Simulation analysis of complex electromagnetic environment effect of helicopter engine

Qiuying Yan¹, Xiuqing Zhou¹, Yunfeng Jia², Lei Chen²

¹AECC Hunan Aviation Powerplant Research Institute, Hunan, China
²Research Institute for Frontier Science, Beihang University, Beijing, China

Abstract—With the improvement of equipment informatization, the adaptability of complex electromagnetic environment of airborne engine equipment is becoming increasingly important. The mechanism and degree of influence of complex electromagnetic environment on engine are quite different, which has seriously threatened flight safety. In order to predict and analyze part of electromagnetic environment faced by airborne engine, FEKO electromagnetic simulation software is used for simulation research. According to the relevant test methods of SAE-ARP5416, SAE-ARP5412, GJB-1389A and other standards of American Society of engineers, the field strength and cable coupling of airborne engine under lightning effect and high field intensity irradiation are predicted by simulation. The conclusion has certain guiding significance for further research on complex electromagnetic field protection of engine.

1. INTRODUCTION
The future war is an all system, all-round, multi arms cooperation information war, a large number of electronic systems and electromagnetic weapons of both sides of the enemy and our side are widely used, resulting in extremely bad electromagnetic environment[1-3]. The adaptability of engine to complex electromagnetic environment has become the focus of attention.

Comprehensive theoretical analysis and simulation prediction of the complex electromagnetic environment is an indispensable work for engine development to enhance the adaptability of electromagnetic environment[4]. The research is very necessary for improving the adaptability of the engine to complex electromagnetic environment, so as to ensure flight safety and play the combat effectiveness[5].

2. INTRODUCTION OF SIMULATION SOFTWARE
In this study, commercial software FEKO is used to calculate the complex electromagnetic environment faced by the engine. The core algorithm of FEKO is the method of moments. It also integrates a variety of accelerating algorithms including fast multipole, multi-layer fast multipole, etc., so the calculation accuracy and efficiency are guaranteed. The calculation principle is that the basis function is selected to expand the unknown function approximately, and then it is brought into the operator equation[6]. The appropriate weight function is selected to make the residual of the equation equal to zero in the sense of weighted average, so that the continuous operator equation is converted into algebraic equation. In principle, MOM can solve the electromagnetic problems of any complex structure.
3. LIGHTNING SIMULATION

In this part, taking an armed helicopter as an example, the lightning effect simulation analysis is carried out. In order to analyze the impact of lightning on the engine cable coupling, a cable path is set in the cabin. The two ends of the cable are respectively terminated with 50 Ω load. The cable types are single core wire and RG58 coaxial line. The cable distribution is shown in Figure 1.

![Cable layout](image)

Figure 1. Cable layout

According to the provisions of SAE-ARP5416-2005 test method, large current pulse injection test and frequency sweep test are required for the whole machine lightning indirect effect test[7]. This paper mainly focuses on the simulation analysis of high current pulse test. In FEKO, the external current is set as the neutral point of lightning strike, and the current outflow point is represented by the inverse phase with the injected current. SAE-ARP5412 specifies the lightning test waveform, and the indirect test needs to use test waveforms A, D and H for pulse injection test. Since the helicopter belongs to low altitude aircraft, waveform a is selected for simulation analysis of current pulse test[8]. The waveform is a double exponential form. The mathematical expression is as follows:

\[ i(t) = I_0(e^{-\alpha t} - e^{-\beta t}) \]  

where:

- \( I_0 = 218810 \text{A} \)
- \( \alpha = 11354 \text{s}^{-1} \)
- \( \beta = 647265 \text{s}^{-1} \)

The time domain waveform is shown in Fig. 2. It can be seen from the figure that the peak current reaches 200kA at 6.4 μs of lightning injection, and at 69 μs, waveform A attenuates to half of the maximum value of 100kA.

![Time domain curve of lightning waveform A](image)

Figure 2. Time domain curve of lightning waveform A

According to Figure 2, when the current amplitude of waveform a drops to 50% of the peak value, the time is 69us, while the overall time of test waveform a specified in SAE-ARP5412 is less than 500us. Due to the need of simulation time, it should at least include the time of lightning current flowing through the whole fuselage T1 = 73ns and the half width time of waveform A T2 = 69us. In order to complete the simulation of the helicopter in the frequency range of 200mhz-50mhz, the simulation can be completed in the range of 200MHz-50MHz. Because this paper mainly analyzes the influence of indirect lightning on helicopter in flight, the six planes of helicopter are all open boundary conditions. The lightning injection path is shown in Figure 3, and the current injection point is set at the head and flows out from the tail.
According to Figure 4, at 6.4 μs, waveform A reaches the peak current of 200kA. At this time, the current injected into the helicopter is the maximum, and the current density on the fuselage surface reaches the maximum. At 69 μs, waveform A reaches 100kA, which is half of the maximum current. At this time, the current injected into the helicopter is smaller than that at 6.4 μs. The helicopter surface current reaches the maximum at the lightning injection point and separation point, and the maximum value reaches 164dBA/m. The surface current of the engine compartment is relatively large, which reaches 100dBA/m.

3.2 Electric field value outside engine compartment

When lightning strikes the aircraft, the distribution of electric field intensity near the helicopter surface at 6.4 μs (maximum) is shown in Figure 4.
Figure 6. Electric field distribution outside engine compartment

It can be seen from Figure 6 that the electric field strength near the helicopter is mainly concentrated in the structure of the nose, rotor and tail wing. Under this path, the instantaneous electric field intensity near the engine cabin surface reaches hundreds of dBV/m when the helicopter injects the maximum current.

3.3 Cloud chart of electric field in engine compartment

According to the results of shielding effectiveness distribution in Figure 7, the shielding effect of each position of the engine can be seen intuitively. The results show that the shielding effect near the engine vent is poor, and the maximum field strength can reach 100dBV/m.

3.4 Engine compartment cable coupling

The shielding effectiveness of helicopter is seriously reduced by the holes, windows, doors and other parts produced by helicopter assembly and welding operations. The pre-set coupling current distribution of helicopter internal cable within 10kHz-50MHz is shown in Figure 8.

Figure 7. Electric field distribution in engine compartment

Figure 8. Cable coupling curve in engine compartment

The maximum coupling current of single core wire is about 80dBA, and the coupling magnitude of coaxial line is obviously smaller than that of single core wire, which reduces about 40dB on the whole. Due to the simplification of the model, only the fuselage is simulated with a precise fully enclosed fuselage, and the current of cable coupling is slightly smaller than the actual. This is because the actual
situation in the cockpit and fuselage of the hole is unavoidable, the cable cabin more severe impact. Therefore, for the protection of indirect effects of lightning, we should try our best to avoid the appearance of fuselage holes and other structures, and take measures to add shielding plates to the key parts to enhance the electromagnetic shielding effectiveness.

4. SIMULATION OF HIGH FIELD INTENSITY IRRADIATION

In order to accurately predict the coupling in the engine compartment under high field intensity irradiation, analyze and predict the real electromagnetic environment in the engine room, establish a 200V/m radiation source, and establish an observation plane in the engine compartment. In order to analyze the influence on the engine cable coupling, a cable path is set up in the engine cabin[9-10]. The cable ends are terminated with 50Ω load[11]. The cable types are single core wire and RG58 coaxial line, and the cable distribution is the same as that of lightning simulation cable[12].

![Figure 9. Cloud picture of electric field in engine compartment 10MHz](image9)

![Figure 10. Cloud picture of electric field in engine compartment 100MHz](image10)

![Figure 11. Cloud picture of electric field in engine compartment 500MHz](image11)
Figure 12. Cloud picture of electric field in engine compartment 1000MHz

According to the distribution of shielding effectiveness of the simulation cloud picture, the shielding effect of each position of the engine can be analyzed. The results show that the shielding effect near the engine vent is poor, and the maximum field strength can reach 100V/m.

Figure 13. Cable coupling curve of engine compartment

It can be seen from Figure 13 that under the same irradiation conditions, the frequency-domain waveform of the coupling current on the increased single core cable is very similar to that on the coaxial line, and the shielding performance is about 40dB higher than that of the single core wire except for some resonance points.

5. CONCLUSION

According to the relevant standards of SAE-ARP5416, SAE-ARP5412 and GJB-1389A, this paper uses the powerful time domain analysis function of FEKO to simulate the electromagnetic environment in the engine compartment, the electromagnetic environment outside the cabin and the induced current of the cable. According to the simulation results, the coupling values of the engine compartment under the influence of complex electromagnetic environment such as lightning effect and high field intensity radiation are given, which provides the basis for the optimization design of engine and the protection of complex electromagnetic environment.

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