

# Effectiveness Evaluation of Aircraft Electromagnetic Launch System Based on RIMER

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**Abstract.** Electromagnetic launching technology is one of the important application technologies in aerospace field in the future. It will change the way of rocket launching and even be applied to aerospace kinetic energy weapon system. Aiming at the characteristics of various bottom indicators, uncertain information probability and expert participation in the effectiveness evaluation system of aircraft electromagnetic ejection system, based on the index hierarchy model, the method of RIMER(rule-base inference methodology using the evidential reasoning) is used to evaluate the effectiveness, which provides some reference for the design and development of aircraft electromagnetic launching system.

## 1 Introduction

Electromagnetic emission technology refers to the technology of accelerating an object to a certain speed through the Lorentz force and launching it out. With the deepening of related research, electromagnetic launching technology has been used in such fields as ship borne aircraft ejection, UAV takeoff and so on<sup>[1]</sup>. Because of many advantages of electromagnetic launching technology, it will be widely used in aerospace field, especially in rocket launching and space high-energy weapon launching. The performance evaluation of aircraft electromagnetic launching system involves many different attributes. The commonly used methods of effectiveness evaluation have their own advantages. They can get reasonable evaluation results for specific evaluation objects, but they also have limitations. The evaluation method based on belief rule base reasoning can synthesize mufti-attribute indicators with high participation of experts and good traceability and interpretability of the results. In this paper, RIMER is proposed to evaluate the performance of aircraft electromagnetic launching system, which can well solve the problems of various types of underlying indicators, uncertain information probability and requiring experts to participate in the effectiveness evaluation system of the system, and greatly improve the efficiency and correctness of the evaluation, and provide a reference for the application of Electromagnetic Launching Technology in aviation field<sup>[2]</sup>.

## 2 Composition and performance index of aircraft electromagnetic launch system

### 2.1 Composition of aircraft electromagnetic launch system

The typical aircraft electromagnetic launching system includes six subsystems, as shown in Figure 1, namely, command and control subsystem, launch and control subsystem, power supply subsystem, energy storage subsystem, pulse power subsystem and electromagnetic catapult<sup>[3-4]</sup>.

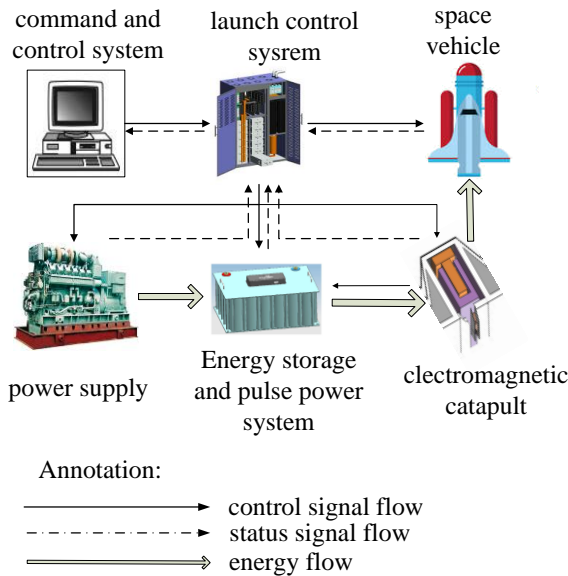
(1) The command and control subsystem is the command information interface between the superior command and the aircraft system, which realizes the upload and delivery of command and control information and instructions transmitted by the aircraft.

(2) The launch control subsystem is mainly composed of input of launch data, discharge control of pulse power supply, control and feedback of aircraft ejection process. Its main function is to load operational parameters of aircraft, adjust launch attitude of aircraft, control coordinated operation of subsystems, system status monitoring, etc.

(3) Power supply subsystem refers to the device that supplies power to the energy storage system by external power supply. It mainly provides stable and reliable power input to solve the energy problems needed for fast energy storage.

(4) The energy storage subsystem is an energy storage device for short time and high power electromagnetic launching of aircraft, which provides the required pulse current.

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**Figure 1.** Composition of electromagnetic ejection system

(5) Pulse power supply subsystem mainly solves the problem of high power and fast discharge, and provides the required current for aircraft electromagnetic transmitter.

(6) Electromagnetic ejector is one of the core components of the aircraft electromagnetic ejection system. Under the control of information, the impulse current is converted into power to accelerate the aircraft, so that the aircraft can reach the required initial speed at a certain acceleration distance, and the ejection mechanism is recovered.

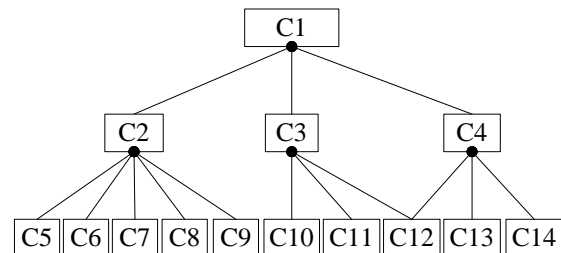
## 2.2 Hierarchical model of system performance indicators

The electromagnetic ejection system should accelerate the aircraft to a certain speed in a certain time by means of the electromagnetic acceleration device within the relative space volume and the allowable mass, and the whole process is completely controllable and stable. Therefore, we define that the performance of the system is determined by three indicators: ejection ability, environmental adaptability and controllability. Among them, ejection capability is determined by motor thrust, motor quality, motor braking capability, motor efficiency, capacity of power conversion equipment and power density of energy storage device, environmental adaptability is determined by motor maintainability, reliability of energy storage equipment and stability of control system, and controllability ability is determined by stability of control system, motor controllability, flexibility of power conversion device and so on<sup>[5]</sup>. Fault detection capability is determined. For ease of description, performance indicators are replaced by different codes.

**Table 1.** Performance Indicators and Symbolic Representation

CODE NAME	PERFORMANCE PARAMETER
C1	electromagnetic emission system performance
C2	ejection ability
C3	adaptive capacity to environment
C4	controllability
C5	motor thrust
C6	motor runner mass
C7	motor braking capacity
C8	motor efficiency
C9	power density of energy storage device
C10	motor maintainability
C11	reliability of energy storage device
C12	control system stability
C13	motor controllability
C14	control flexibility of power conversion device
C15	fault detection capability

Then the following hierarchical structure model is established for each capability index.



**Figure 2.** Hierarchical structure model of performance indicators

## 3 RIMER-based efficiency evaluation method

When using RIMER-based method to evaluate effectiveness, there are the following steps<sup>[6]</sup>:

1. Constructing initial confidence rule base based on experience or expert knowledge;
2. Converting input data and calculating matching degree;
3. Aggregating efficiency from bottom to top to get final effectiveness value.

### 3.1 Constructing an initial confidence rule base

The process is to express the capability requirement, evaluation criteria, expert knowledge and battle case experience of the relevant indicators of equipment

support effectiveness in a unified format. Rule libraries are usually represented as:

$$R_k : \text{if } A_1^k \wedge A_2^k \wedge \dots \wedge A_{r_k}^k, \\ \text{then } \{(r_1, \beta_{1k}), (r_2, \beta_{2k}), \dots, (r_L, \beta_{Lk})\} \quad (1)$$

In rule  $k$ ,  $\beta_{ik}$  denotes the reliability of the conclusion  $r_i$  when the preconditions are established.

### 3.2 Converting input data

Taking a special combat unit as the evaluation object, the value of the underlying capability index is collected as the input of the evaluation, and the input value is converted into the reliability structure data to calculate the matching degree of the attributes in the preconditions of the input rules. The formula is as follows:

$$v(x_i, A_{ij}) = \begin{cases} \frac{A_{i(k+1)} - x_i}{A_{i(k+1)} - A_{ik}} & j = k(A_{ik} \leq x_i \leq A_{i(k+1)}) \\ \frac{x_i - A_{ik}}{A_{i(k+1)} - A_{ik}} & j = k + 1 \\ 0 & j = 1, 2, \dots, |A_j|, j \neq k, k + 1 \end{cases} \quad (2)$$

Among them,  $x_i$  represents the input value and  $A$  represents the value of a certain capability index.

Calculate the matching degree  $\alpha_{ij}$  of individual attributes for all capability indicators. The formula is as follows:

$$\alpha_{ij} = \frac{v(x_i, A_{ij})\varepsilon_i}{\sum_{|A_j|} v(x_i, A_{ij})} \quad (3)$$

Among them,  $\alpha_{ij}$  represents the matching degree of the  $j$  value  $A_{ij}$  of input index capability requirement  $c_j$  to a single attribute.

### 3.3 Index effectiveness aggregation based on evidence reasoning

In this paper, the analytic algorithm is used to aggregate the effectiveness of indicators [6]. The concrete formulas are as follows:

$$\beta_l = \frac{\mu[\prod_{k=1}^K (v_k \beta_{lk} + 1 - v_k \sum_{l=1}^N \beta_{lk}) - \prod_{k=1}^K (1 - v_k \sum_{l=1}^N \beta_{lk})]}{1 - \mu[\prod_{k=1}^K (1 - v_k)]} \quad (4)$$

$$\mu = \frac{[\sum_{l=1}^N \prod_{k=1}^K (v_k \beta_{lk} + 1 - v_k \sum_{l=1}^N \beta_{lk}) - (N-1) \prod_{k=1}^K (1 - v_k \sum_{l=1}^N \beta_{lk})]^{-1}}{\quad} \quad (5)$$

Whereas  $\beta_l$  represents the confidence level of the  $l$  level and  $r$  represents the correction factor.

## 4 Performance evaluation of ejector

### 4.1 Establishment of rule base

According to the established performance hierarchical structure model, according to the relationship between competency factors at different levels, combined with expert opinions and experimental data, the competency of the superiors is empirically determined under different combinations of inferior competencies. Because the evaluation method of confidence reasoning will give confidence to different levels, in general, only qualitative indicators are defined as high, medium and low levels, while quantitative indicators are given three numerical levels. The rule base is established as follows:

**Table 2.** Rule base of C1

C2	C3	C4	satisfie d	basically satisfied	can not satisfied
strong	strong	strong	0.9	0.1	0
strong	strong	weak	0.8	0.1	0.1
middle	middle	weak	0.5	0.3	0.2
strong	weak	strong	0.5	0.2	0.3
strong	weak	weak	0.3	0.3	0.4
weak	strong	strong	0.2	0.7	0.1
weak	weak	weak	0	0.1	0.9

**Table 3.** Rule base of C2

C5	C6	C7	C8	C9	strong	middle	weak
high	95	strong	95	high	0.9	0.1	0
high	95	strong	95	middle	0.8	0.1	0.1
high	85	middle	85	low	0.7	0.2	0.1
middle	85	weak	85	high	0.6	0.2	0.2
middle	60	weak	60	middle	0.5	0.3	0.2
middle	60	strong	60	low	0.4	0.4	0.2
middle	60	weak	95	high	0.5	0.2	0.3
low	95	weak	85	middle	0.7	0.1	0.2
low	85	strong	60	low	0.6	0.2	0.2
low	60	weak	60	low	0	0.1	0.9

**Table 4.** Rule base of C3

C10	C11	C12	strong	middle	weak
95	95	strong	0.9	0.1	0
95	95	middle	0.8	0.1	0.1
85	85	strong	0.7	0.2	0.1
85	85	middle	0.6	0.2	0.2
60	60	strong	0.5	0.3	0.2
60	60	middle	0.4	0.4	0.2

**Table 5.** Rule base of C3

C12	C13	C14	strong	middle	weak
strong	high	strong	0.9	0.1	0
strong	middle	weak	0.8	0.1	0.1
middle	low	weak	0.7	0.2	0.1
weak	high	strong	0.6	0.2	0.2
weak	middle	weak	0.5	0.3	0.2
strong	low	middle	0.4	0.4	0.2
weak	high	strong	0.5	0.2	0.3
weak	middle	weak	0.6	0.2	0.2
strong	low	weak	0	0.1	0.9

#### 4.2 Performance value calculation

When evaluating efficiency, the value of the lowest index should be input. Three groups of different underlying performance parameters (A, B, C) are selected for evaluation.

**Table 6.** The value of bottom indicators

NO.	C5	C6	C7	C8	C9
A	high	98	strong	89	high
B	middle	77	weak	82	middle
C	low	55	weak	61	middle
NO.	C10	C11	C12	C13	C14
A	95	95	strong	high	strong
B	69	84	middle	middle	weak
C	73	56	weak	low	middle

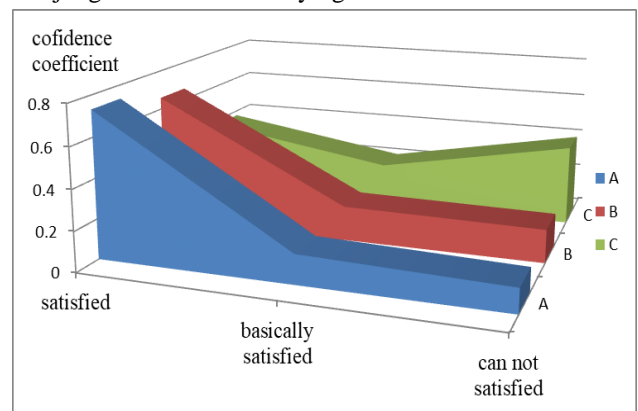
Through calculation, the following evaluation results are obtained.

**Table 7.** Effectiveness evaluation results

equipment	satisfied	basically satisfied	can not satisfied
A	0.7329	0.1473	0.1198
B	0.6596	0.1748	0.1656
C	0.3734	0.2202	0.4046

#### 4.3 Result analysis

From the calculation results, we can see that the overall efficiency of A equipment is better than B equipment, while C equipment is the worst, which is consistent with our judgment of the underlying indicators.



**Figure 3.** Schematic diagram of effectiveness evaluation results

#### 5 Rule base optimization

Since the initial rule base is determined by empirical values, the evaluation results are not very objective. In order to obtain better evaluation results, it is necessary to optimize the confidence rule base. Based on the existing evaluation results of similar systems, this paper adopts the method of parameter optimization to deal with them [7].

The optimization model is as follows:

$$\min MSE(x, \theta, \beta) \quad (6)$$

s.t.

$$lb_m \leq x_m^k \leq ub_m,$$

$$k = 1, \dots, K; m = 1, \dots, M$$

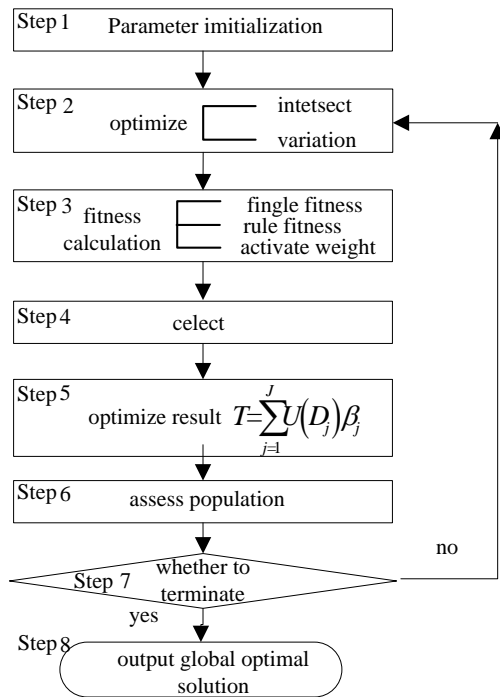
$$x_m^1 = lb_m$$

$$x_m^K = ub_m$$

$$0 < \theta_k \leq 1$$

$$0 \leq \beta_{s,k} \leq 1, \quad s = 1, \dots, S \quad (7)$$

Among them, Formula (6) represents the minimum error between the result and the learning data, and Formula (7) represents the range of the precondition attribute and the initial rule weight.



**Figure 4.** Flow chart of parameter optimization algorithm

The optimized rule base can be obtained by programming.

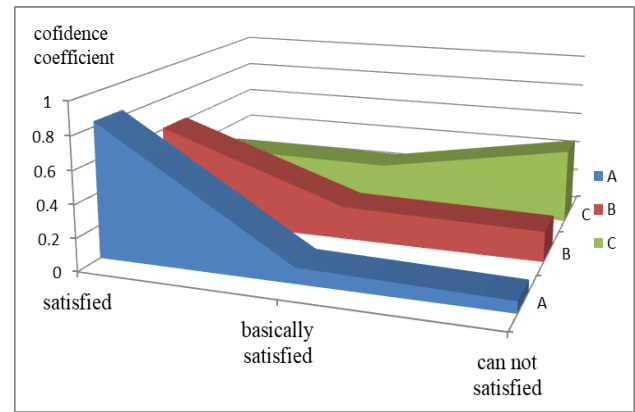
**Table 8.** Optimized rule base (Take C3 as an example)

weight	C11	C12	C13	C14	strong	middle	weak
0.288	60	60	60	60	0.002	0.091	0.91
0.665	64	83	91	99.555	0.728	0.274	0.01
0.028	90	75	85	67.524	0.006	0.316	0.68
0.813	61	69	100	81.102	0.324	0.392	0.28
0.209	100	100	100	100	0.946	0.028	0.04

New assessment results as follow:

**Table 9.** New assessment results

equipment	satisfied	basically satisfied	can not satisfied
A	0.8329	0.0973	0.0698
B	0.6096	0.2048	0.1856
C	0.2714	0.2602	0.4684



**Figure 5.** Schematic diagram of new results

The new evaluation results show that the gap between different equipment has widened, which is to some extent conducive to distinguishing the evaluation results. At the same time, this gap is the true reflection of the effectiveness level of each equipment.

## 6 Conclusion

Aerospace vehicle has high cost and high requirement of launch control, which puts forward higher requirements for the performance of aircraft electromagnetic launch system. Whether in the development and production stage or not, it is important to make a scientific evaluation of the performance of the transmitter. In this paper, the reasoning method based on confidence rule base is applied to evaluate the performance of aircraft electromagnetic ejection system. It not only eliminates the evaluation difficulties caused by qualitative and quantitative index doping, but also fully incorporates the opinions of relevant experts. At the same time, it can adjust the evaluation parameters according to the existing examples, and achieves good results. It provides a reference for the future application of Electromagnetic Launching Technology in aerospace field. It can be used for reference.

## References

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