Research on Electromagnetic Conflict Optimization Algorithm for Aircraft Formation

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Abstract. With the continuous development of science and technology, the electromagnetic environment has become increasingly complex and harsh, and electronic information equipment of various types, models and high degree of informatization, presenting the characteristics of many frequency-using devices, covering a wide bandwidth, and overlapping frequency interleaving, it is very easy for electromagnetic interference between systems to occur, which seriously affects the overall effectiveness of electronic and electrical equipment.

At present, most of the cases focus on analyzing the electromagnetic compatibility effect of the individual aircraft's electromagnetic interference between systems. However, there is no detailed study on the forms of electromagnetic interactions between airplanes in a fleet of airplanes acting together and interacting with each other, and on how to reduce interference and increase efficiency.. Therefore, we hope to build an environment for observing the electromagnetic disturbance of the air fleet under microscopic conditions, and analyze from a small place to seek for the best flight attitude, trajectory, etc., so as to solve the real electromagnetic conflict problem.

Our ultimate goal is to observe and find the "steady state" of the aircraft fleet when they work together, to take one aircraft as the center, and by adjusting the flight attitude, mode and other parameters of the other aircraft, to minimize the overall electromagnetic interference, so as to achieve the result of maximizing the overall electromagnetic compatibility benefits.

Keywords: Electromagnetic conflict, Aircraft formation, Optimization algorithms.

1 Background

1.1 Electromagnetic interference sources of aircraft formation

Antenna electromagnetic interference problems are mainly manifested in the following aspects:

Wireless communication frequency band interference: With the increase in the demand for flight data transmission, the wireless communication system in the aircraft uses more and more frequency bands. However, there is a possibility of mutual interference between antennas of different frequency bands, resulting in degradation of communication quality or even interruption of communication, which affects the normal communication between the crew and ground dispatchers.

Navigation system interference: Aircraft rely on the navigation system for flight control and positioning, and some antennas in specific frequency bands may cause interference with the navigation system, affecting the accuracy of the flight's heading, altitude, and other parameters, and increasing the risk of flight.

Airborne radar interference: Airborne radar is an important aircraft collision avoidance and meteorological monitoring equipment, and the electromagnetic interference of the antenna may cause the radar system to misjudge the target position or fail to work properly, bringing potential danger to flight safety.

1.2 Existing challenges

The antenna electromagnetic interference problem also has the following challenges:

Complex environmental impact: Aircraft flight environment is variable, and various electromagnetic interference sources are numerous, such as lightning activity, close radio frequency equipment, etc., which increases the possibility of antenna interference. 2.

Equipment influence each other: many equipment inside the aircraft, antenna and other equipment layout location will also affect its electromagnetic compatibility, improper design may lead to electromagnetic interference between the antenna or between the antenna and other equipment. 3. fault handling difficulty: once the antenna and other equipment, the antenna can not be used, the antenna can not be used.

Troubleshooting difficulty: Once the antenna malfunctions due to electromagnetic interference, it is often necessary to cumbersome troubleshooting and processing, which consumes time and labor costs, and affects the normal conduct of flights.

2 Algorithm Design

2.1 Solid logic

Since the wingman and the lead-plane usually fly in formation, the best companion attitude of the wingman can be artificially specified according to the given position and attitude of the lead-plane. The results are calculated by Friis formula to determine if the next adjustment is needed. If the expectation is not met, the direction and modulus of the distance vector between the two aircraft are considered to be adjusted simultaneously using an optimization algorithm. This is a problem of solving a local optimum by a multivariate function, which can be optimized using an algorithm.

After experimentally using the convex optimization algorithm, bee colony algorithm, and evolutionary algorithm, we found that: since the given antenna direction map is in fact a three-dimensional point distribution map, the individual direction antenna gain obtained after performing the algorithmic calculations has a large deviation from the actual situation. However, due to the limitation of experimental conditions, it is difficult for us to measure the parameters of each part of the antenna more accurately, and thus the above method is discarded.

We established a fitted 3D distribution function for the directional map, and gradually calculate the gain point by point from the smaller side flaps of the directional map. The time used is still very short, which can satisfy the project's requirement for the timeliness of the algorithm.

2.2 Specific implementation

From Friis' formula, the received power in free space from the wingman's transmitter antenna to the host's receiver antenna is:

$$P_r = \frac{P_t G_t A_e}{4\pi d^2}$$

A_e is the effective aperture of the receiving antenna, which can be expanded into the following equation:

$$A_e = \frac{\lambda^2}{4\pi} G_r$$

Coupling the two formulas gives rise to:

$$P_r = \frac{P_t \lambda^2}{(4\pi)^2} \frac{G_t G_r}{d^2} = K \frac{G_t G_r}{d^2}$$

In the process of analyzing the search for the optimum value, the value of K is a constant and does not affect the results of the qualitative analysis.

In order to minimize the adjustment time, the wingman's attitude should be adjusted first so that it is kept at a smaller value; if the requirement cannot be met by adjusting the attitude, then changing the spatial coordinate C is considered.

From the ground reference system to the host reference system, it should go through the coordinate system rotation and coordinate system translation, and the rotation coordinate transformation matrix are as follows:

$$\mathrm{P} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_x & \sin\theta_x \\ 0 & -\sin\theta_x & \cos\theta_x \end{bmatrix} \begin{bmatrix} \cos\theta_y & 0 & -\sin\theta_y \\ 0 & 1 & 0 \\ \sin\theta_y & 0 & \cos\theta_y \end{bmatrix} \begin{bmatrix} \cos\theta_z & \sin\theta_z & 0 \\ -\sin\theta_z & \cos\theta_z & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

θ_x , θ_y and θ_z are the rotation angles of the host coordinate system around the ground coordinate system.

3 subsequent improvement

This algorithm still has problems. For example, it can only determine the optimal position and attitude of the target aircraft, but it cannot effectively give the moving route of the target aircraft from the initial position to the final position. If it moves in a straight line, there is a possibility of electromagnetic conflicts exceeding the threshold value during the moving process. Example data are shown in Table 1 and Figure 1.

Table 1. Variation of EMI intensity generated by the two wingmen in the sample as a function of time(/dB).

wingman1	3.6	1.2	0.6	-1.0	4.6	-2.7	11.5	20.0	1.2
wingman2	7.7	4.2	3.4	2.0	0.5	-1.3	-2.1	-2.9	-3.7

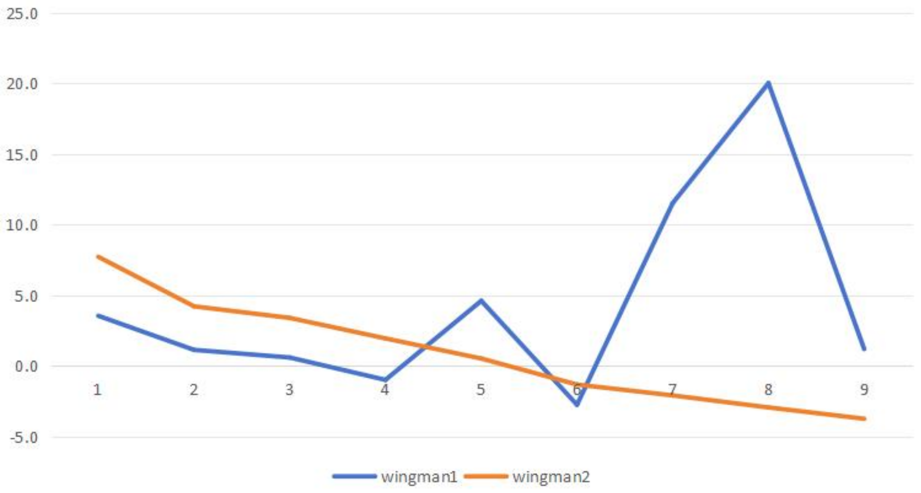

Fig. 1. Curves of the electromagnetic interference intensity generated by the two wingmen in the sample as a function of time.

From the figure, it can be seen that after the intervention of the algorithm, the change curve of the electromagnetic interference generated by wingman 2 is the ideal case, where the interference intensity decreases continuously with time; while the electromagnetic interference generated by wingman 1 has a significant bump in the time domain, i.e., the interference intensity increases significantly at a certain period of time.

After practical calculations and data support, we found that, usually, the interference generated by moving in a straight line and the time when the interference exceeds the threshold are within the tolerable range of aircraft systems, but in order to minimize the risk of electromagnetic conflicts, how to effectively find a suitable moving route is the goal of the next phase of our research.

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