Research on Key Technologies of the General Module Library of Aeronautical Composites Production Line

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Abstract. System simulation technology has become more and more widely used in aviation manufacturing industry. A general module library for aeronautical composites production line was developed, according to the characteristics of the production line layout and production process, combined with practical engineering experience. Based on it, the simulation analyst can create models for different types of composite material production lines quickly and easily, and can do the layout simulation evaluation, bottleneck research and scheme quantitative comparison and so on. Moreover, a demonstration usage of the module library for a practical case was given.

1. Introduction
Aviation composites have become the favored structural materials for aviation products due to their excellent properties such as light weight, high strength, high modulus, fatigue resistance, high chemical stability and designability brought by anisotropy. After decades of development, China has mastered a large number of advanced composite parts manufacturing technology. With the increase of composite production, the construction demand of composite production line is also increasing rapidly. The design and layout of composite material production line is very important to the product output, product quality and operating cost.

At present, the requirement of system simulation has been put forward in the planning and design of composite material production line. Simulation analysis, evaluation and optimization has become a key procedure in composite material production line design. Via the production line simulation, the feasibility of the previous layout scheme can be evaluated and demonstrated, so as to guide the design and operation of the composite material production line. In recent years, more and more researches and applications of system simulation technology have been conducted in China's aviation manufacturing industry [1, 2]. Qu Qi et al. [3] took the assembly line of typical fuselage parts in aircraft as the research object, established the simulation model based on Plant Simulation, analyzed and optimized the production capacity, bottleneck, balance rate and other problems of the assembly line. Wei Fang-Jian [4] built the simulation model of aircraft pulsating production line on DELMIA V6, and studied the system operation status, production capacity and resource utilization rate. Zhang Chao et al. [5] evaluated an integrated machining facility based on Plant Simulation, according to a few key performance factors such as output rate, equipment utilization, storage of semi-finished articles and robustness of the production line in detail. Based on an aeronautical composite materials digital production line, Cui Jing et al. [6] completed simulation modeling and simulation experiment.
of process layout based on plant Simulation, and made quantitative analysis and demonstration of process layout scheme, so as to guide the planning, design and operation of composite production line. As far as many production line simulation studies are concerned, most of them focus on specific objects. When the research object or its technological process changes, it is quite a time-consuming job to rebuild the simulation model manually. In this paper, according to the characteristics of the production line layout and production process, combined with several practical engineering experience, the general module library for aeronautical composite material production line was developed based on Plant simulation, on which the simulation model for different types of composite material production lines can be built quickly and easily. What’s more, the effectiveness of the general module library is verified by practical examples.

2. Division of Simulation Module for Aircraft Composites Production Line

The manufacturing technology of aviation composite parts is a kind of special technology which integrates raw material cutting, parts forming and parts processing. The typical process includes material preparation, tool preparation, cutting, laying-up, curing, demoulding, machining and surface treatment etc., as shown in Fig. 1. With the rapid increase of the application of composite materials in aviation industry, the dimension and structure complexity of composite parts are gradually increased, so as the manufacturing process complexity of parts keeps the same way. The manufacturing process is long, and parts of the working procedure is processed repeatedly, take the cases of multiple iterations of the lay-up and curing processes, machining and non-destructive inspection, for example.

The production process is the key factor that determines the process design of composite material production line. In the processing of composite products, the process independency is strong, the equipment used in each section and the requirements of the environment are different, so the modular feature of the function area of the composite product line is obvious. According to the manufacturing process, composite material production line usually includes storage area, clean room, curing area, demoulding area, machining area, quality testing area and final inspection area etc.

![Figure 1. Process Flow of Aviation Composite Material.](image)
Meanwhile, the processing requires the mould in clean room and curing area, so its storage and transportation also have an important impact on the layout design. In addition, the production line has the characteristics of the coexistence of manual and automatic process, the mixing of cold and hot process, the heavy use of tooling, the large amount of material flow, the variety of power use and large energy consumption.

3. Key Technology of Simulation Module Development for Composites production line

According to the process and the composition of aviation composite materials production line, modules such as cold storage, thawing area, mould storage, mould preparation area, clean room, curing area, demoulding area, machine area and quality inspection area are built in the general module library. The following will describe the cold storage module, the clean room module and the curing zone module in detail, which have the typical characteristics of the composite material production line.

3.1. Cold Storage Module

The cold storage is mainly used to store the prepreg and other materials with cold storage requirements. Therefore, the cold storage module mainly has two important functions in the simulation: one is the control of prepreg outgoing, which is necessary to communicate with mould storage and auxiliary material storage to control the production rhythm; the other is to record the time of prepreg outgoing, and assign the parameters of prepreg work life \( T_{wl} \), mechanical life \( T_{ml} \) and accumulative prepreg out time \( T_{cr} \). In the simulation system, it is required to calculate the corresponding parameters before and after the prepreg outgoing, lay-up and curing processes.

\[
T_{wl} = T_{w} - \sum_{i} T_{i}
\]  

Where, \( T_{wl} \) is the prepreg work life, \( T_{w} \) is the initial prepreg work life, \( n \) is the number of processes that prepreg experiences, and \( T_{i} \) is the time consumed in each process.

3.2. Clean Room Module

Cutting the prepreg kit, laying-up, bonding and curing packaging process are executed in clean room. At the same time, it also involves the combination of manual handling, crane and AGV transportation, which makes this module one of the most complex modules in the whole aircraft composite material production line. In particular, the process control is more complicated when the prepreg, honeycomb core and other materials are used in the laying-up or bonding process, and the manual laying-up mode is considered.

Fig. 2. introduces the layup process of composite material when only one kind of machine material is involved. For the pasting process that requires multiple materials on the machine, it is necessary to judge whether the required molds and raw materials are in place before the pasting process starts, so as to avoid occupying the pasting equipment or pasting table due to the absence of raw materials in the pasting process. At the same time, \( T_{wl} \) and \( T_{sum} \) should be checked before the beginning of the laying process to ensure the laying operation within the work life. After laying, parameters such as \( T_{ml} \) and \( T_{sum} \) should be updated.
3.3. Curing Area Module

In actual production, the curing area is mainly responsible for pre-curing preparation, curing and other tasks. As the main key equipment in the production, autoclave has high cost and high energy consumption. The combined feeding method, which should be considered in simulation, is usually used to improve the utilization ratio in production. If there is a combined feeding scheme in actual production, simulation is carried out to verify the schema rationality. Otherwise, a certain principle should be followed to automatically generate the combination scheme and record the output.

The principle of combination that should be observed in the production line simulation is proposed. According to the principle, the curing zone module adopts the process for control is shown in Fig.3., in which the maximum allowable waiting time can be determined comprehensively according to the product delivery date, curing and subsequent process time, prepreg out time and mechanical life.

**Figure 2.** The realization process of Lay-Up in the Module.

**Figure 3.** Realization of combined feeding in simulation.
4. Simulation Case of Aircraft Composites Production Line

Taking the aviation composite material production line as an example, combined with the investigation of simulation input information in the factory, the simulation model was built with the general module library. Through simulation, the optimization of the number of equipment, the number of molds and the number of transportation equipment can be achieved. Meanwhile, the quantitative analysis can also be carried out from the aspects of production capacity, line inventory, material flow and equipment load rate and so on.

4.1. Optimization of Mould Quantity

In this project, due to the large annual output of skinning, stiffened-wall panels and internal and external auxiliary rib parts, simulation experiments were carried out for the above three types of parts with the number of molds of 10~12, 10~14 and 10~12 respectively. Fig.4. shows the influence of the number of molds on the capacity. The experimental Numbers 19, 20 and 24 can meet the production demand, and the number of molds is 12/12/14, 12/12/16 and 12/14/16, respectively. Therefore, the number of molds is recommended to be 12, 12 and 14.

![Figure 4. Influence of mould number on production capacity.](image)

4.2. Capacity Analysis

After optimizing the parameters such as mould number, the production program of the simulation system was specified according to the production program, and the annual output of the simulation was shown in table 1. It can be seen that the current layout basically met the requirements of the production program, while the wip was maintained at a low level.

| Part ID | Simulation Average | Confidence intervals | Planned output | requirement rate/% | WIP |
|---------|--------------------|----------------------|----------------|--------------------|-----|
| part1   | 16                 | 16±0                 | 16             | 100                | 4   |
| part2   | 16                 | 16±0                 | 16             | 100                | 4   |
| part3   | 15                 | 15±1                 | 16             | 93.8               | 4   |
| part4   | 16                 | 16±0                 | 16             | 100                | 4   |
| part5   | 464                | 464±4                | 460            | 100.9              | 34  |
| part6   | 492                | 492±5                | 490            | 100.4              | 38  |
| part8   | 64                 | 64±1                 | 64             | 100                | 6   |
| part9   | 16                 | 16±0                 | 16             | 100                | 4   |
| part13  | 16                 | 16±0                 | 16             | 100                | 4   |
| part14  | 598                | 598±8                | 600            | 99.7               | 78  |
| part15  | 96                 | 96±2                 | 96             | 100                | 24  |

Table 1. Simulated results of annual outputs and storage of semi-finished articles.
4.3. Equipment Load Rate Analysis

The equipment utilization rate is an important indicator of the utilization of the production line. Through several simulation experiments, the equipment utilization rate of important equipment is analyzed. The equipment load rate is shown in Table 2. As can be seen from the table, the utilization rate of key equipment in the project is relatively high, averaging around 85%. In particular, the load rate of automatic stacking machine and curing oven is respectively 88% and 91%, which exhibits to be the bottleneck of actual production.

| Equipment name                | load rate | average load rate |
|-------------------------------|-----------|------------------|
| Autoclave                     | 80.4      | 80.62            |
|                               | 78.63     |                  |
|                               | 82.83     |                  |
| Curing oven                   | 90.87     | 91.185           |
|                               | 91.5      |                  |
| Automated tape-laying equip.  | 88.49     | 88.49            |
| Ultrasonic detection equip.   | 83.31     | 83.31            |
| Five-axis machining center    | 84.34     | 84.32            |
|                               | 84.3      |                  |

Through simulation analysis, it can be seen that the design scheme of the composite material production line can basically meet the requirements of the production program. But it should be noted that the high load rate of the curing oven and the automatic laying-up equipment may constitute the bottleneck of production. From this design example, it can be seen that the modeling of the planned production line can simply and truly identify the problems existing in the system, and play a very good auxiliary role in the evaluation and optimization of the system.

5. Conclusion

Through the aviation composite material production line simulation, the operation of the production line can be predicted in the planning and design stage, and the quantitative analysis and demonstration of the design scheme can guide the optimization design. In the production stage, various simulation experiments can be done for the existing production line to analyze the rationality of production scheduling and to achieve better control the production capacity of the production line. The practical example shows that the general simulation module library of aviation composite material production line can be used to build simulation models of different types of composite material production line quickly and conveniently, so that more simulation analyst can use the proposed lib, which is conducive to the application and promotion of process simulation in actual projects.

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