$R_D = D_2 + \frac{M_{a1} \cdot Q_8 + C_{e2} \cdot D_1 + C_{e2} \cdot D_2}{C_{e2} \cdot M_{a2} + C_{e3} \cdot M_{a1}} M_{a2}$$

(11)

3.5 Fuel consumption rate evaluation models without fuel consumption curve[4]

The blow equations evaluate the fuel consumption rate when there are no fuel consumption data.

This is the fuel consumption rate model modified by the aircraft speed.

$$C_{e,Ma} = C_{e,0}\left(a_1 + a_2 \cdot M_a - a_3 \cdot M_a^2\right)$$

(12)

In the Eq. (12), the variable $C_{e,0}$ is basic fuel consumption rate; the variable $C_{e,Ma}$ is fuel consumption rate; a_1,a_2,a_3 is the modified coefficient.

This is the fuel consumption rate model modified by the aircraft height.

$$C_{e,H} = C_{e,0}\Delta^b$$

(13)

In the Eq.(13), the variable $C_{e,0}$ is the basic fuel consumption rate; the variable △ is the atmosphere density; b is the modified coefficient.

4 .The Flight Radius in Real Time

The flight radius in real time is difference with planned flight radius. The flight radius in real time is actual flight range, but the planned flight radius is an evaluated flight range before the fighter aircraft takes off.

The flight radius in real time is calculated by integral method. First, the fuel consumption rate can be gained by interpolation calculation, then the remainder fuel is calculated by integral method, third, the level distance between fighter aircraft and airport and cruise return distance is compared, finally, if the two distances is equivalent, the cruise return distance is the flight radius in real time. So the level distance between fighter aircraft and airport is:

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

(14)

In the Eq. (14), the variable x_1,y_1 is the fighter aircraft coordinates; the variable x_2,y_2 is the airport coordinates. The Remainder fuel in real time is $Q_r = \int C_e dt$, so the flight radius in real time is:

$$D_r = \frac{Q_r \cdot M_{a2}}{C_{e3}}$$

(15)

When D=D_r, the variable D is the flight radius in real time.

5 .The Simulation

The fuel quantity in an aircraft is set: Q_1=7050kg, Q_3=3000kg, Q_4=150kg, Q_5=150kg. Hypothesis the combat speed is 1.2M_a and combat time is 5minutes in the high altitude, the combat speed is 0.9Ma and combat time is 5 minutes in the low altitude. Then the flight radius is calculated as follows:

Table 2 result of planned flight radius(km)

Flight Profile	Flight Radius
high-middle-high-middle	1421
middle -middle- middle -middle	1028
low-middle-high-middle	942
low-middle-low-middle	707

Conclusion

This paper gives a quick calculation method for flight radius of fighter aircraft. The flight radius is full consideration of the flight profile, engine state, external store and fuel quantity of aircraft, it can be used in air fight mission planning, air fight simulation and air fight effectiveness analysis, the quick calculation method for flight radius of fighter aircraft is valuable to engineering application.

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