VIRTUAL PROTOTYPING ENGINEERING FOR COMPLEX PRODUCT

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ABSTRACT

At present, the virtual prototyping technology for complex product is one of the research and application hotspots in current simulation technology. In authors' viewpoint, the virtual prototype development for complex product has become a systematic engineering, which can be called the complex product virtual prototyping engineering (CPVPE). In this paper, the architecture, key technologies and its supporting environment of CPVPE are primary discussed firstly. Combined with the research project and primary practice undertaken by the authors, a typical application demonstration of the aerospace complex product virtual prototyping engineering (including mechanism, dynamics, software and control system) is also introduced based on the virtual prototype supporting environment developed by the authors. Finally, some further research works on CPVPE are also presented in this paper.

1 INTRODUCTION

In recent years, under the pulling of the requirements of new product development and the pushing of the evolution of associated technologies, virtual prototyping technology whose core technology is system modeling & simulation has developed rapidly. The complex product virtual prototyping technology is becoming the hotspot of the product research and development of manufacturing. The typical example is the successful development and application of virtual prototyping technology in boeing 777. We define "complex product" as a kind of product which has complex customer requirements, complex product composition, complex product technologies, complex manufacturing processes and complex project management, such as aerospace vehicle, airplane, car, complex Mechano-electronics equipment, weapon system, etc.

It is well known that the virtual prototyping technology is a type of digital design method based on computer simulation model of product. A virtual prototype is a simulatable digital one which combines simulation models of various engineering disciplines, it resembles the physical product as closely as possible in terms of visual, auditory, haptic, functional, performance and behavioural characteristics. At present, the virtual prototyping technology, represented by various CAX (CAD, CAM, CAE, etc) /DFX (DFA, DFM, etc) technologies, has got lots of research achievements and successful applications in the fields of machinery, electron, control and software. At the same time, in recent years, people have begun to emphasize the research and development of multidisciplinary collaborative CAX/DFX technology, and have successfully developed corresponding software tools, such as ADAMS, Statemate.

Based on the recent research and practice undertaken by the authors and their colleagues on virtual prototyping technology, the authors consider that the development of virtual prototype for complex product has become a systematic engineering. The concept, principle, technology and method of system engineering should be adopted in the research, development, implementation and maintenance of CPVPE. In order to enhance the T,Q,C,S(Time to market, Quality, Cost, Service) of enterprise and increase their market competition competence, systematic viewpoint must be applied during the study on CPVPE. Therefore, the concept of "virtual prototyping engineering for complex product" is put forward by the authors. It is similar to the development process of physical prototype designing and manufacturing technology from CAX to integrated and optimized CIMS (contemporary integrated manufacturing system)[1]. The successful implementation of CPVPE is concerned with integration and optimization of many elements during the whole engineering period, such as person/organization, management and technology, etc, integration and optimization of information flow, work flow, fund flow in engineering. All of these take a series of challenges to the research and development for traditional virtual prototyping technology. In this paper, based on the characters of complex product virtual prototype(CPVP),

the architecture and key technologies of virtual prototyping engineering of complex product are primary discussed, such as system technology, modeling technology, collaborative simulation technology, engineering management technology, system concept design and system performance evaluation technology for virtual prototype, integrated supporting environment, etc. Some cases undertaken by the authors and their colleagues during the research period are also presented. Furthermore, some further research works on CPVPE are also introduced in this paper.

2 THE ARCHITECTURE OF VIRTUAL PROTOTYPING ENGINEERING SYSTEM FOR COMPLEX PRODUCT

2.1 The Composition And Its Unique Features For Complex Product Virtual Prototype

(1) The complex product virtual prototype(CPVP) is a complex system, which has complex composition, complex interactions with outside environment, complex development processes. The CPVP also features in involving many subsystems, multi-disciplinary domains, persons and tools.

(2) The CPVP is a union of distributed, heterogeneous models from many areas of expertise and different simulation tools, such as CAD model, appearance rendering model, functional model, performance model and environment model, etc..

(3) The CPVP involves various kinds of simulation and multidisciplinary domain, and can be put into use in many areas, which includes virtual simulation (including the hardware-in-loop simulation and the man-in-loop simulation) and construction simulation, involving mechanism, electronics, software and control field. Virtual prototype can be used in engineering simulation system, engagement simulation system, mission simulation system and campaign simulation system.

(4) The CPVP can be applied to the whole lifecycle of product development from requirement analysis to disposal, including concept design, detail design, manufacturing, testing and evaluation, deployment, maintenance and training, etc..

2.2 The Development Technology And Its Unique Features For CPVP

Virtual prototyping technology for complex system is the expansion of CAx (e.g., CAD, CAM, CAE, etc.)/ DFx (e.g., DFA, DFM, etc.) techniques. It further integrates information technology, advanced manufacturing technology and advanced simulation technology, and applies these technologies in the whole lifecycle and the whole system of complex system. Virtual prototyping technology for complex product also introduces comprehensive management capabilities. It is an advanced engineering design pattern, which stresses all lifecycle virtual design and emphasizes to analyze and simulate the complex system from the view of the system level. Virtual Prototyping technology for complex product involves kinematics and kinetics modeling theories and implementation techniques of multi-body system, it is a synthetic technology based on virtual reality, advanced modeling and multidisciplinary simulation techniques, information management techniques and engineering design techniques.

Virtual prototyping technology means the process of using these virtual prototypes instead of, or in combination with, physical prototypes for innovation, test and evaluation of product design to compress development cycles, decrease product cost and improve the accuracy of development to meet the needs of the customer and the market.

The development process utilizing virtual prototyping technology is a continually refined and improved process of product model across the whole product lifecycle. It is shown as figure 1. During the whole product lifecycle, from requirements to employ and disposal, the virtual prototype can be constructed under virtual environment by utilizing various domain design tools (such as CAD/CAE tools, appearance/function/behavior modeling tools, etc.) and existing product model (such as CAD model, appearance rendering model, function and performance simulation model, etc.). Under the support of VV&A process, the satisfied virtual prototype can be developed through iterative analysis and evaluation from various aspect of function, performance and behavior of virtual prototype to meet the needs of customer.

The development technology for CPVP has many new features contrasting to traditional product design technology, shown as follows:

(1)The viewpoint of system, which emphasizes to simulate the appearance, function and behavior under some special environment from the view of the system level.

(2)The viewpoint of the whole product lifecycle, which applies virtual prototype evolved with the product development process in the whole lifecycle of product development.

(3)The viewpoint of all aspects in product performance evaluation, which supports multidisciplinary specialists to test, analyze and evaluate virtual product concurrently from different aspects.

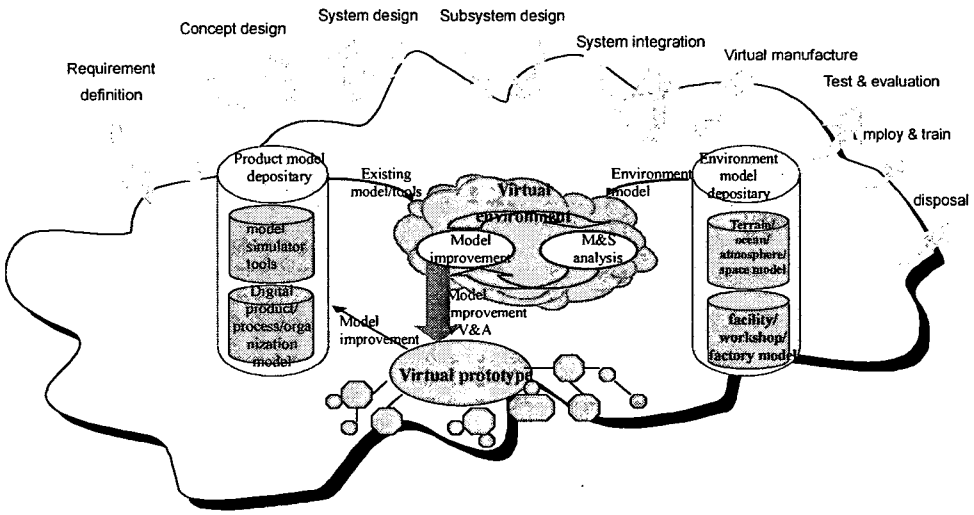

Figure1 The development process of virtual prototype

2.3 The Composition And Its Unique Features For CPVPE

The CPVPE is a systematic approach to efficiently support the development of virtual prototype. According to the theory of concurrent engineering(CE), the CPVPE takes the virtual prototype as a core,.based on integrated supporting environment, the three key elements (i.e. team/organization, business administration and technology) in the whole product lifecycle are soundly organized, and the information flow and workflow in various activities in product development process are considered as a whole integrated mode which is managed and controlled for global optimization to implement the integration of engineering design technology, modeling/simulation technology and VR/visualization technology to improve the T,Q,C,S,E of enterprise product development. The typical system cycle chart for CPVPE is shown in figure 2.

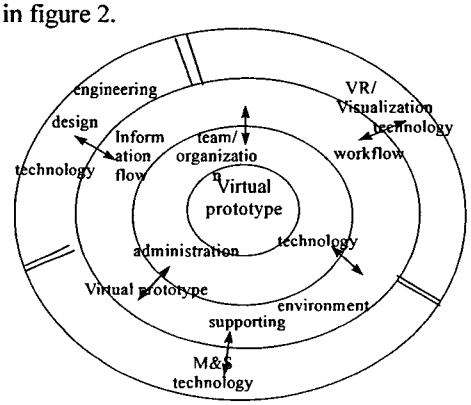

Figure2 The system cycle chart for CPVPE

The CPVPE presents many outstanding features shown as follows:

(1) The CPVPE stresses virtual development process across the whole lifecycle under virtual environment, such as virtual product design, virtual product development and virtual product application.

(2) The CPVPE involves complex management technology, including the management and optimization of diverse data, models, tools, persons and processes.

(3) The CPVPE is an integrated and optimized engineering, which involves the integration and optimisation of three key elements (i.e. team/organization, business administration and technology) and three types of technology (i.e. engineering design technology, modeling/simulation technology and VR/visualization technology).

(4) The supporting environment for CPVPE is a collaborative development environment, which fulfills the integration and optimisation of three key elements and three types of technology to support CPVP.

The Architecture Of CPVPE System

A complex product usually consists of many subsystems, such as electronic subsystem, mechanical subsystem, control subsystem, software subsystem, etc. The architecture of CPVPE system is indicated in figure 3.

This architecture consists of collaborative design supporting platform, model depositary including environment model database, product model database, etc., virtual prototyping engine and VR/visualization environment, etc. The collaborative design supporting platform provides a collaborative design environment, which comprises integrated platform, management tool suit including team/organization management tools, workflow

management tools, virtual product management tools and project management tools, etc. The models of model depositary involve system level main model,electronic subsystem model, mechanical subsystem model, control subsystem model, software subsystem model and environment model, etc. System level is responsible for design/development and appearance/function/behavior modeling and simulation for virtual product on system layer, such as the kinematics/kinetics M&S, prototype behavioral M&S in special environment, etc. Virtual prototype engine including the tools suit of various domain CAX/DFX tools simulates the prototype by appearance/function/behavior and feeds the simulation data into VR/visualization environment. After VR rendering, the prototype is shown by appearance/function and various behaviors in virtual environment.

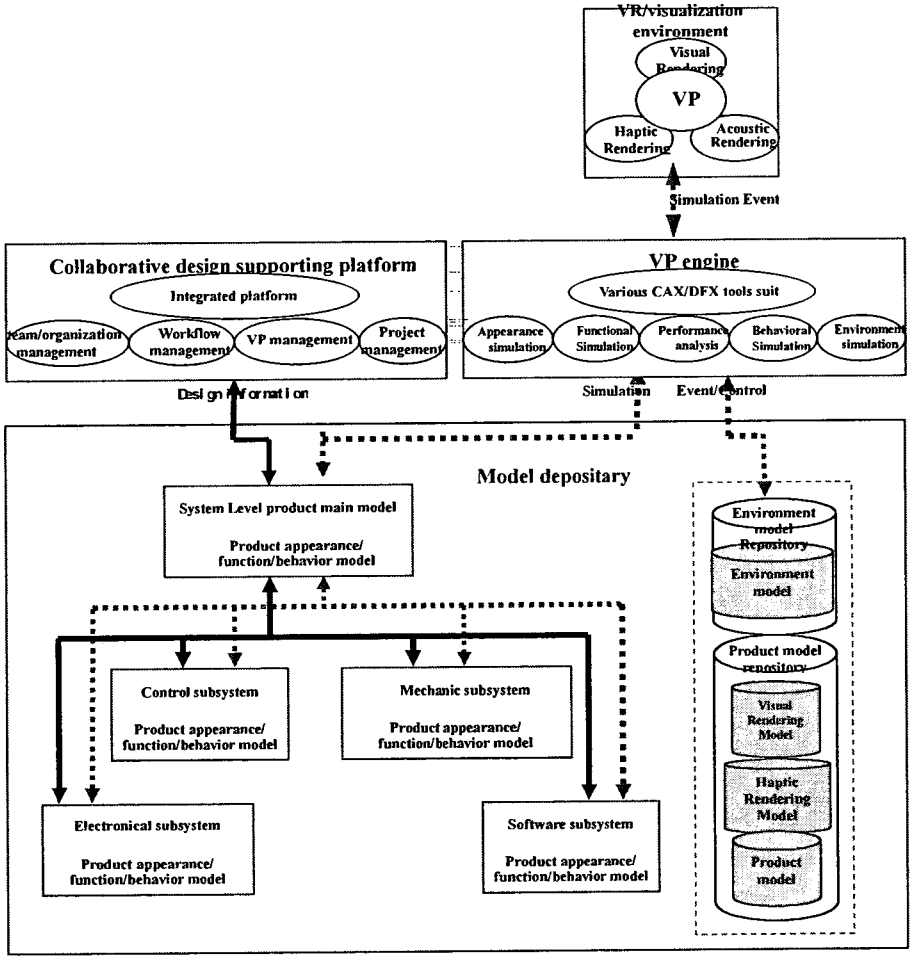

Figure 3 The architecture of CPVPE system

3 THE RELATED KEY TECHNOLOGIES ON CPVPE

There are many key technologies and related research fields existing in the development and implementation for CPVPE, such as the system technology for CPVP, the modeling technology for CPVP, the collaborative simulation technology for CPVP, the management technology for CPVPE, system concept design and system performance evaluation technology, virtual environment technology (including environment emulate and VR technology), the VV&A technology of model and the supporting platform technology. Some of them will be discussed as follows in detail,such as the system technology for CPVP, the modeling technology for CPVP, the collaborative simulation technology for CPVP, the management technology for CPVPE, system concept design and system performance evaluation technology and the supporting platform technology.

3.1 The System Technology For CPVPE[2]

The system technology for CPVPE provides the solution for issues related with the whole system and the relationships and interfaces among subsystems from the view of system layer. It specifies and coordinates the running patterns of subsystems and soundly organizes them to realize the shareness of information and resources to meet the needs of the whole system target. The system technology involves many related technologies, such as architecture, standards, specifications and protocols, network and database, system integration and integration approach and system running pattern, etc.

System integration techniques and integration approaches study the relationships and interfaces among subsystems from the view of whole system. The integration and optimization for three elements and three types of technologies in enterprise activities is the core for CPVPE, which includes:

(1) The integration and optimization technology for product engineering design environment, modeling and simulation environment for product function and behavior, and VR/visualization environment,

(2) The integration technology for multidisciplinary development environment of complex product,

(3) The integration technology for multidisciplinary distributed modeling ,

(4) The integration technology for multidisciplinary distributed collaborative simulation,

(5) The integration technology for CAD/CAE/CAM/DFX tools,

(6) The interoperation and integration technology for the whole lifecycle modelling and simulation tools.

With the rapid development of information technology, system integration technology has been developed quickly, such as Web/CORBA based enterprise integrated platform. Furthermore, HLA[3] based advanced simulation technology provides a synthetic simulation environment to support the integration of three types of simulation (i.e. construction simulation, virtual simulation and live simulation), the interoperation and reuse among various models and simulation applications, and the integration of various modelling and simulation tools.

3.2 The Virtual Prototype Modeling Technology For Complex Product[4][5]

Virtual prototype is efficient integration and collaborative application for multidisciplinary CAX/DFX models, simulation models and VR/visualization models. The core of virtual prototyping technology is how to collaboratively, consistently, efficiently describe, manage and operate related models. The shareness, integration and collaborative interoperation among different models, tools and person can be achieved by providing a product integrity description linked to the whole life cycle product information for user.

The traditional product modeling technology is mainly focus on the geometry information of product. For virtual prototype modeling technology, there are many new modeling technologies to be studied and applied in current application fields, such as layered modeling technology, multi-paradigm modeling technology, meta-modelling technology, distributed modeling technology, and knowledge based modeling technology, etc.

The Collaborative Simulation Technology For Complex Product[6][7]

The collaborative simulation technology for complex product consists of collaborative modelling technology, collaborative simulation infrastructure technology and collaborative simulation management technology, etc. The collaborative modeling and simulation technology mainly solve how to support distributed, collaborative simulation among distributed, heterogeneous models from many areas of expertise and different simulation tools to support the concurrent development of virtual product and collaborative simulation from system view. Collaborative simulation management technology supports the management of simulation running, activities and results.

The Virtual Prototype Management Technology For Complex Product

The CPVPE has become a complex systematic engineering, which involves lots of data, models, tools, processes and persons. The core of efficient practice on CPVPE is to organize and manage the whole lifecycle related information, sending the right data to the right man and tools in the right time by the right means, to implement the integration of information and process. The related technologies include IPT technology, virtual prototype management technology, workflow management technology and project management technology, etc.

It is an efficient approach to extend the function and performance of PDM in model depositary and knowledge management to efficiently support CPVPE.

3.3 The System Concept Design And System Performance Evaluation Technology For CPVP

Began with SIMMNET (SIMulator NETworking) plan in 1983, distributed simulation technology has been developed rapidly. With the further application and practice for distributed simulation technology, a set of standards and protocols for distributed interactive simulation have been established. All of these have greatly

promoted the development of the new generation simulation technology and its application in military and civil fields.

Applying simulation technology to the whole product lifecycle including engineering development, training and evaluation is highlighted by many countries in the world. The design technology for complex product has been extended to support system concept design and performance evaluation. By constructing high performance simulator and virtual prototype, the later operation and system performance evaluation of complex product can be considered in the early concept design phase.

The system concept design technology and system performance evaluation technology for CPVP involves many key technologies, such as the development and practice technology for synthetic simulation environment, performance evaluation technology, integration technology with engineering design phase[10].

3.4 The Integrated Supporting Environment For CPVP[8]

In order to efficiently support the development of virtual prototype, the supporting environment for CPVP should have the following features:

(1)to provide a integrated and reusable model depositary including related product model and environment model to speed up the construction of virtual prototype and virtual environment.

(2)to provide a standard-based computing environment (such as CORBA, WEB, RTI) to achieve the plug-and-play for applications based on "system soft-bus" under distributed and heterogeneous environment and enable user to develop and execute distributed collaborative engineering and virtual prototyping session.

(3)to provide an integrated supporting platform to support the management of team/organization, process, virtual product date/model and project and the integration of various tools and applications to implement concurrent engineering methodology.

(4)to provide advanced, multi-domain supported M&S environment and VR/Visualization environment.

(5)to provide a set of integrated multidisciplinary CAX/DFX tool suit for supporting the whole lifecycle development of CPVP.

(6)to adopt popular (GOTS/COTS Government/ Commercial Off-The-Shelf) products and standards that are available and widely used currently to enhance its open, scalability and flexibility.

The architecture of layered supporting system for CPVP is shown in figure 4. It consists of seven layers namely computer and operating system, network and database, common middleware (CORBA, JAVA, ROSE, etc.), enterprise framework, field framework, application support software, user-oriented multidisciplinary collaborative layer.

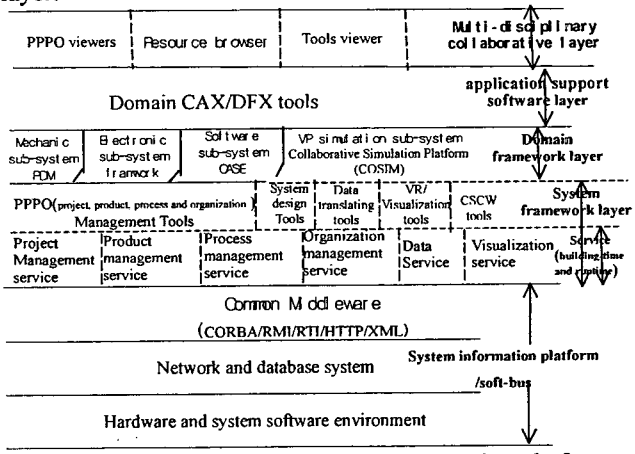

Figure 4 The architecture of CPVP supporting platform

4 TWO TYPICAL APPLICATION DEMONSTRATIONS OF CPVPE

4.1 Aerospace CE Project Supported By National 863/CIMS Subject[9]

Based on the application background of an aerospace complex product involving multidisciplinary domain, the study, application and primary practice on CPVP technology are performed in this project. Based on the self-developed virtual prototype supporting platform, especially for the analyses and design of virtual prototype from system level, various design and analysis tools are integrated by collaborative simulation platform to construct an collaborative analysis/ simulation environment to support various design activities, such as digital product design, product requirement test for system, control, dynamics and structure, and design scheme verification, etc., to decrease the number of manufacture and trial of physical prototype.

Based on the requirements of system and control function to mechanical structure, many design tools, such as PRO/E, PATRAN, NASTRAN, ICSL, MATLAB, etc., are collaboratively used to model, simulate and post-analyze the integrated virtual prototype system to design the mechanical structure of aerospace product, and to implement the simulation of kinematics and dynamics of controlled flexible system to fulfill synthetic optimization among related disciplinary domains of virtual prototype including system, control and structure domain.

The architecture of the virtual prototype system for the complex aerospace product is shown in Figure5.

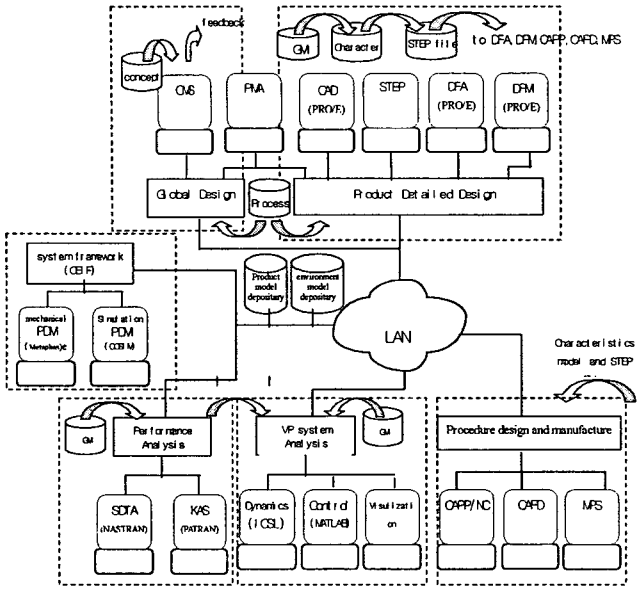

Figure 5 The architecture of the virtual prototype system for complex aerospace product

4.2 Synthetic Simulation Environment (SSE) system[10]

The synthetic simulation environment (named SSE) based on advanced distributed interactive simulation technology and virtual reality technology developed by the authors and their colleagues is a synthetic simulation system which provides a realistic virtual environment to support system concept design and system performance evolution of aerospace product.

The SSE is implemented according to the standards of DIS and HLA. In this system, application protocol, communication protocol, exercise management protocol and feedback protocol are built, and system integration scheme and protocol data unit interface specification are also worked out. The architecture of SSE is shown in the figure 6.

5 CONCLUSION AND FURTHER WORK

It is known from the primary practice that:

(1) the virtual prototyping technology provides an effective approach for enterprise's new product innovation and development.

(2) the implementation of virtual prototype system has become a complex systematic engineering involving the integration and optimization of three key elements (i.e. team/organization, business administration and technology).

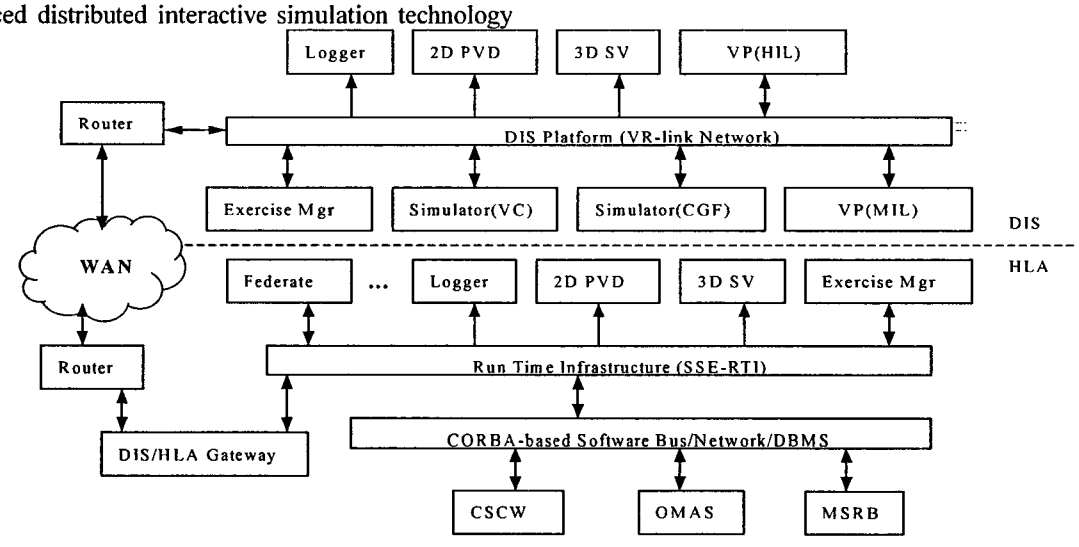

Figure 6 SSE based complex aerospace product concept design and performance evaluation

(3) The simulation technology is quickly developing towards serving the whole system lifecycle, the whole system, and the all aspects of managements. It has not been simple experiment and "computing" based on model. In fact, it should be synthetically concerted with modern management technology, modern information technology,

various domain advanced manufacturing technology and also the factor of human.

(4) The application research should be highlighted on virtual prototyping technology to form continuous improved development pattern, which is from application to deveopment and improvement and feedback to application repeatedly.

In our further research work, combined with practice engineering application background, the authors and their colleagues will deeply study the related key technologies and implementation technology on virtual prototyping technology for massive complex product and to further exploit and integrate existing simulation technology, information technology and advanced design and manufacture technology to extend its application into system design and performance evaluation for supporting complex system simulation engineering. We will further develop a complex product virtual prototype supporting platform and a set of integrated tool suit, which have the independent property right of copyright and general, open, distributed and secure features, to support all lifecycle distributed, collaborative engineering for complex system dispersed over multi-sites and even to promote it to support SBA pattern.

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AUTHOR BIOGRAPHIES

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