# THE RESEARCH ON AIRCRAFT RDT&E COST BASED ON GRAY CORRELATION ANALYSIS THEORY AND EQUALATION-ENGINEERING-VALUE-RATE

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## Abstract

*Recently, technology advance in aerospace industry and the introduction of factors as life cycle cost (LCC) make a change of design ideas and design emphases for aircraft. Aircraft design is making a shift from traditional "optimum design for performance" to "design for affordability and quality". Aircraft design is shifting and extending the tradeoffs between traditional disciplines as aerodynamics, propulsion, structure etc to the tradeoffs between these traditional disciplines and non-conventional disciplines including subjects like reliability, maintainability, safety and survivability, as well as crossover disciplines as economics and stability. Economics is becoming a key factor that decision makers judge optimal scheme from some feasible design concepts of aircraft. As the economics metrics, life cycle cost of aircraft is an important design index for modern aircraft system and is one of the key metrics of evaluating the goodness of design scheme for aerospace product. Furthermore, the analysis of life cycle cost is the basis of cost-effectiveness analysis on aircraft.*

*The research, development, test, and evaluation (RDT&E) cost are an important part that makes up the total life cycle cost (LCC) of an aircraft. A method based on gray correlation analysis theory and equalation-engineering-value-rate method for estimating RDT&E cost of aircraft especially in early conceptual design stage is presented. The first task of establishing cost model in the parametric method of life cycle cost is to determine the cost drive factor. Based on large amount of historical data at home and abroad, using the method of gray correlation analysis in gray system theory, the article establishes the determination method of cost drive factor, which overcomes the shortcoming of the lack of data. Combining the features of less known knowledge in early conceptual design stage for aircraft design, the authors propose the definition of equalation-engineering-value-rate and study the RDT&E cost for aircraft by applying the method of equalation-Engineering-value-rate to modify the existed cost model on the basis of the determined cost drive factor and historical data. The method proposed provides a new theory for the establishment of LCC model for aircraft top-level design. Furthermore, the method provides the decision gist for the decision tradeoffs of early stage in aircraft design, and establishes the basis for cost/effectiveness analysis in aircraft design.*

## 1 Introduction

Recently, technology advance in aerospace industry and the introduction of factors as life cycle cost (LCC) make a change of the design ideas and design emphases for aircraft. Aircraft design is making a shift from traditional "optimum design for performance" to "design for affordability and quality". Aircraft design is shifting and extending the tradeoffs between traditional disciplines as aerodynamics, propulsion, structure, etc to the tradeoffs between these traditional disciplines and non-conventional disciplines including subjects like reliability, maintainability, safety and survivability, as well as crossover disciplines as economics and stability [1,2]. Presently, decision makers and designers think much of high effectiveness and high benefit in the deployment of weapon equipment. Meantime, they also think much of the economics and practicability. In the recent years, the economics of aircraft is increasingly paid more attention in aircraft design. The importance for economics of aircraft is equal with the aircraft performance. Economics is becoming a key factor that decision makers judge the aircraft product and an important gist that decision makers select optimal scheme from some feasible design concepts of aircraft.

As economics metrics and comprehensive index of economy feasibility evaluation, the life cycle cost of aircraft is not only the best important design index for modern aircraft system [3], but also one of the key metrics of evaluating the goodness of final design scheme for aerospace product [4,5]. Furthermore, the analysis of life cycle cost for aircraft is the basis of cost-effectiveness analysis on aircraft. The research, development, test, and evaluation (RDT&E) cost are an important part that makes up the total life cycle cost (LCC) of an aircraft. However, a first, important task of LCC especially RDT&E cost analysis is to establish the cost model that is the basis of estimating RDT&E cost. Presently, the method of establishing cost model includes: analogy method, parametric method, engineering estimation method [6]. Parametric method is suited for early stage of aircraft design that has an important influence on aircraft design and entire aircraft system [1]. The parametric method has an important effect and meaning on aircraft cost analysis in aircraft design. Cost parametric model is composed of characteristics parameters that showed the attributes of weapon equipment system such as time, weight, performance, size, and outputs, which composed the equations or equation sets of cost estimation. However, much cost parametric model is mainly obtained by using the technology of multiple regression analysis based on large amount of sample data. In aircraft design fields, the prototype considering the life cycle in China is few and the data is so scarce that they cannot provide effective use for parametric method. So, the research of EDT&E cost for aircraft in China is a question of small sample and multiple data analysis. Under this circumstance, how to effectively, quickly determine what parameter of aircraft system is related to RDT&E cost and furthermore to estimate the cost of new designed aircraft through establishing cost estimating relationship (CERs)/cost parametric model with the historic data according to the determined cost drive factor or establishing the new cost parametric model through choosing the appropriate cost parametric model to modify with other methods to quickly effectively provide a useful tool for estimating RDT&E cost in LCC analysis of new aircraft and scheme optimal selection for aircraft early conceptual design are the springboard and backgrounds.

An available approach to determining cost drive factor in cost parametric model is utilizing the gray correlation analysis technology in gray system theory. In this paper, based on large amount of historical data at home and abroad, using the method of gray correlation analysis in gray system theory to determine the cost drive factor, which overcomes the shortcoming as the scarce product prototypes which considering the entire life cycle and the few sample data when utilizing the technology of multiple regression analysis to establish the mathematics model. Meanwhile, combining the features of less known knowledge in early conceptual design stage for aircraft design, the authors propose the definition of equalation-engineering-value-rate and study the RDT&E cost for aircraft by utilizing the method of equalation-engineering-value-rate to modify the existed cost model established in other countries on the basis of the determined cost drive factor and historic data. The method provides a new theory for the estimation/evaluation of RDT&E cost on aircraft in aircraft top-level design stage. Furthermore, the method provides the basis and decision gist for the decision tradeoffs of early stage on optimal selection of aircraft design scheme and the cost/effectiveness analysis in aircraft design.

## 2 Cost drive factor

The characteristic parameters influencing the cost in LCC model are called cost drive factor. The characteristic parameters influencing the RDT&E cost are more, such as weight, maximum level speed, maximum climb rate, maximum range, mission radius, maximum operational loading factor, utility ceiling, engine maximum thrust, distance of take-off run, landing distance. In cost analysis, it is impossible and unnecessary to consider all parameters when establishing the cost model, we need only to select some important parameters as cost drive factor. If selecting all parameters in cost relation equation, the equation derivation and computing work are very complex, which will increase the difficulty and complexity of the design work. The disposal can catch hold of the mostly contradiction and neglect the subordination contradiction, and decrease the difficulty and interference, and reduce the design cost and improve design efficiency.

### 2.1 the demand for the cost drive factor

Firstly, the parameter is logically, theoretically related to the estimating cost. This mainly emphasized that there are inherent consequence between the chosen cost drive factor and the corresponding cost element, such as the material cost for airframe body is closely related with the airframe weight.

Secondly, the change of cost drive factor is consistent with the change of cost element.

Thirdly, the numerical value of cost drive factor is easily to determine in early stage for aircraft design and manufacture.

Finally, the mutual influence among all cost drive factor for the cost is independently and there is no inherent relation in these cost drive factors.

### **2.2** three dimensional mode of cost drive factor

The parameters meeting the essential demand of cost drive factor are much more. The parameter should be able to comprehensively reflect the features of the design system. These factors can also seen as the available sets of cost drive factors. The parameters can be divided into three types:

Firstly, they are performance parameters that reflect the concrete value of aircraft performance, such as maximum flight speed, maximum operational loading factor etc.

Secondly, they are physics parameters that reflect the possession degree of system to resource such as weight, size, engine power etc.

Thirdly, they are time parameters that reflect the technology level and the advanced degree of system.

These characteristics of system above-mentioned are also called three-dimensional mode of cost drive factor.

### 2.3 Cost drive factor in present research

At present, the RDT&E cost model for aircraft mainly includes three kinds of RDT&E cost parametric model for Aircraft Airframes, avionics and engine. The estimation model of RDT&E cost for Aircraft Airframes involved in the PRC547 model established by American Planning Research Corporation in 1965, the series of DAPCA model established by American RAND Corporation since 1967, the FR-103-USN model proposed by American J.Watson Noah Associates in 1973, MLCCM model updated by American Grumman Aerospace Corporation in 1980, LSSR 56-82 model proposed by American army technology college in 1982 [6-10]. The cost drive factor used in these cost models is listed in table 1.

Table 1 cost drive factor in cost model

| Model | Item | |
|---|---|---|
| | Cost drive factor | Application areas |
| PRC547 | Maximum speed at high altitude, sea-level speed, the ratio for maximum takeoff weight with empty weight, the times index of aircraft designed, the complexity index for airframe weight and adopted technology | Estimating the RDT&E cost |
| DAPCAIII | Airframe weight, maximum speed at best altitude, the times of development and manufacture reflecting the technology level | Estimating the RDT&E cost |
| FR-103-USN | Maximum speed, the ratio for takeoff weight with airframe weight, the technology index of the equipments, the labeled variable reflecting primary missions or performance requirements | Estimating the RDT&E cost for all classes of military aircraft |
| MLCCM | Maximum operational load factor, maximum flight Mach number, gross wetted area, maximum takeoff gross weight, prototype quantity | Estimating the RDT&E cost, operation and maintenance costs of Airframe, Engines and Avionics |
| LSSR 56-82 | Maximum operation load factor, maximum flight Mach number, gross wetted area, maximum takeoff gross weight, prototype quantity | Estimating the RDT&E cost of Airframe engineering for fighters |

## 3 The gray correlation analysis method for the determination of cost drive factor

The first task of establishing the RDT&E cost model in the parametric method is that how to effectively, quickly determine what design parameter of aircraft system is related to the cost, then to estimate the cost of new designed aircraft through establishing cost parametric model using the historic data according to the determined cost drive factor or establishing the new cost parametric model through choosing the appropriate existed cost parametric model and making use of other method. The common quantitative method choosing cost drive factor is mathematical statistics method, as primary element analysis, factor analysis, regression analysis, and variance analysis. These methods have solved many practical questions and played an active role in practice. However, as these methods often need large amount of sample, which is quite difficult to achieve in practice. Thus, it is very difficult to establish the RDT&E model when using statistical method in this circumstance. So, we should explore a new method to establish RDT&E model in few samples. Gray correlation analysis method in gray system theory is a kind of method fitted for the less amount of sample. With the correlation degree analysis, we can find the cost drive factor whose correlation degree related to the cost is bigger and furthermore, we can establish the relation between these cost drive and cost.

The basic theory of gray correlation analysis is to analyze the similarity degree of geometry relation between system data series and based on the similarity degree of geometry relation between data series, to judge the correlation degree between system elements [11]. If geometry relation between a set of data series is very more similar, then the correlation degree between the corresponding data series and system elements represented by data series is bigger, vice versa. If the correlation degree between parameters is bigger, the parameters can indicate each other. The correlation degree between parameters is little, the independence is higher each other and these parameters have no inherent relation. Thus, with the correlation degree analysis, we can judge the key cost drive factor affecting RDT&E cost, furthermore to establish relationship of RDT&E cost model. We can delete large amount of subordination parameters and keep back some characteristic parameters, which is mutually independent and whose influencing degree to cost is bigger. As a result, we can simplify the cost parametric equation under the circumstance in a premise of keeping the calculation precision.

The step of gray correlation analysis is following: (1) determining the compared data series and the referred data series. (2) Calculating the correlation coefficient. (3) Calculating correlation degree, (4) ordering the correlation degree.

Assuming the chosen referring data series is $A_0 = [A_{01}, A_{02}, \ldots A_{0j}, \ldots A_{0m}]$ $(1 \le j \le m)$ , the estimating cost element for different types of aircraft is chosen as the referred data series and an comparing benchmark. $m$ denotes the number of aircraft product type, $A_{0j}$ denotes the cost element of $j^{th}$ product type. $A_i = [A_{i1}, A_{i2}, \ldots A_{ij}, \ldots A_{im}]$ is the compared data series $(1 \le i \le n, 1 \le j \le m)$ . $n$ indicates the number of alternative cost drive factor, $A_{ij}$ is the element that corresponds to $i^{th}$ cost drive factor and $j^{th}$ type. The design parameters that are alternative cost drive factor such as weight, range etc, are chosen as the compared data series in LCC estimation model.

### 3.1 The normalization of indexes value

There are many indexes whose dimensions are different and whose initial values have great quantitatively difference, such as weight, maximum level speed, maximum climb rate, maximum range, mission radius, maximum operational loading factor, service ceiling, distance of take-off run, landing distance and cost. The dimension and initial value for these indexes has remarkable difference. Since the dimension and initial data value between each of cost drive factors and cost data series is quite different, they cannot be compared directly. In order to easily compare and eliminate the influence of different dimension, initial value for the decision result, the initial data of data series is often normalized or non-dimensional when we implement the correlation degree analysis and eliminate the influence induced by the evident difference between data series dimension and initial value. Furthermore, a larger value for some attributes would indicate a preference whereas a lower value would indicate preference for others attributes. This is achieved by converting the attribute rating, $A_{ij}$ , to a normalized rating, $R_{ij}$ . The normalized scales range from 0 to 1 with a larger number indicating a preference. There are different ways for normalization. The common disposal method includes initial value normalization method, average value normalization method, maximum value transforming method [7]. In this paper, the initial value normalization is chosen as follows:

For the benefit index (the larger is the number, the more preferred is the index), the normalization equation is:

$$R_{ij} = \frac{A_{ij}}{A_{i1}} \qquad (1)$$

For the cost index (the smaller is the number, the more preferred is the index), the normalization equation is:

$$R_{ij} = \frac{A_{i1}}{A_{ij}} \qquad (2)$$

where $A_{i1}$ and $A_{ij}$ in both formulas respectively represent the first value and $j^{th}$ value of the $i^{th}$ alternative data serial $(1 \le i \le n, 1 \le j \le m)$ . $R_{ij}$ represents the normalized value of $A_{ij}$ that is corresponding to the $j^{th}$ value of the $i^{th}$ alternative data series.

Using the equation (1) and (2) to normalize the initial data in referencing data series and the comparing data series, we will get equation (3) and (4):

$$R_0 = [r_{01}, r_{02}, \ldots r_{0j}, \ldots r_{0m}] \qquad (3)$$

$$R_i = [r_{i1}, r_{i2}, \ldots. r_{ij}, \ldots. r_{im}] \qquad (4)$$

### 3.2 Computing the correlation coefficient between benchmark data series and comparing data series as well as constructing the correlation coefficient matrix

The correlation coefficient is used to show the relating degree of the corresponding number for the indexes in alternative data series and the referred data series. The larger number for the correlation coefficient indicates the higher relating degree or influencing degree. The difference degree for the evaluation result between the referred data series and the compared data series is represented with the correlation coefficient.

The referred indexes set normalized, $R_0 = [r_{01}, r_{02}, ... r_{0m}]$, is used as the comparing benchmark data series, $R_i = [r_{i1}, r_{i2}, .., r_{im}]$ is used as the comparing data series. The correlation coefficient between the number of $j^{th}$ product for the $i^{th}$ alternative cost drive factor and the cost element for the $j^{th}$ product is defined as [11]:

$$\xi_{ij} = \frac{\min\limits_{i\in n}(\min\limits_{j\in m}|r_{0j} - r_{ij}|) + \xi \max\limits_{i\in n}(\max\limits_{j\in m}|r_{0j} - r_{ij}|)}{|r_{0j} - r_{ij}| + \xi \max\limits_{i\in n}(\max\limits_{j\in m}|r_{0j} - r_{ij}|)}$$

$$(i \in [1, n],\ j \in [1, m]) \qquad (5)$$

where $\xi$ is differential coefficient, whose function is to increase the notability between the correlation coefficient. $\xi \in (0,1)$, it is often selected as 0.5.

The correlation coefficient matrix constructed from the equation (5) is:

$$E = \begin{bmatrix} \xi_{11} & \xi_{12} & \cdots\cdots & \xi_{1m} \\ \xi_{21} & \xi_{22} & \cdots\cdots & \xi_{2m} \\ \cdots & \cdots & \xi_{ij} & \cdots \\ \xi_{n1} & \xi_{n2} & \cdots\cdots & \xi_{nm} \end{bmatrix} \qquad (6)$$

where $\xi_{ij}$ $(i \in [1, n],\ j \in [1, m])$ is the correlation coefficient between the $j^{th}$ number of the $i^{th}$ alternative cost drive factor and the number of the $j^{th}$ cost element.

### 3.3 The calculation model of correlation degree between the compared data series and the referred data series

Based on the correlation coefficient corresponding to the alternative data series of $m$ kind of product type product for the cost drive factor and the referred data series of cost element, we can synthesize to obtain the correlation degree corresponding to the alternative cost drive factor and the cost element, we can also order the correlation degree. The larger the number of the correlation degree is, the larger the influence of the corresponding alternative cost drive factor on the cost is. Thus, based on the sequence of the correlation degree, we can evaluate the influence degree of all cost drive factors on cost. Furthermore, we can determine the key cost drive factor in cost model whose correlation degree with cost is larger and which is closely related to the cost, we can provide the basis and gist for the establishment of cost model.

In cost analysis, we can obtain the computing model between the $i^{th}$ cost drive factor and the cost elements through synthesizing the correlation coefficients of all product types for every cost drive factors. The computing model of correlation degree is:

$$P_i = \frac{1}{m}\sum_{j=1}^{m} \xi_{ij} \qquad (7)$$

where $P_i$ represents the correlation degree of the $i^{th}$ cost drive factor for cost element.

After obtaining the correlation degree between the design parameter and cost for the weapon arm, furthermore, we can estimate the cost of new designed aircraft at home through establishing cost parametric model using the historic data according to the determined cost drive factor or establishing the new cost parametric model through choosing the appropriate cost parametric model to modify.

## 4 The method of the equalation-engineering-value-rate

4.1 The definition of equalation-engineering-value-rate

The equalation-engineering-value-rate is the invest ratio of the committed cost when different countries develop and produce the same product with respective valuta in the same year. In different countries, as the different velocity of economy development and technology advancement, the different change of the valuta, the different time for product design, all these factors will induce the evident influence on the ratio. So, the equalation-engineering-value-rate is not a simple ratio and it has the dynamic feature.

4.2 The achievement of the equalation-engineering-value-rate

In order to obtain the dynamic equalation-engineering-value-rate, we should compare and analyze the existing, correlative technology fields and get the equalation-engineering-value-rate. The simplest and the more reliable method is to establish the dynamic technology parametric cost model for the corresponding technology fields in different countries. It is:

$$C_A = C_A(X_i, T_A, t_A) \qquad (8)$$

$$C_C = C_C(X_i, T_C, t_C) \qquad (9)$$

So, the equalation-engineering-value-rate is:

$$R_i(X_i, T_A, T_C, t_A, t_c) = \frac{C_A(X_i, T_A, t_A)}{C_C(X_i, T_C, t_C)} \qquad (10)$$

Equation (8) means that the committed cost that the countries, A, develops and produces the product $X_i$ when using the technology level at $T_A$ year and counting the sum of all costs with the unchanged price of $t_A$ year. Equation (9) means that the committed cost that the countries, C, develops and produces the product $X_i$ when using the technology level at $T_C$ year and counting the sum of all costs with the unchanged price of $t_C$ year. Equation (10) means that the ratio of the committed cost in two different countries, A,C, that these two countries develop and produce the product $X_i$ that is completely equal in technology performance when they respectively used the technology level at the year of $T_A$ and $T_C$ and counted the sum of all committed costs with the unchanged price at the year of $T_A$ and $T_C$ respectively.

In this paper, the technology field means that the field of the aircraft industry. A is denoted the American. C is denoted the Chinese.

4.3 The features of the equalation-engineering-value-rate

Firstly, the equalation-engineering-value-rate is obtained based on analyzing the statistical model in correspondingly related technology fields such as aircraft, missile, spacecraft, launch vehicle. So, the equalation-engineering-value-rate can better comprehensively reflect the true ration of the equalation-engineering-value for the same fields in two countries.

Secondly, there is no direct relation between the equalation-engineering-value-rate and the exchange ratio of the different valuta for the two compared countries.

## 5 Applied example for aircraft LCC model and the method of equalation-engineering-value-rate

5.1 Sample data

The data for the development and production cost as well as concrete performance data for seven aircraft product are shown in table 2[12]. For keeping secret, the type of different aircraft is indicated as the number of 1, 2⋯7 instead of true name.

Table 2 the sample data of cost and performance parameters for different aircraft products

| Item/type | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 aircraft RDT&E cost (Million RMB) | 34.50 | 140 | 500 | 1776 | 1600 | 11848 | 15624 |
| 2 empty weight (kg) | 14308 | 35488 | 58000 | 34170 | 67970 | 18191 | 12540 |
| 3 maximum level speed (km/h) | 518 | 662 | 974 | 620 | 916 | 2485 | 2650 |
| 4 seal level climb rate (m/s) | 8.08 | 10 | 20 | 9.65 | 14.8 | 150 | 370 |
| 5 ceiling (m) | 8750 | 10400 | 12000 | 10060 | 11370 | 15240 | 18300 |
| 6 distance of take-off run (m) | 640 | 1270 | 2318 | 1090 | 1829 | 427 | 232 |
| 7 distance of landing run (m) | 620 | 1050 | 2143 | 518 | 1174 | 884 | 762 |
| 8 range (km) | 1868 | 5620 | 6400 | 4000 | 5150 | 3220 | 5745 |

5.2 To determine the cost drive factor with the gray correlation analysis theory

The initial data in table 2 have been normalized and non-dimensional. The normalized data are shown in table 3. After computing the correlation degree, the correlation degree of each performance data with cost is shown in table 4.

Table 3 the normalized data of cost and performance parameters for different aircraft product

| Item/type | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 aircraft RDT&E cost | 1.00 | 4.058 | 14.493 | 51.478 | 46.377 | 343.42 | 452.87 |
| 2 empty weight | 1.00 | 2.48 | 4.054 | 3.315 | 4.75 | 1.27 | 0.876 |
| 3 maximum level speed | 1.00 | 1.278 | 1.88 | 1.197 | 1.768 | 4.797 | 5.116 |
| 4 seal level climb rate | 1.00 | 1.24 | 2.48 | 1.19 | 1.83 | 18.56 | 45.8 |
| 5 ceiling | 1.00 | 1.19 | 1.37 | 1.15 | 1.30 | 1.74 | 2.09 |
| 6 distance of take-off run | 1.00 | 1.98 | 3.62 | 1.70 | 2.87 | 0.67 | 0.36 |
| 7 distance of landing run | 1.00 | 1.70 | 3.89 | 0.84 | 1.89 | 1.43 | 1.23 |
| 8 range | 1.00 | 3.01 | 3.43 | 2.14 | 2.76 | 1.72 | 3.08 |

Table 4 the correlation coefficient matrix and the correlation degree ratings for cost and performance parameters

| Item/type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | total |
|---|---|---|---|---|---|---|---|---|
| 1 aircraft RDT&E cost | | | | | | | | |
| 2 empty weight | 1 | 0.993 | 0.956 | 0.824 | 0.845 | 0.398 | 0.334 | 0.7643 |
| 3 maximum level speed | 1 | 0.998 | 0.947 | 0.818 | 0.835 | 0.401 | 0.3557 | 0.7637 |
| 4 seal level climb rate | 1 | 0.998 | 0.9496 | 0.8182 | 0.8355 | 0.3976 | 0.3512 | 0.7627 |
| 5 ceiling | 1 | 0.9875 | 0.9452 | 0.818 | 0.8339 | 0.3984 | 0.3342 | 0.7596 |
| 6 distance of take-off run | 1 | 0.9909 | 0.9542 | 0.8197 | 0.8387 | 0.3976 | 0.3333 | 0.7621 |
| 7 distance of landing run | 1 | 0.9897 | 0.9552 | 0.8171 | 0.8357 | 0.3982 | 0.3338 | 0.7614 |
| 8 range | 1 | 0.9919 | 0.9534 | 0.821 | 0.8384 | 0.3984 | 0.3347 | 0.7625 |

Reviewing the calculation ratings of the correlation degree for cost and performance parameters, we can find that the correlation degree between the empty weight and cost is the biggest and the value is 0.7643. The correlation degree for maximum level speed and climb rate with cost is bigger, their value are respectively 0.7637, 7627. So, when the designer calculates the cost, they can replace each other. It is common to take the maximum level speed as the parameter in LCC model. Additionally, the correlation degree of the aircraft range with cost is bigger and its value is 0.7625. The correlation degree for the takeoff distances and landing distances with cost are comparatively smaller, the value are respectively 0.7621, 0.7614. The correlation degree of the ceiling with cost is the smallest, the value is only 0.7596.

According to the analysis result above, we can choose the weight, maximum level speed as the design parameters or cost drive factor in LCC model. Additionally, since the time of developing and producing the aircraft also affects the cost of aircraft system in some degree, we introduce the manufacturing time exponent into the LCC model. Furthermore, a characteristic parameter that is non-performance parameter, aircraft output, has also an important effect on the aircraft cost. So, the parametric cost model for the development and produce cost for the aircraft airframe is:

$$C = C(W, V_M, T, N) \qquad (11)$$

where $W$ is the airframe weight, $V_M$ is the maximum level speed; $T$ is the design time exponent, $N$ is the aircraft outputs.

According to the cost drive factor determined by using the gray correlation analysis theory, we can choose the appropriately existed cost model to modify and obtain the proper cost model fitted for the new design aircraft product.

5.3 The RDT&E cost model and the modification of the model

Utilizing the determined cost drive factor above and contrasting the cost models in table 2, we select the cost model, DAPCA Ⅲ, designed by the RAND Corporation in American as the basis of the cost model of new aircraft. For brevity, the description of the cost model, DAPCA Ⅲ is no mentioned here and has been omitted for space limitations. The interested reader can see the references [6,8].

The basis of the establishment for the cost model of the DAPCA Ⅲ in RAND Corporation is the sample data in American. The cost model cannot be directly applied to the aircraft product in China and the DAPCA Ⅲ model must be modified by using the equalation-engineering-value-rate.

Selecting the data for five kinds of aircraft product as the input data to the RDT&E cost model, DAPCA Ⅲ, we can calculate and obtain the development and production cost for five kinds of aircraft product under the circumstances of American. By comparing the different development and produce cost in two different countries and calculating the equalation-engineering-value-rate, we can get the equalation-engineering-value-rate for the equal vent product. The result is shown in table 5 and plotted in Figure 1.

Table 5 the cost and the equalation-engineering-value-rate for different types of aircraft product

| Item/type | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 RDT&E cost (Million RMB) | 10.2 | 12.66 | 16.87 | 51.16 | 374.1 |
| 2 Calculated cost (Million Dollar) | 50.55 | 47.6 | 63.77 | 189.3 | 1223.2 |
| 3 equalation-engineering-value-rate | 4.96 | 3.78 | 3.76 | 3.70 | 3.27 |

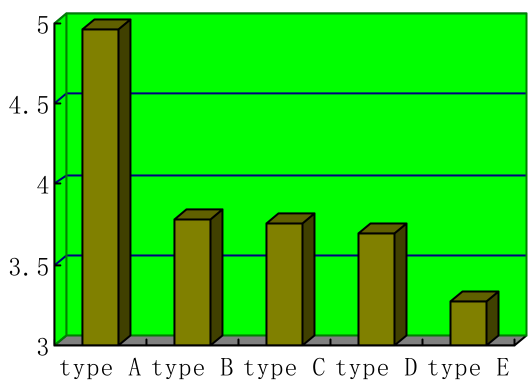


Fig.1the results of the equalation-engineering-value-rate

We can take the average number of the sum for the equalation-engineering-value-rate calculated for different aircraft product as the final equalation-engineering-value-rate. The final value for the equalation-engineering-value-rate is 3.89.

Modify the cost model, DAPCA Ⅲ, established by RAND Corporation in American with the final equalation-engineering-value-rate, we can obtain the cost model fitted for the new aircraft product designed in China. If we need predict the cost of new aircraft product in China, we can get the predicted value of the new designed aircraft, $C_{predicted,new}$, by using the cost model in foreign countries. Then, the value $C_{predicted,new}$ is transferred to the value $C_{invested,new}$ through utilizing the formula: $C_{invested,new} = C_{predicted,new} / k$ . Thus, we can get the cost for the new designed aircraft in China.

## 6 Conclusions

In this paper, aiming at the shortage that the amount of aircraft product lived through life cycle is few at home and the sample data cannot provide effective use for the parametric method of the LCC model, based on the large amount of historical data for aircraft cost and performance at home and abroad, the authors discussed a method that determines the cost drive factor in RDT&E cost research for aircraft by using the method of gray correlation analysis theory in gray system theory. Its basic characteristic is to determine the key factors that influence the aircraft cost according to the number of the correlation degree between different cost drive factors and cost elements. Furthermore, combining with the features of less known knowledge in early conceptual design stage for aircraft design, the authors propose the definition of equalation-engineering-value-rate and modify the parametric cost model established by using the data in foreign countries to obtain the new cost model fitted for the aircraft product in China, which can estimate the cost of aircraft product in early conceptual design stage in China. The paper provides the simpler method for the practicality of aircraft cost model. Meanwhile, we can also introduce the equalation-engineering-value-rate into the cost model established by using other method. The method in this paper can effectively overcome the shortcomings as the few product amounts considering the life cycle and the few sample data for aircraft cost research in China. The method provides a new thought and theory for establishing and determining the LCC model in aircraft top-level design stage. Furthermore, the method provides a new thought or decision basis for the decision tradeoffs of aircraft early design stage in aircraft design. Ultimately, the method provides the useful gist for the cost/effectiveness tradeoffs and the optimal scheme selection in aircraft design.

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