29th Congress of the International Council
of the Aeronautical Sciences
St. Petersburg, Russia; September 7-12, 2014

THE TRANSFORM PRINCIPLE AND MODEL FOR AIRCRAFT MTTR IN THREE-DIMENSIONAL DIGITAL DESIGN CONDITION

Gangde Lu
Chengdu Aircraft Design & Research Institute, Chengdu, China

Keywords: *digital design; MTTR transform; modeling; maintainability*

Abstract

To solve the foundation problem of maintainability design that base on aircraft digital model, this paper puts the maintainability design parameter and maintainability demand, the expression manner and best method of the maintainability parameters-set of all kinds of electron product and machine product and mechanism product on study. By analyzing the essence of the Mean Time to Repair(MTTR) which is the important parameter in aircraft maintainability design, this study bring forward the technique, method and model, which can disassemble and transform the MTTR into parameters that can be designed and controled easyly in digital-design condition. Base on three-dimensional digital design model, the parameters-set of maintainability analysis and design has been formed, and the base theory and method of quantitive maintainability design has been constructed. This model is proved sound practicable through preliminary verification in the prototype system.

1 Maintainability Design Demand and Its Actualizing Puzzle

Generally, in aircraft maintainability design, it needs to adopt series of activities of design and analysis and evaluation of maintainability, which make it convenient, fast and economic to repair aircraft. It needs to raise qualitative and quantitative demands of maintainability design.

Qualitative demands have the main aspects: accessibility, crossing-over, standardization, anti-mistake methods, maintenance safety identification, and good testability; minimize the needs of works and human skills, human factor engineering, adjustment, assembly, layout design, maintenance cover definition and design, etc. In the process of maintenance design, qualitative demands come true through restriction of criterion documents, and make sure by the designers. In possible occasion, the electronic sample or real sample is used to demonstrate or check to confirm that the qualitative demands are meet.

Parameterized maintainability quantitative demands, are mainly MTTR, direct maintenance man-hours per flight hours (DMMH/FH) and engine repair time (ERT). These quantitative demands, in design, generally are allocated to the system by allocation model, and then the equipments, and be realized by design of the equipment and system. The methods are mainly repeating allocation and prediction, and design modification to meet the demands.

But it is seeming and ideal situation, mostly it is confused that, in the early design stage, we can't get the data to meet the demand of the maintainability prediction, especially in new design, so the aim of the assessment, calculation and improvement of maintainability can’t be achieved. Until the flight test stage, analyze and assess the maintainence level by using the real aircraft, when we dig out that the index can’t be achieved, the design is finishied, there are many difficulties to solve the problem of maintainability to achieve the index, the problems such as influence many aspect, cost a lot, no time or hard or impossible to improve. And, in the current design to meet demand of the MTTR, MTTR will be broken down to system and then to equipments, the equipments become the carrier to realize the demand. In fact, equipment maintenance design is just a part of its MTTR, and the aircraft general layout is the main part of MTTR design. It is the main reason of not having high maintainability level, that the maintainability influence of the general layout design and the system design is not considered, and that there is no technical method to ensure them to be considered in aircraft design. The core is that maintainability parameters is independent in design parameters, that the method of design and analysis of maintainability is also assistant, that there is no good way which can being used to combine with the process of aircraft design. All of above cause that maintainability can't get change along with the change of design project of the equipment and the subsystem, and can't be controlled, calculated, evaluated, improved dynamically.

At present, the method and theory adopted looks like systematization, but in real design process, the parameterized maintainability demands are separated with the design, the challenge is more stands out especially in digital design condition. Now, the process of design, adjustment and optimization of aircraft is mostly the process based on the 3D sample model, how can we solve the old problem to fit the new need? That is, to transform the traditional quantitative index (such as MTTR) to demands of the aircraft design' parameter. The core problem is that the maintainability parameter should be transformed to physics parameter which can be designed and controled, in order to realize the index in phase.

2 Digital Representation of Maintainability Design

2.1 Maintainability Design Process Analysis

Before the maturity of three-dimensions design condition, the methods and process of maintainability design, analysis, prediction, are a series of manual-design and calculation which surrounding engineering design. It has obvious difference between digital maintainability design and traditional maintainability design. In the digital-engineering design condition, the process of maintainability design, analysis, prediction, is calculational activity and the parallel dealing.The differences are shown in fig.1 and fig.2, as follow.

In digital design condition, it is needful that the maintainability design process can cooperate with the process of product design. The changes of the maintainability level that following the changes of the product design should be known at any moment. Here, in the design process, the demands and parameters of maintainability need to express to digital demands and parameters, rather than paper demands and parameters. The paper demands are just baseline archives. This is the challenge for maintainability design.

2.2 Digital Representation of Maintainability Design

Three kinds of models have been studied and adopted to meet the demand of maintainability design digital representation under 3D condition. They are:

Maintainability information model (MIM, fig.2). MIM is a model describing maintenance information by digital manner and hierarchy structure being consistent with aircraft design process. MIM expresses perfectly the logic, hierarchy and sorting information of maintenance. MIM includes cabin maintainability information model (CMIM) and system maintainability information model (SMIM). Using the form of info unit, CMIM describes cabin, equipment and disassembly relationship between equipments (e.g. node 1 info unit, node 2 info unit, node 3 info unit, … , disassembly relationship info unit, cabin info unit). CMIM is built by researching the sequence of removing equipment from cabin. Node info unit involves requirement info, design info and resource info. SMIM describes system, equipment, arrangement of system and equipment. Such as node 1 info unit, node 2 info unit, node 3 info unit, …, composing of system info unit, hierarchy structure info unit, etc.

Designing & controlling Parameter model (DCPM, fig.2). DCPM is put forward based

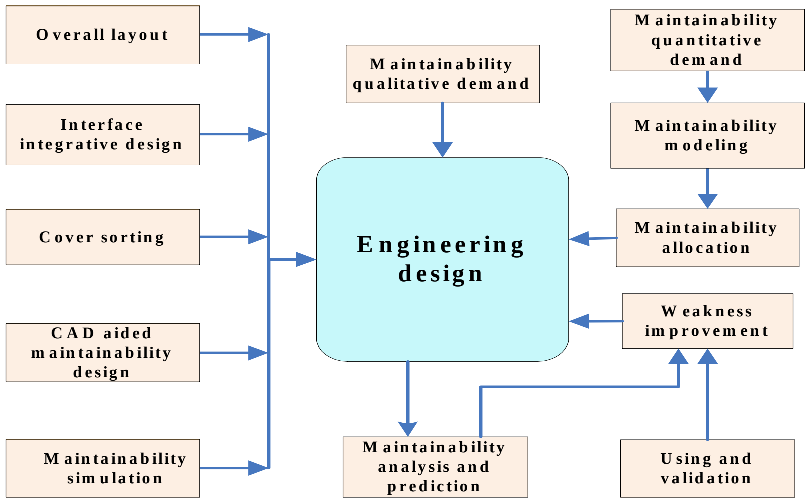

Fig.1 The Traditional Maintainability Design Process

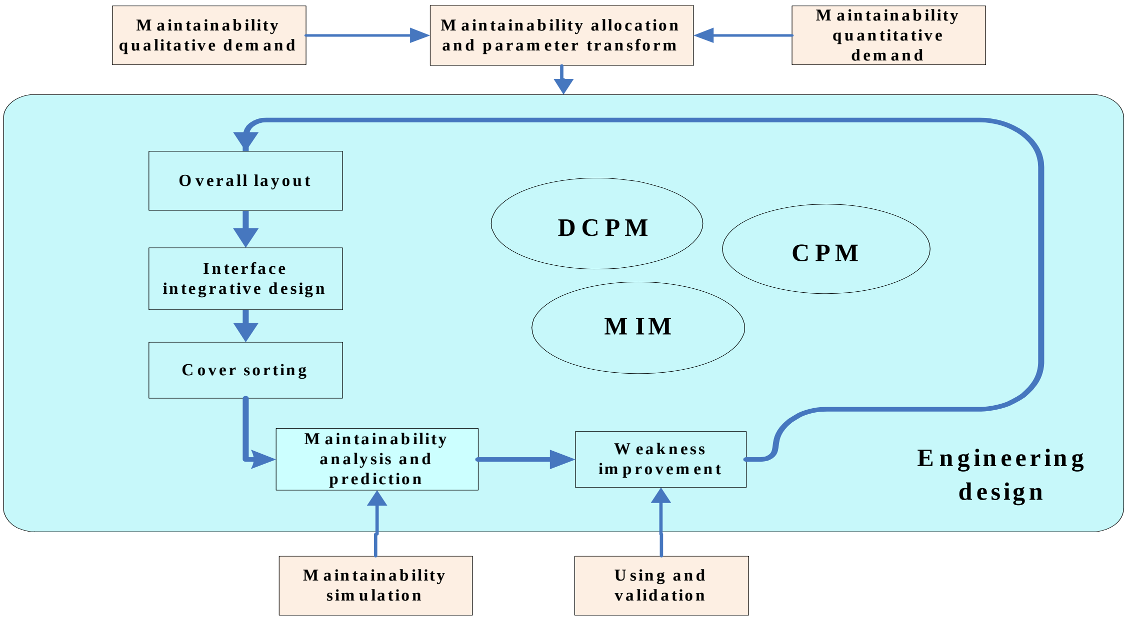

Fig.2 The Maintainability Design General Process In Digital Condition

on requirement and design characteristic of maintenance in three typical equipments which mean machine-electron, electron, and mechanism. DCPM expresses perfectly the info in which indicated system, equipment and machine's designing factors, using digital and hierarchy structure in three-dimensional design condition. DCPM integrally explains the logic, hierarchy and designing factor info. In DCPM, the design parameters exist in the form of aggregate of designing factors. In the three-dimensional design condition, the designing factors include interspace, time, process and order of disassembly & installation, and obstructing from disassembly. The aggregate of designing factors are embeded in engineering environment in the form of property, such as interface, fixing, position and access. DCPM involves restriction parameter, sort of access parameter, size of access parameter, position parameter, connecting parameter, interface parameter, contiguity, clearance, inside and outside, link of function, etc.

Calculation parameter model (CPM, fig.2). CPM is a model describing maintenance quantificational calculating information by digital and hierarchy structure in the research & manufacture process of aircraft. CPM expresses the logic, hierarchy and sort structure of maintenance quantificational information. CPM includes failure rate of equipment, failure mode, expressions, weight, disassembly & installation time of unit, bracket, and bolt, metadata, experience-data, restriction-data, sortting of equipment, etc.

3 Method and Model for MTTR Transform

3.1 Maintainability Design Parameter Transform

For translating the index of maintainability into the process parameters and design control parameters in product design, we define and take the following process.

First, put the maintainability design requirements into parametric description and quantitative digital representation. The index for the whole aircraft, need express to vector parameters which are divisiory according to location in cabin. Division in parameters, the MTTR can be described into M_{CT1}、 M_{CT2}、 M_{CT3}、 …, M_{CTn}, for example. Here, the ‘n’ stand for the number of roomage partition. And then, the maintainability parameters are validated and analyzed according to the design of cabin, system, aircraft, these parameters are based on roomage partitioning and positioning. Whereafter, design process model will be founded according to cabin, and the parameter index will be put into the desgin process parameters index which based on special cabin. Then, translate the desgin process parameters into restriction parameters for design element. Lastly, in the course of the entire design, it is only need to control the design element that affect maintainability level according to fulfill maintainability requirement.

The commonly process for the maintainability design parameters transform is shown in Fig.3.

3.2 Conversion Method and Design Method for MTTR

It is explained in the following, MTTR conversion as the core, that the technical methods and models to convert maintainability parameters to design parameters. Assume the aircraft MTTR is $\overline{M}_{ct}$, for MTTR of anyone cabin:

$$\overline{M}_{cti} = \frac{\overline{M}_{ct}\sum\lambda_i}{n\lambda_i} = \frac{\overline{M}_{ct}}{nW_i} \qquad (1)$$

$$W_i = \frac{\lambda_i}{\sum_{i=1}^{n}\lambda_i} \qquad (2)$$

here, λ_i —dummy failure rate of cabin ‘i’, n—total number of cabin, W_i — weighted factor of dummy failure rate of the ith cabin.

Analyzing and validating the dummy MTTR of each cabin from 1 to i, and checking computation the aircraft MTTR ($\overline{M}_{ct}$), need to fulfil $\overline{M}_{ct} \le \overline{M}^*_{ct}$. The $\overline{M}^*_{ct}$ is aircraft MTTR index

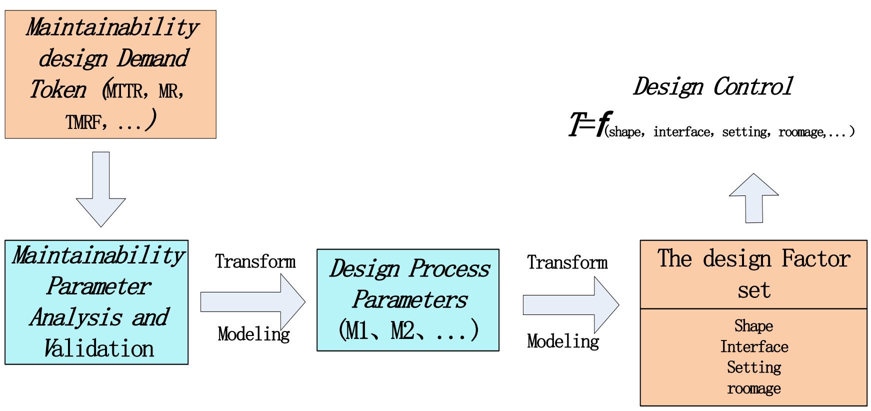

Fig.3 The Process of The Maintainability Design Parameters Transform

required. For all cabin 'n', the baseline demand set D ($\overline{M}_{ct1}$, $\overline{M}_{ct2}$, $\overline{M}_{ct3}$, …, $\overline{M}_{cti}$, …, $\overline{M}_{ctn}$) is formed.

For a complex aircraft system, the difference between each subsystem is bigger, to different subsystems (such as avionics system, aircraft management system, fuel system, power system, etc.) and different device, the design factor and the influence mechanism and the way which affect maintainability are not the same. For this reason, we sort the equipments of aircraft to three typical types: machine-electrical, electrical, structural, and similar equipment has similar maintainability feature. All sorts of conversion technology and the corresponding models are separately discussed, so that the time requirement can be converted to time characteristics, which can be controlled by designer in engineering design setting, can be directly restricted by physics design characteristics. After analyzing of system and equipment, the design characteristics, and the relationship of maintainability demand and design characteristics, we find:

The requirement $\overline{M}_{cti}$ for specific cabin is formed by all of its internal equipment maintenance activities. The design requirement MTTR of equipment in cabin is:

$$\overline{M}_{etj} = \frac{\overline{M}_{cti}}{m \cdot \lambda_j} \sum \lambda_j \qquad (3)$$

here, λ_j—failure rate of equipment 'j', m —total number of equipments.

For all equipments 'm' in cabin, the baseline demand set E ($\overline{M}_{et1}$, $\overline{M}_{et2}$, $\overline{M}_{et3}$, …, $\overline{M}_{etj}$, …, $\overline{M}_{etm}$) is formed.

Mechanical-electrical equipment is typical part of the environment control system, the hydraulic system, the fuel system, the power supply system, and the engine system, etc. Level 1 maintenance is divided into several parts, such as location fault (T_{fc}), teardown (T_{td}), instead and installation (T_r), running seeing (T_{rs}).

$$T_e = T_{fc} + T_{td} + T_r + T_{rs} \qquad (4)$$

There are a large number of electronic equipments in avionics system, aircraft management system. In design, the kind of equipment has generally good testability and build in test ability, the fault is detected and confirmed after a short time. Level 1 maintenance is divided into several parts, such as fault detection (T_{di}), teardown (T_{td}), instead and installation (T_r), power on check (T_c). Maintenance time is mainly the time to replace the fault pieces, and the power up checking time. The equipment maintenance time is:

$$T_e = T_{di} + T_{td} + T_r + T_c \qquad (5)$$

Structure type devices are mainly aircraft body, wings, mechanisms, rudder structure and their affiliated pieces of parts. Don't here for discussion.

Based on the analysis of the above, the remove and installation time account for the most part in the entire replacing repair. In process of equipment disassembling, installation and maintenance, the remove-installation time is a function of the process unit. Define process unit standard time as metadata for support maintainability design process. Maintenance remove-installation time model is as follows. Define t_1 and t_k as open cover unit and close cover unit for maintenace processes unit, separately, well then:

In simple serial cases, take down and fixing time T_{tf} is:

$$T_{tf} = \sum_{i=1}^{k} t_k \qquad (6)$$

With parallel cases, assume that from 'l' to 'm' units in parallel, the parallel part T_{lm} as follow:

$$T_{lm} = \max\{ t_l, \ t_{l+1}, \ t_{l+2}, \ldots, \ t_m \} \quad \ldots\ldots\ldots (7)$$

in a general way,

$$T_{tf} = t_1 + t_2 + t_3 + \ldots + \max\{ t_l, \ t_{l+1}, \ t_{l+2}, \ldots, \ t_m \} + \ldots + t_k \quad \ldots\ldots\ldots (8)$$

The disassembly-fixing repair process, is directly related to the design parameters of equipment and cabin, and these parameters can be designed and controlled directly also. The impact of these design parameters on the maintenance is embodied in the process unit t_i.

Define process unit sensitivity S_p, in which, S_i is the ratio of the disassembly-fixing time increment of equipment and the ith process unit time increment, namely $S_p=\triangle T/\triangle t_i$. Define MAX3 as the preceding three value of S_1, S_2, S_3, …, S_n, they are ordered from big to small. Noted as MAX3 $\{S_1,S_2,S_3,\ldots,S_n\}$, then the design parameters that correspond with MAX3 are the control parameters.

Then, compute the MTTR of devices and the virtual MTTR of cabins in the following formula, and confirm that the equipment baseline requirements E and the cabin baseline requirements D can be satisfied. Namely $M_{etj} \le \overline{M}_{etj}$, $M_{cti} \le \overline{M}_{cti}$.

$$M_{etj} = (\sum_{i=1}^{k} t_i \lambda_i) \ / \ \sum_{i=1}^{k} \lambda_i \qquad (9)$$

$$M_{cti} = (\sum_{j=1}^{m} M_{etj} \lambda_{ej}) \ / \ \sum_{j=1}^{m} \lambda_{ej} \qquad (10)$$

With digital design model, maintainability design parameters include the parameters of the product geometry, the physical interface, the cabin space, and the repair process units. Using the maintainability conversion method, as above, it is possible to directly characterize, design and evaluate maintainability by typical design parameters in the design of product.

4 Preliminary Application Demonstration

With 3D digital design environment, by establishing a simple maintainability information model, design control parameters model and calculation parameters model, MTTR requirement baseline D and E defined in this paper are established, the MTTR conversion method proposed in this paper is adopted to write a simple calculation program. All of them form a prototype system, and the maintainability design analysis process in which the MTTR is translated into design control requirement is verified by the prototype system formed in this paper.

In the instance, three equipments are selected to be installed in the cabin, they are one mechanical-electrical equipment installed to use screw and clamp hoop, two electronic equipments installed with a standard rack. There are a B-class cover and A-class cover on the surface of shipping space. Baseline required time D for 15 minutes. Maintenance process is divided into open cover, remove hold up equipment, diamantle equipment and pipeline, install equipment, join pipeline, install hold up equipment, and close cover, a total of seven steps.

By transforming connect-part amount and fixed way, assume the metadata of maintenance step time that are synchronous with design are t_1, t_2, t_3, t_4, t_5, t_6, t_7, and consider that there are parallel units, the preliminary practicability of MTTR transform model proposed this paper is validated. The verification for the MTTR disassemble and transform model is shown in fig.4.

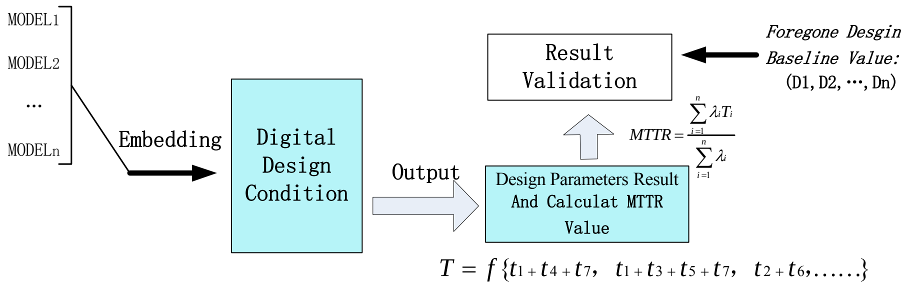

Fig.4 The MTTR Disassemble and Transform Model Verification

5 Conclusion

In this paper, based on the analysis on the general flow for maintainability design, maintainability parameter digital representation model is established. Through the analysis of design essence and design parameter set of MTTR, put forward a set of MTTR transformation method and model in the three dimensional design environment.The method and model are proved practicable by preliminary validating in the prototype system. It has laid a foundation for more research on maintainability design and control.

Reference

[1] 张柳，于永利. 基于 GRASP 的系统维修时间和维修工时模型. *中国机械工程*, Vol. 13, No. 7, 第 577-579 页, 2002 年 4 月.

[2] 袁劲涛, 孙宇峰 等. 装备系统 RMS 要求论证数据模型研究. *航空可靠性工程技术与应用*, 第 369-374 页, 国防工业出版社 2008 年 10 月.

[3] REN Xinxin, YANG Bingxi, LIU Yixin, MA Jiangyi. THE ANANLYSIS AND IMPROVEMENT FOR IEC706-6-94 MAINTAINABILITY ALLOCATION METHOD. *The Proceedings of the Fist International Conference on Maintenance Engineering,* October 15-18, 2006, Chengdu, China. pp 980-985, SCIENCE PRESS 2006.

Copyright Statement

mail to: lvgangde@sina.com.cn