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MBD-Based Parallel Change Management for Aircraft Assembly Tooling

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Abstract. Aircraft assembly tooling is developed according to the assembly requirements of aircraft, and frequent aircraft changes can cause assembly tooling tasks to change frequently. Due to the mutual relations between the tasks of assembly tooling, change in one task can be propagated to many other tasks. This paper propose a parallel change process of aircraft assembly tooling development. A method is given to simulate the change process to shorten the duration and save resource consumption.

1. Introduction

In order to shorten the development cycle of aircraft, aircraft assembly design and assembly tooling development are implemented in parallel. The design of aircraft assembly can be changed frequently and assembly tooling is developed according to aircraft assembly requirement, which can inevitably lead to the change of assembly tooling. Besides, assembly tooling parts can be mutually affected due to the realtions (e.g. geometrical constraint) between them. This paper presents a method to analyze the parallel change process of assembly tooling parts due to the change of aircraft assembly requirement.

2. Related researches

At present, the research on the collaborative change of aircraft-assembly tooling is mainly reflected in the associative design and the analysis of change propagation, which have a strong dependency between each other. Associative design has many applications in the mechanical design industry [1, 2].

In order to achieve multiple professional association design in aircraft design, the multi-stage skeleton model of the design is established by Fu [3]. Fuh [4] developed a distributed CAD system based on network technology, which realizes the distributed collaborative design of products. At present, parameterized association design is widely used in mainstream CAD software, such as CATIA V5 and ProE. Pan [5] put forward a kind of assembly tooling variant design method based on axiomatic design principle in the course of frequently modification of assembly tooling design. However, there is little research on the collaborative change management of aircraft and assembly tooling based on 3D digital model. At present, the collaborative change process of aircraft-assembly tooling is mainly about process management. Aircraft-assembly tooling lacks a digital correlation expression and the influence of engineering change on assembly tooling cannot be analyzed overally. It has become one of the bottlenecks in the collaborative change management of aircraft-assembly tooling.

3. Aircraft-assembly tooling collaborative defined MBD model

3.1 Assembly process MBD model of aircraft assembly

Assembly process MBD model of aircraft assembly is produced in the process plan. The MBD model of aircraft assembly and sub-assemblies can be expressed in formula (1) and (2).

$$\mathrm{M_P}(\mathrm{A}_t)=\left\{\sum_{i=1}^{m}\mathrm{M_P}(\mathrm{SA}_i)\oplus\sum_{j=1}^{n}\mathrm{M_E}(\mathrm{P}_j)\oplus\sum_{k=1}^{s}\mathrm{CF}_k\oplus\sum_{l=1}^{t}\mathrm{FN}_l\right\} \quad (1)$$

$$\mathrm{M_P}(\mathrm{SA}_i)=\left\{\sum_{j=1}^{n}\mathrm{M_E}(\mathrm{P}_j)\oplus\sum_{k=1}^{s}\mathrm{CF}_k\oplus\sum_{l=1}^{t}\mathrm{FN}_l\right\} \quad (2)$$

where MP(A_t): assembly process MBD model of aircraft assembly A_t; MP(SA_i): assembly process MBD model of sub-assembly SA_i; ME(P_j): part design MBD model; CF_k:coordination characteristics of assembly tooling design; FN_l: assembly process document number.

3.2 Assembly tooling development MBD model

Assembly tooling is used to control the aircraft geometry and position parameters in its assembly process. Assembly tooling can be structurally divided into assembly, sub-assembly and parts.The aircraft assembly is used for assembly parts of aircraft to ensure the assembly accuracy. Sub-assembly are independent modules in assembly tooling. The parts are the objects at the bottom level of the assembly tooling. The assembly tooling design MBD model can be expressed by formula (3), the MBD model of sub-assembly and part can also be expressed as formula (4) and (5).

$$\mathrm{M_E}(\mathrm{A}_{\mathrm{A}t})=\left\{\sum_{c=1}^{p}\mathrm{CF}_c\oplus\sum_{d=1}^{z}\mathrm{FN}_d\oplus\sum_{i=1}^{m}\mathrm{M_E}(\mathrm{SA}_{\mathrm{A}i})\oplus\sum_{j=1}^{n}\mathrm{M_E}(\mathrm{P}_{\mathrm{A}j})\oplus\sum_{k=1}^{s}\mathrm{Q}_{\mathrm{A}k}\oplus\sum_{q=1}^{z}\mathrm{L}_{\mathrm{A}q}\oplus\sum_{l=1}^{t}\mathrm{N}_{\mathrm{A}l}\right\} \quad (3)$$

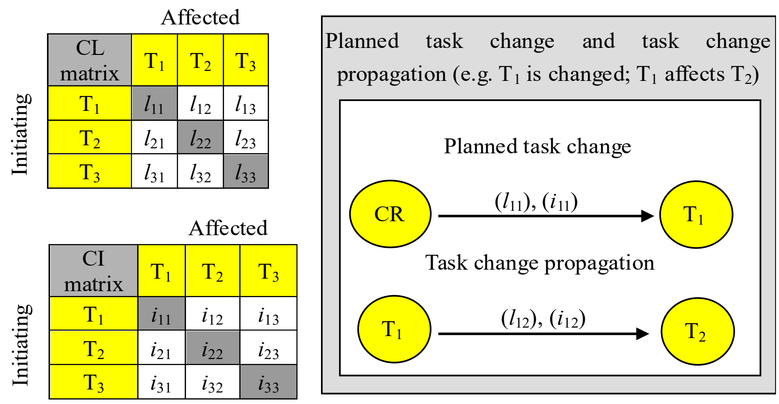
$$\mathrm{M_E}(\mathrm{SA}_{\mathrm{A}i})=\left\{\sum_{j=1}^{n}\mathrm{M_E}(\mathrm{P}_{\mathrm{A}j})\oplus\sum_{k=1}^{s}\mathrm{Q}_{\mathrm{A}k}\oplus\sum_{q=1}^{z}\mathrm{L}_{\mathrm{A}q}\oplus\sum_{l=1}^{t}\mathrm{N}_{\mathrm{A}l}\right\} \quad (4)$$

$$\mathrm{M_E}(\mathrm{P}_{\mathrm{A}j})=\left\{\sum_{h=1}^{n}\mathrm{G}_{\mathrm{A}h}\oplus\sum_{k=1}^{s}\mathrm{Q}_{\mathrm{A}k}\oplus\sum_{l=1}^{t}\mathrm{N}_{\mathrm{A}l}\right\} \quad (5)$$

where $M_E(A_{At})$: assembly tooling development MBD model; $M_E(SA_{Ai})$: sub-assembly development MBD model; $M_E(P_{Aj})$: part MBD model; CF_c, FN_d is coordinate feature geometry set and assembly process file number respectively. Q_{Ak}: characteristic; L_{Aq}: constraint relations, which records the mapping relationship between aircraft assembly requirement and assembly tooling part, parallel development process of assembly tooling parts; N_{Al}: annotation; G_{Ah} : part geometry model.

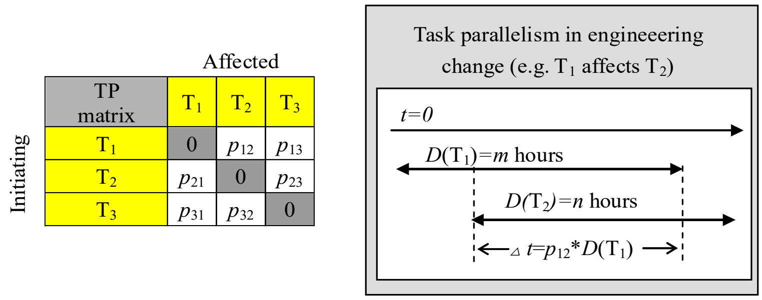
4. Relation between assembly tooling parts

In this paper, CL (change likelihood) and CI (change impact) are used to describe the change propagation relation between assembly tooling parts. TP (task parallelism) is used to demonstrate the parallel extent between development process of assembly tooling parts. Besides, in figure 1 and 2, CL (CI) matrix and TP matrix for the assembly tooling are introduced to demonstrate relations between tasks of assembly tooling change.



Tip: CR represents changed assembly requirement of aircraft; T_1, T_2, T_3: development of assembly tooling parts

Fig.1. CL matrix and CI matrix of assembly tooling



Tip: $D(T_1)$, $D(T_2)$ represent the duration of tasks T_1 and T_2 respectively; T_1, T_2, T_3: development of assembly tooling parts

Fig.2. TP matrix of assembly tooling

5. Parallel change process between assembly tooling parts

5.1 Task model

Development task model of assembly tooling part can be described as shown in Equation (6).

$$A_p = (s, t, r, n) \tag{6}$$

where $1/s$ is the weight of the activity within a task and the larger $1/s$ is, the earlier the activity is executed. t is the expected duration of the activity. r and n are the code and quantity of required resource for the activity.

5.2 Parallel change process

Assumptions are made to simulate the parallel change process as follows:

a. A change propagation path of assembly tooling tasks is regarded as a candidate of the engineering change scheme for the changed assembly requirement of aircraft.

b. In the iteration process, the same changed task of assembly tooling cannot be implemented simultaneously.

c. Resources can be used for multiple activities and can be used again once they are released.

d. The change propagation process will be ended when the impact factor of the upstream task on the affected task is less than 1%.

e. The affected tasks cannot be finished earlier than the upstream tasks.

According to the above assumptions, mathematical models are formulated in Equations (7-10):

$$t_S^k(\mathrm{T}_j) + pi_{ij} * D(\mathrm{T}_j) \le t_S^{k+1}(\mathrm{T}_j) \tag{7}$$

$$t_S(\mathrm{A}_i) + RD(\mathrm{A}_i) \le t_S(\mathrm{A}_j), \quad i < j,\ w_i \ne w_j, (\mathrm{A}_i, \mathrm{A}_j) \in \mathrm{T}_c \tag{8}$$

$$\sum_{i=1}^{N} r_{id} \le R_d, \quad \forall d, t \tag{9}$$

$$t_E^U(\mathrm{T}_i) \le t_E^D(\mathrm{T}_j) \quad (10)$$

where $t_S^k(\mathrm{T}_j)$ is the start time of task T_j of assembly tooling change for the *k*th iteration. $D(\mathrm{T}_j)$ is the duration of task T_j. $t_S(\mathrm{A}_i)$ is the start time of activity A_i from a task of assembly tooling change. $RD(\mathrm{A}_i)$ is the duration of changed activity A_i. w_i and w_j are the weights of activities A_i and A_j. r_{id} is the quantity of resource *d* needed for the activity A_i. R_d is the total quantity of available resource *d*. $t_E^U(\mathrm{T}_i)$ is the end time of an upstream task T_i. $t_E^D(\mathrm{T}_j)$ is the end time of an downstream affected task T_j.

In order to shorten the cycle and save resources of change process, the optimization target is as follow:.

$$\text{Minimize } D(S_i)\ \&\ R(S_i) \quad (11)$$

where $D(S_i)$ and $R(S_i)$ are duration and resource consumption of the parallel change process respectively.

6. Summary

In this paper, three contributions are highlighted as follows: first, MBD models of aircraft-assembly tooling are introduced, which can contribute to the automation of change analysis. Second, a task model is proposed to detail the development process of assembly tooling part. Third, parallel change process of assembly tooling parts is developed to optimize the duration and resource consumption. However, intensive study is required to further validate the method. Beside, more factors will be integrated into the parallel change process model, and a wider range of areas shoud be covered.

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