AN INTEGRATED PLATFORM FOR AIRCRAFT DESIGN: FLIGHT ENGINEERING SIMULATOR

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Abstract

This paper describes a distributed engineering simulator developed by FAI (the First Aircraft Institute), where it has been used to support the design of a new aircraft to solve complex, interdisciplinary problems in the procedure of aircraft design. A rapid prototype environment for the design of flight control laws, aircraft displays and avionics can be rapidly configured by means of an integrated set of software modules and flexibility of components in the system.

The overall aspects of FAI engineering simulator are presented in this paper, that include the discussions on the use of flight simulator for aircraft design, system architecture, the features of subsystem, the composition of simulator software, approach to simulation model validation. And also some of the ongoing research work and future plans are discussed.

1 Introduction

The traditional approaches to aircraft design are confronted with a challenge because of the complexity of current aircraft, which can't carry out the design of high-performance aircraft by them. The design of flight control system as well as aircraft with high performance, safety can't be carried out by theory calculation and mathematics simulation. Also can't solve the complex, interdisciplinary problems in the procedure of aircraft design.

Flight testing for new aircraft is both time consuming and expensive. While the purpose of flight testing is to establish aircraft performance and stability throughout the flight envelope, an additional role of flight testing is the evaluation and certification of aircraft system and avionics. Data from flight tests is used to confirm the effectiveness of aircraft system in meeting a functional specification and to assess the effect of these systems on pilot performance [1].

Engineering simulator is an appropriate platform to fulfill above task. If the fidelity of simulator is high enough, the data from simulator trial can be used to validation and certification of aircraft systems. During process of this, airborne flight trials are used to validate the effectiveness of simulation studies.

In general, to utilize the feature of pilot-in-the-loop, engineering simulator can be used to establish the design scheme of new aircraft, optimize the design parameter, especially assess the flight dynamic characteristic and maneuver characteristic, validate avionics in a simulation environment close to real, that engineer can cooperate with pilot closely. Otherwise, an important role of engineering simulator is the development of flight control systems, especially for fly-by-wire aircraft.

FAI engineering simulator was developed for a new aircraft design. The independency of software modules and flexibility of hardware elements in system allow FAI engineering simulator to be configured different prototyping environment for the design of flight control laws, aircraft displays and avionics. In addition to the setup of flight database and some related databases, FAI engineering simulator has become an integrated platform for aircraft design and testing.

2 Simulator Function

FAI engineering simulator acts as an important role in most part of aircraft design stages. In stage of conceptual design, the best solution can be obtained by means of flight trials using a piloted simulator. In stage of detail design, some of important tasks were effectively conducted, such as the optimization of control law, the perfection of aerodynamic layout, the estimation of the layout of cockpit system as well as man-machine characteristics, the definitude of the relationship among aircraft systems. In the stage of synthesis test, the synthesis test of aircraft was accomplished, preparing for the first flight and test. In the stage of flight-test, the reasons arose failure situation were been found out, and then reasoned out a solution to the problem so as to speedup the course of finalizing design. General speaking, FAI engineering simulator has being accomplished the following tasks:

1. Design of flight control system
   - design of control surface
   - design of control law
   - selection of parameters of trimming and balancing system
   - determination of configuration of redundant systems and strategy of redundant management
2. Design of man-machine components
   - arrangement of cockpit layout
   - design of manipulation system
   - design of instrument system
3. Validation of avionics
   - function test of avionics
   - performance optimization of avionics
4. Analysis the reason of failure case in flight test
5. Pilot training before manipulation in flight

In general, the design of flight control system and man-machine interface is the man-in-the-loop simulation, while validation of avionics is the hardware-in-the-loop simulation.

3 System Architecture

The primary elements of FAI engineering simulator are shown in Fig.1.The Ethernet, SCRAMNet (share memory) and 1553B BUS are three means of interconnecting these subsystems. According to the needs of real time in simulation, flight host computer, display control computer, image generator, control loading system, operator station are interconnected via SCRAMNet and Ethernet, just for debugging easily exploiting Ethernet to interconnect them. The rest of subsystems are interconnected via Ethernet, the components of avionics are interconnected via 1553B BUS besides Ethernet. The operator station acts as a role of bridge between SCRAMNet and Ethernet, The display control computer carries out the data exchange between 1553B BUS and SCRAMNet as a gateway.

The considered emphasis of network design is flexibility, expandability, latency and throughput. The transmission delay for SCRAMNet is deterministic and very low, less than 800 ns per node. With 5 nodes this is less than 4 ms, which is negligible compared to the rest. In addition, SCRAMNet has a guaranteed net throughput of 6 MB/sec [4]. The features of these assure the real time demands of simulation. On the other hand, Ethernet has become an accepted standard for local area communications, although Ethernet is not deterministic and the throughput is dependent on the number of transmitters on the network, the low-cost and interconnection easily make it well suit for the remote access application, such as database system. Some of the components in system interconnect via Ethernet work, with UDP protocol to transport data in a broadcast manner so as to reduce latency.

All the simulator modules are slaved to a common frame rate of 50 Hz. This implies that all the code within each module is executed within the period of 15 ms, with 5ms margin to avoid exceeding the frame rate.

When simulator is operating, the control commands such as START, PAUSE, STOP, etc from operator control computer are sent to the other subsystems via Ethernet and SCRAMNet. The display control computer receives the data from avionics and flight control system via

1553B BUS, and then sends to flight host computer, operator station, instrument computer and etc via Ethernet and SCRAMNet. The flight host computer broadcasts the results of solving equations of flight dynamics to the other subsystems via Ethernet.

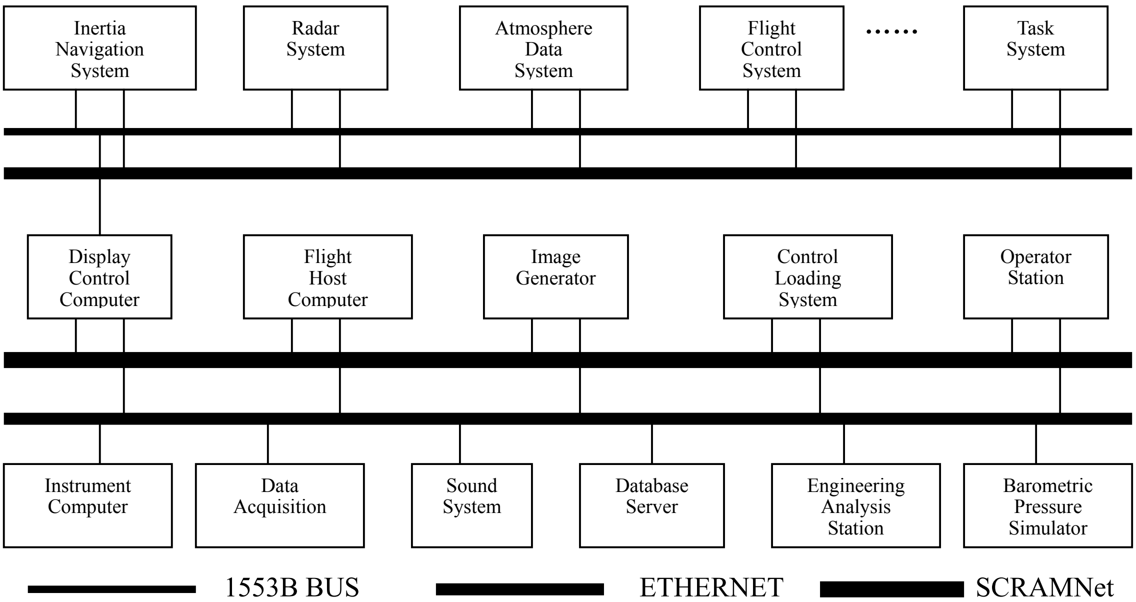

Fig. 1 System Architecture of FAI Engineering Simulator

4 Subsystem Description

4.1 Operator Station

Unlike training simulators, the operator station of engineering simulator should be with a higher flexibility. The functions of the Operator Station of the FAI engineering simulator are briefly described as follows:

- Set the configuration of system, including software and hardware
- Control of simulation process, such as sending the instructions of START, STOP, PAUSE, and so on.
- Observe all kinds of parameters in real time in the process of simulation

One standard PC serves as operator station, which is interconnected with other system via Ethernet and SCRAMNet. The software for operator station has been developed in the environment of Visual C++.

4.2 Flight Simulation System

The simulation host computer is composed of single board type processor boards, a backboard with VME bus and a SCRAMNet board. The processor boards are two sets of PowerPC 7400, which are interconnected via VME bus. One of processor board is designed as the host computer that supports the operation of a real time operating system (VxWorks), the other are used to perform flight dynamics computation, network operation. Flight dynamic computation is the top priority task that updates the common data structure called share memory that resides in SCRMNet board.

Flight modeling is the core part that supports an engineering simulator. We adopt non-linear six-degrees-of-freedom equation as the aircraft dynamics model. The equations of motion for the airframe aerodynamics and the engines are solved at an iteration rate of 50 Hz. The aerodynamic forces and moments are defined in terms of the aerodynamic and engine data for the aircraft, these variables are available in the form of tables. In order to reduce the time to table look-up, these data make a pre-process work. The original aerodynamic data obtained mainly from wind tunnel test is the key of flight simulation fidelity. To get a high realism and fidelity, these data must be modified time after time and flight-test validation. After the relativity of data from wind tunnel and flight-test data to been ascertained, the simulation results have useful value.

4.3 Visual System

Visual system provides out-the-window scene information for pilot for determining the orientation and position of the simulated aircraft. It's an important information source for pilot estimating aircraft handling quality. Out-the-window scene content plays an important role in pilot's perception in estimating position, attitude, and their rate of change. Usually, visual system is composed of image generator and display system.

Visual system of FAI simulator has the field of view (FOV) of horizontally 200 degree, vertically 60 degree in 1280 by1024 resolutions, and five channels mode with the update rate of 30 Hz. Its projection screen is a part sphere of 4.5 meter in radius.

The visual system software was developed based VEGA that is a commercial software package from U.S., it runs in the environment of IRIX UNIX. Visual computer exchanges data with other subsystem via SCRAMNET. At the beginning of simulation, it receives the command of selection functions sent by Operation Station, such as airport selection, time of day, weather selection and so on, and in the process of simulation, it receives the attitude values and position values of simulated aircraft sent by Main Simulation Computer. At the same time, it sends the height of terrain, the signal of collision detection to other subsystem.

4.4 Control Loading System

Control Loading System (CLS) is an important unit that generates the correct control forces on the primary and/or secondary controls of a simulator as sensed by the pilot. It is a commercial-off-the-shelf product from Fokker Company in Holland (ECoL8000) in FAI Engineering Simulator, which carries out simulation of handling performance of stick and vibration performance of pilot seat. The ECoL8000 system consists of two major sub-systems [2]:

- The Control Loading Computer computes the mathematical models of the aircraft flight control system and the actuator control loop. The software is written in C++ and runs under the VxWorks real-time operating system. The output of the actuator controller drivers a control signal to each channel.
- The Control Loading Unit, which converts the control signal into actuator movements, which drive the controls.

The system architecture is shown in Fig. 2. All external forces and moments acting on the control systems are calculated in the Host computer and transferred to the control-loading computer. The control systems dynamics are calculated in the dedicated model that runs on an update rate of at least 1 kHz. Using a development PC with the applicable software running, it is possible to generate a dedicated model, such as the characteristic of stick force/stick position. The applicable software was developed on Visual C++. Ethernet is used as a basic transmission medium for the interface between the Host computer and the Control Loading Computer, with the UDP/IP protocol to transport data between the processes running on the Host and Control Loading Computer. The real time software can be downloaded to the Control Loading Computer via Ethernet. The operating state of system can be sent to the development PC so that engineers can monitor system operation.

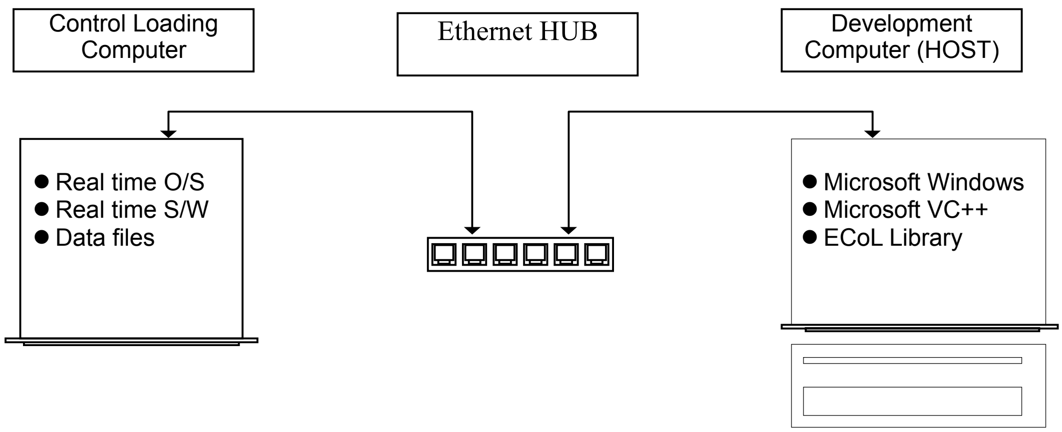

Fig. 2 System Architecture of CLS

4.5 Data Acquisition and Processing System

The data acquisition system carries out the obtaining and processing of the control signal in the simulated cockpit, which includes 13 A/D, 10 D/A, 342 DI, and 236 DO in FAI Engineering Simulator. It consists of SCXI (Signal Conditioning eXtensions for Instrument) signal conditioning system, PXI chassis, and control computer. SCXI is a versatile, high-performance signal conditioning platform, which consists of a full line of modules that amplify, filter, isolate, and multiplex a wide variety of signal types. To reduce the length of signal wire, SCXI signal conditioning system and PXI chassis were placed near the simulated cockpit; for convenience of monitor, the control computer was placed with Operator Station computer together; the optical fiber is used as transmission medium for the interface between them. It communicates with other subsystem via SCRAMMNet. The system architecture is shown in Fig. 3.

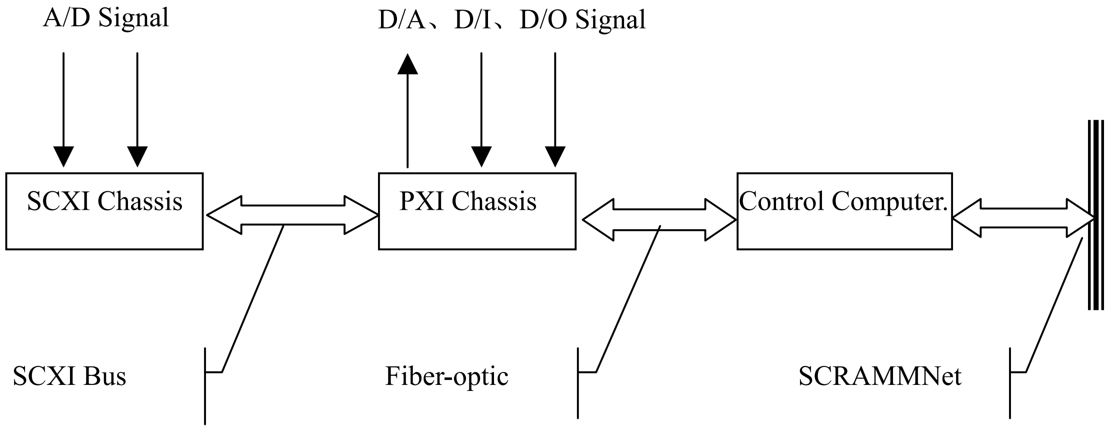

Fig. 3 Architecture of Data Acquisition System

The software for data acquisition was developed based on LabWindows/CVI and runs under the Windows operating system with a frame rate of 5ms.

4.6 Database System

FAI simulator is a network environment with many hosts interconnected each other, in which database system is a prominent feature, using ORACLE DBMS as a management tool; it is designed as client/server mode. Dynamic library and static library are two kinds of library according to the creating form of them. Fig. 4 shows the composition of Database System.

1. Dynamic Library

In the process of simulation, the database server logs the data packet produced periodically by simulation host computer, the size of which relies on the initial file created by Operating Station, this results in the file of database to be created dynamically. In addition, the database server also logs the data packets from other subsystems in real time. All these libraries are called dynamic library.

To improve the speed of data logging, the memory database completes the transaction processing, while Oracle database completes the data backup and management, that is, the memory of server is used as buffer storage of disk database.

2. Static Library

Engineering simulator is an integrated environment for aircraft design and test; a typical example is the design of flight control system. Because large amount of data is needed in the process of aircraft design, the main libraries created in engineering simulator list as follows:

- Original aerodynamic derivative library
- Modified aerodynamic derivative library
- Navigation data library
- Method library: saves all calculation methods used in simulation as well as relevant implement file (source program) in C language
- Information library: saves the related specification for simulation testing
- Graphics library: saves graphs of flight quality, as a guide of flight quality analysis
- Model library: saves mathematics model of the each parts and whole system of flight control system
- Aircraft equation library

4.7 Audio System

Audio system produces audio cues for pilot. It is a standard PC with a programmable sound generation card which replicates a range of aircraft sounds including engines, gear rumble, aural warnings, navigation and communication sounds etc. There are four speakers that are situated inside and outside of the simulated cockpit. The sound system computer communicates with the host computer via Ethernet/UDP.

All kinds of sounds that are needed in the process of simulation are preprocessed and stored in the hard disk of sound computer. These sounds are coded and then forms a look up table by which can get required sound easily.

4.8 Avionics System

During the research and design of aircraft, a flight simulation environment and tactics simulation environment are needed to support highly synthetic avionics system experiment. Engineering simulator is an ideal platform for completing this task. Pilots manipulate aircraft in simulated cockpit, and visual system provides a virtual battlefield environment for them.

The components of avionics system in FAI engineering simulator are interconnected via SCRAMNet and Ethernet. The flight host computer broadcasts the results of solving equations of flight dynamics to avionics systems and the other subsystems over Ethernet. The data are exchanged among the components of avionics system via 1553B bus; some of them are sent to display apparatus in cockpit and other subsystems.

4.9 Display System

Unlike flight training simulators, aircraft displays based on replication of the flight deck environment and often use simulated electro-mechanical instruments [1]. The displays in an engineering simulator should be functionally correct and support an update rate that is matched to the flight model iteration rate. Therefore, the aircraft displays do not need to have a high level of resemblance to specific displays and, for most applications, it is appropriate to emulate aircraft displays by means of real time computer graphics [1].

The aircraft displays in FAI Engineering Simulator use LCD with small size as display terminal driven by PC. One PC drives two LCD via VGA graphics card with dual output port, and one LCD can displays several instruments. The software was developed based on OpenGL in the Visual C++ environment, which have a good portability. The system structure is shown in Fig. 5.

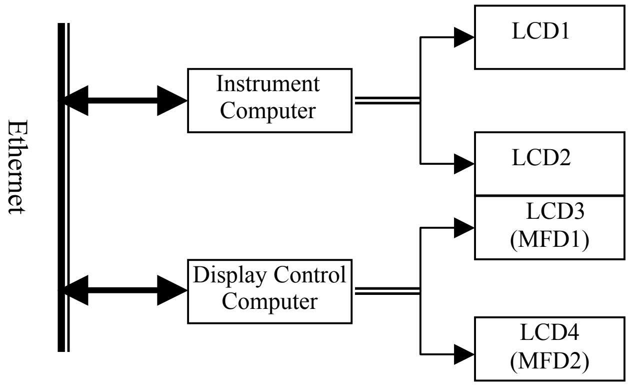

Fig. 5 Display System Structure

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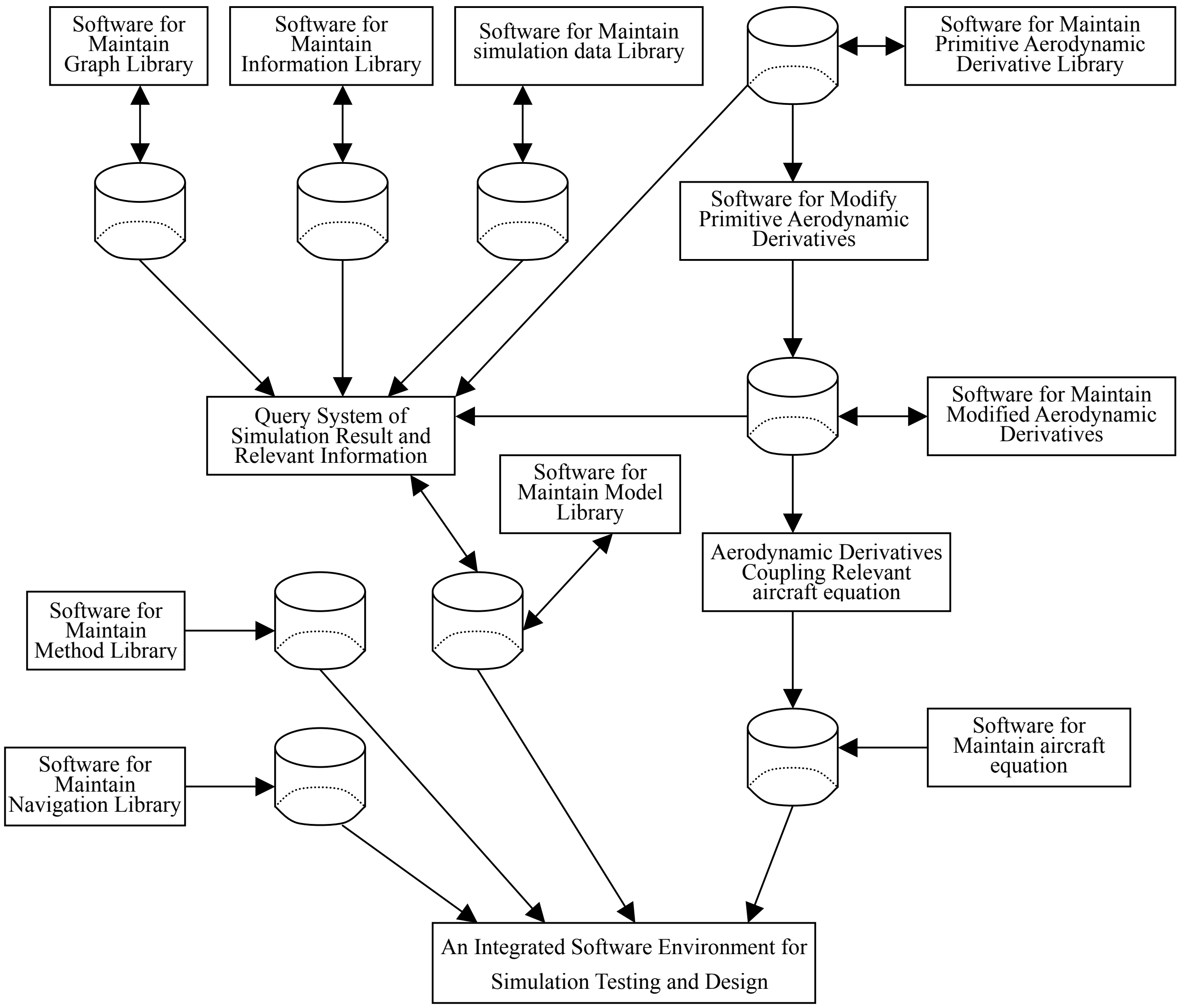

Fig. 4 Structure of Database System

5 Model Validation

The development of engineering simulator is a perfecting process continuously all the times in the period of aircraft design. In order to get a high fidelity, VVA (Verification, Validation, and Accreditation) as a design methodology for simulation system is used in the process of aircraft model design.

A flow chart of aircraft model validation is depicted in Fig. 6 in terms of VVA principle [3]. There are two means of input signal produced by man manipulation and self test software, the simulated output data from the model is compared with criteria data, which maybe is flight-test data, experiment data or specification parameter for design, the comparison results are evaluated according to performance criterion and then drawing a conclusion. If some of performance parameters are out of criterion, the model will be modified until satisfying the requirements.

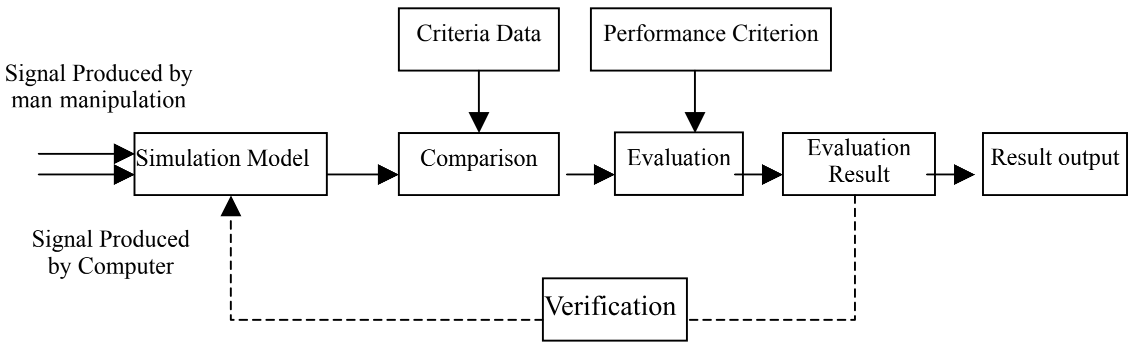

Fig. 6 Flow Chart of Simulation Model Validation

6 Conclusions and Future Work

By means of the engineering simulator, the tasks such as the design and validation of flight control system, solving the coupling problems between subsystems and so on have been carried out in the process of new aircraft design. The system has become an integrated platform for aircraft design, but still requires continuous improvements in several aspects.

At the present, we are concentrating upon the development of database so as to establish an adequate platform for the design of future aircraft design.

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