An Immersive Virtual Maintenance Simulation Process for Civil Aircraft Based on Cavernous Automatic Virtual System

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Abstract. This paper discusses the immersive virtual maintenance simulation in the design and verification phases of civil aircraft. Firstly, the concepts of maintainability design and Virtual maintenance are introduced. Secondly, the workflow of immersive Virtual maintenance simulation based on cavernous automatic virtual environment (CAVE) system for civil aircraft is discussed in detail. Through the computer virtual model to simulate and estimate the product maintainability and maintenance support system and other aspects of the possible problems, improve prediction and decision-making level, make maintainability design technology out of the dependence on experience, develop to a new stage of all-round prediction. Finally, the development trend of civil aircraft maintainability design and immersive virtual maintenance simulation method is discussed, and some suggestions on the research and application of this field are put forward.

1. Introduction
Maintainability is the capability of products to maintain or restore their specified state under specified conditions and within specified time according to specified procedures and methods. Maintainability is a quality characteristic of a product, that is, the product is endowed with the inherent attribute of simple, rapid and economical maintenance by design [1].

Maintenance costs account for a large part of aircraft operating cost, which will directly affect the economy of airlines. For aircraft manufacturers, considering maintainability from the early stage of development will reduce the life-cycle cost and improve the competitiveness of the civil aircraft.

Virtual maintenance uses computer simulation and virtual reality technology, implement product in the process of maintainability design and analysis, maintenance procedure planning and verification, maintenance operation training and maintenance support, maintenance organizations of management and control, In order to enhance the decision-making and control capacity at all phases of the product life cycle and at deferment levels of the aircraft system [2].

Virtual maintenance by computer virtual model to simulate and forecast the product maintainability problems, improve the level of prediction and decision-making, the maintainability design technology out of the dependence on experience, development to a new stage of predict. It is not a single maintenance simple combination of simulation technology, but on the basis of relevant theories and has accumulated knowledge to systematic maintenance knowledge, the comprehensive modelling on the engineering objects and maintenance activities, before real products, using computer to assess the design and maintenance activities, to modify unreasonable part in the design [3].
The concept of "virtual maintenance technology pyramid" [4] is proposed, and the basic characteristics of virtual maintenance technology are briefly explained. Virtual maintenance pyramid consists of three "I", as shown in Figure 1, Immersion, Interaction and Imagination.

Its goal is to verify maintainability through simulation and provide the basis for optimization by combining the key points of maintainability design in each phases of new type of civil aircraft design [5].

![Figure 1. 3I Features of Virtual Maintenance.](image1)

![Figure 2. Virtual Maintenance Environment Based on Image Method.](image2)

Immersive virtual maintenance simulation is a virtual maintenance simulation under immersive virtual simulation system environment. Virtual maintenance simulation is based on planned maintenance process to complete a series of action simulation, including virtual man behaviour, virtual prototype behaviour, and virtual man-virtual tool-virtual prototype interaction simulation. Aaron Bloomfield's research shows that the interaction mode with tactile feedback can provide higher user satisfaction, stronger sense of immersion and more accurate operation positioning for disassembly work simulation [6].

The product design centred virtual maintenance emphasizes the application of virtual reality technology in the simulation of design and maintenance operation process. The virtual reality technology is mainly applied to the simulation of disassembly, assembly, tool or instrument use and other processes. According to the task focus of different design phases, the simulation can be aimed at the part or the whole aircraft. It can be for important maintenance steps, or for the whole process of maintenance.

2. CAVE Immersive Virtual Maintenance Simulation Analysis Process

Maintainability analysis is to analyse and evaluate the maintainability design results of civil aircraft, with the purpose of analysing whether the characteristics endowed by the design of civil aircraft meet the specified maintainability requirements, and giving feedback to the design in time [7]. Maintainability analysis is carried out in the whole process of civil aircraft preliminary design, detailed design, test flight, operation and so on [8]. The simulation analysis flow of immersive virtual maintenance based on CAVE system is shown in Figure 3.

![Figure 3. Simulation Analysis Flow of Immersive Virtual Maintenance Based on CAVE System.](image3)
2.1. Determination of the Simulation Analysis Task
To solve the maintainability problem, it is necessary to identify the task of immersive virtual
maintenance simulation, and then collect product CAD data and maintainability information based on
the input data and related constraints required by virtual maintenance simulation[9]. CAD data
includes digital models generated by CATIA, Pro/E, UG and other software.

2.2. Construction of the Virtual Maintenance Digital Prototype Model
Virtual maintenance digital prototype model is the main input data of virtual maintenance simulation
test. After completion of data collection, immersive virtual maintenance simulation based on the
requirements of input data, optimize the collected data and relevant information processing, including
check needs to be lightweight and whether meet the requirement of the simulation input data format,
and finally form an immersive virtual maintenance digital prototype model.

2.3. Building a Virtual Maintenance Environment Model
Virtual maintenance environment is a nearly realistic 3D scene for maintenance work simulation
established for qualitative analysis of maintenance process and maintainability. It is the environment
for the virtual maintenance, as shown in Figure 2.

According to specific maintenance task, virtual maintenance environment models are created,
including virtual man model and maintenance scene model, among the virtual maintenance scene
model includes ground model, maintenance shop model and maintenance tools and support equipment
model.

2.3.1. Virtual Man Model
The virtual man model is the main body of the virtual maintenance scene, which has its own geometric information and can interact with the surrounding environment. The virtual man geometric model based on anthropometric data is 3D digital variable parameter model. By adjusting these parameters, more accurate virtual man model can be obtained. In the process of virtual maintenance simulation, all the maintenance actions of real people are realized by the corresponding movement of virtual man model.

2.3.2. Virtual Maintenance Scenario Model
a) Ground Model
The ground in the virtual maintenance scene is the base level of the virtual maintenance and the
working platform for maintenance to carry out various operations. In the modelling tool, the ground
model of appropriate size is constructed according to the actual situation as the datum.

b) Maintenance Shop Model
Add the ground, virtual man and virtual maintenance prototype in the virtual scene, and then add
the maintenance workshop. The maintenance shop should be able to put down all virtual maintenance
prototype models that need to be simulated for virtual maintenance.

c) Maintenance Tools and Support Equipment Model
Add necessary maintenance tools and support equipment, such as tool carts, wrenches, and ladder
frames, to the virtual scene.
2.4. Immersive Virtual Maintenance Simulation

After the establishment of digital prototype model of immersive virtual maintenance and virtual maintenance environment model, immersive virtual simulation system was used to conduct simulation of immersive virtual maintenance [10]. The simulation process is shown in Figure 4.

2.4.1. Establishment of the Initial Space Position of Virtual Maintenance Simulation

Import scene model and virtual maintenance based on terrain model space position, determine the virtual man static model, maintenance workshop, maintenance tools and equipment model of space position and direction, and then the virtual digital prototype model to join the virtual maintenance scenario, adjust direction of digital prototype virtual maintenance, there will be one side of maintenance operations and maintenance man to close as far as possible, so that the repair work can be carried out.

2.4.2. Constraining on Interaction Relationships. In the process of virtual maintenance simulation, there are three interactions involving, virtual man and maintenance tools and support equipment, virtual man and virtual maintenance digital prototype, and maintenance tools and support equipment and virtual maintenance digital prototype. Therefore, before the virtual man motion simulation and virtual maintenance digital prototype motion simulation, the interaction constraints of the virtual man static model, maintenance tools and support equipment model and virtual maintenance digital prototype model were carried out to complete the motion simulation.

2.4.3. Virtual Man Action Simulation. In the process of immersive virtual maintenance simulation, the action simulation of virtual man is driven by the real action of the man. The motion capture system, the standard posture of the virtual man static model and the standard posture of the tester need to be calibrated before the real maintenance task movement of the tester is collected. After the calibration, the test personnel began to perform maintenance task actions, using multi-mode input devices such as data suits/data gloves, motion capture devices and other tracking devices to collect maintenance action data [11]. Read the maintenance action data to drive the virtual man to carry out the same action as the test person. The virtual man action simulation process is shown in Figure 5.

Figure 4. Immersive Virtual Maintenance Simulation Process.
2.4.4. Virtual Maintenance Prototype Motion Simulation. According to interaction constraints, virtual man action simulation drives virtual maintenance digital prototype movement such as translation and rotation of digital prototype, and simulation physical field movement of virtual maintenance digital prototype after virtual human operation, such as gravity deformation of cable.

2.5. Output of Simulation Result
The output results of immersive virtual maintenance simulation based on CAVE system include digital mock-up of virtual maintenance simulation process, demonstration process, verification results and haptic force feedback [12].

3. Example of Application
By using the above method, the coordination between the real-time human-computer engineering interaction system and the immersive virtual display system of E/E bay of civil aircraft is realized, and the simulators can directly complete the walking and visual inspection independently. In the digital model and real aircraft equal ratio display environment, real and virtual man can be fully matched, so as to realize the real-time interaction between real mechanic and virtual digital prototype, the simulator more intuitive system parts for regional inspection, maintenance, disassembly and other processes simulation. The simulation process is shown in Figure 6.
4. Conclusion

The advantages of immersive virtual maintenance can be summarized into five aspects: Time, Quality, Cost, Safety and Environment. Firstly, immersive virtual maintenance directly utilizes or transforms existing digital models to get rid of the dependence on physical prototypes and advance the start time of product maintainability verification. At the same time, immersive virtual maintenance provides realistic maintenance scenes, alleviates the difficulty of understanding objects, and solves the problem of product maintenance accessibility well. Immersive virtual maintenance saves the expensive cost of manufacturing physical prototype, and the analysis process can be repeated, which effectively reduces the design cost. Verification in a virtual environment will not cause accidents and can ensure the safety of personnel. Finally, the virtual maintenance environment makes the maintenance verification work not limited by environmental conditions such as site and time, and has green environmental protection [13]. Based on the above, immersive virtual maintenance has obvious advantages in the maintainability analysis of civil aircraft, and has been applied in civil aircraft development. It provides a basis for fully satisfying the maintenance needs of aviation maintenance simulation.

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