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THE APPLICATION OF COMPUTER SIMULATION IN A FLIGHT VEHICLE CAD SYSTEM

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ABSTRACT

This paper describes an effort in applying computer simulation to the design of flight vehicle systems. The flight vehicle computer aided design (CAD) system is in itself a simulation of the designer's thinking processes. The system includes many modules to simulate the knowledge structure of a designer group. And it is possible to be adjusted and replenished in time just as in the case of human designers who have to do likely. It is able to input, output, store and generate information under external human manipulation, together with inter-exchanges of data between its modules within the system. The design process goes on iteratively just like in the case with human designers.

Several examples of applying simulation techniques to the CAD system are then presented. They includes a flight dynamics simulation module, a strapdown inertial navigation subsystem simulation module and a simulation approach for an on-board seeking subsystem's scanning process.

1. INTRODUCTION

Computer simulation has been widely used for a great variety of purposes. No matter how complicated a system may be, it can be simulated on a computer, as long as a mathematical model can be built up for it or for the dynamic processes involved.

One of the most complicated systems we can imagine is the human brain, and one of the most complicated processes is the thinking process going on in the brain. Several authors have already discussed the problem of Neuron Net Modelling (See Zeigler, 1975 and Eilbert and Salter, 1986), yet it remained an unsolved problem to model the human brain. As to the problem of simulating the thinking process, and if the process includes not only that of logical thinking but also illogical thinking, few existing literature can be found.

On the other hand, we can simulate some kinds of thinking processes, if it be strictly restricted to logical ones. Numerous examples of various kinds of calculations, that are daily carried out on computers, can be considered as instances of such simulations. When we write a simple computer program for the solution of a mathematical problem, we are simulating the human thinking process of calculation. But all we can do in simulating the human thinking processes still remain only a scanty small proportion of the whole.

The design process appears as a kind of function not uncommon among human activities. It may be found, e.g., from the creation of a simple chair to that of a huge space shuttle. Some authors have properly remarked that "the recent literature on simulation methods does not reflect the importance of simulation in design" (Encarnacao and Schlechtendahl, 1983). They have also noted a similarity between the concepts used for simulation and those used in design processes, but this point has not been brought out in detail.

The design process of any engineering system is essentially a kind of human thinking process, characterized by creativeness throughout the whole procedure. The designers have to face with challenging goals yet they have to work with limited resources under strictly constrained conditions. They are usually encouraged to give the rein to their imaginations. They must create something new in design concepts, in patterning or other respects. Obviouly, it is usually not feasible to build a mathematical model covering the whole design process. But can we manage to simulate such a process? How and in what extent can we do so? In what follows we shall try to tackle the problem through the process of designing a flight vehicle.

2. A FLIGHT VEHICLE CAD SYSTEM BUILT ON PRINCIPLES OF SIMULATING THE DESIGNER'S REASONING PROCESSES

2.1. Design of a Flight Vehicle System

A flight vehicle system is one of the most complicated engineering systems, consisting of many subsystems. And between the subsystems exist complicated relations. The design of any one of the subsystems is usually closely dependent on the design of the flight vehicle system as a whole. On the other hand, the design of the whole system is inseparable from the design of each and every subsystem. Thus the design process of a flight vehicle system is usually carried on iteratively. (See, for example, Haberland et al., 1984.)

Owing to the complexity of the flight vehicle system's design, it always needs the joined efforts of a group of engineers and/or specialists working together to complete the design mission. The fields of the designer's knowledge may cover many areas such as aerodynamics, flight dynamics, navigation, propulsion, airframe and take-off subsystems etc. Besides, there is needed the knowledge of a systems engineering expert so as to synthesise the overall system. Any one among these disciplines in itself consists of a relatively independent knowledge system.

Thus, the design task of any one of the subsystems might be carried out relatively independently, but the information obtained from all disciplines must be inter-exchanged between themselves in time. The amount of information obtained expands as the design process goes on. Some of the information must be modified and replenished when one of the iterative steps becomes completed. At the end of the design process, it is necessary that all information obtained ought to be documented as an integrated, consistent tachnical data package that can be used as a guidance for the new flight vehicle's production process.

2.2. Human Designer Taken as a Physical Hardware Loop in Simulation

In order to simulate complicated systems which cannot be simply modeled mathematically, one often has to resort to a well-known approach, that is physical simulation. In such an approach, engineers use physical models to simulate the complicated subsystems, whose mathematical models are yet unknown, or he even use the subsystem itself as a hardware loop. The remaining subsystems, if any, that are simpler than those already modelled physically, are often modelled mathematically without much difficulty. The complex system can thus be simulated either with a physical model or with a hybrid model.

As an example of such physical simulation, we may take the pilot flight trainning simulator. In this simulator system, the most complicated subsystem is the pilot himself, all others are simpler and can be modelled mathematically, if we like. Note that here we consider the human pilot as a hardware loop of the system.

Now we can also consider the CAD system as a physical or hybrid simulation of the designer group. In the CAD system, we purposely avoid modelling the illogical aspect of the human designer's thinking process, limiting our efforts on modelling logical thinking only. In other words, we take the group of human designers as some physical hardware loops of a CAD system and connect the mathematical model to the human designers through interfaces. With this understanding, we can now begin to simulate the design process. Figure 1 shows the idea schematically.

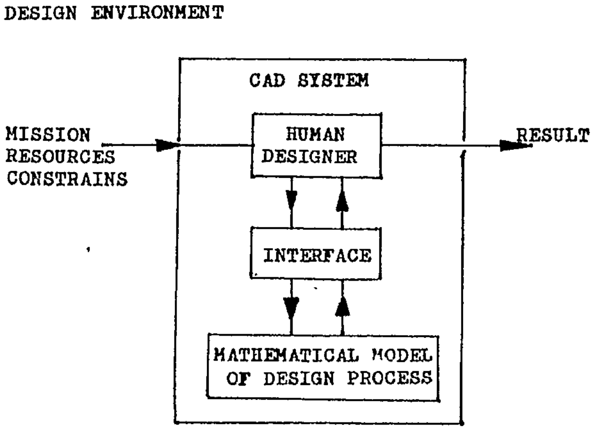

Figure 1 Block Diagram of a CAD System

2.3. The Structure of a Flight Vehicle CAD System

Simulating the functioning of the designer group, the structure of the CAD system consists of many subsystems. It is illustrated in Figure 2.

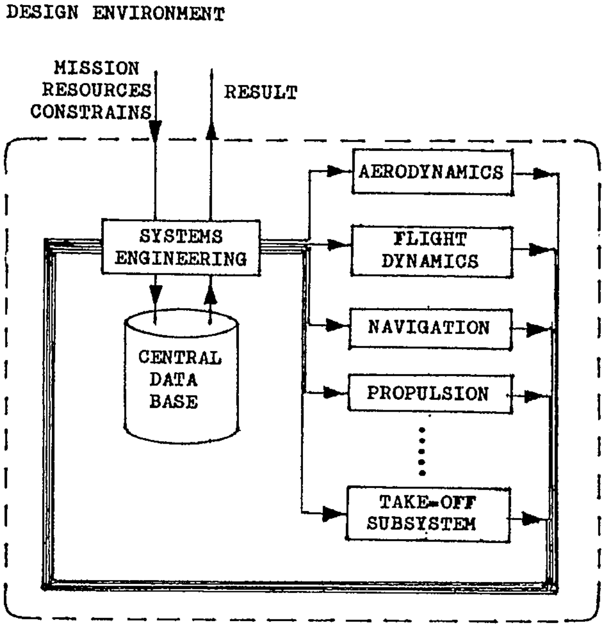

Figure 2 Structure of the CAD System

Each of the CAD subsystems as illustrated in Figure 2, includes at least one engineer or specialist, a software package, a man-machine communication interface and other necessary hardwares. The engineer or specialist manipulates the design process going on within the computer and makes his decision when needed. The software package embodies the mathematical model corresponding to the design process, which can be simulated mathematically.

The block corresponding to the discipline of systems engineering is very important. It assigns design tasks and allocates initial data among all other CAD subsystems. Then it collects and synthesizes the information output from them. All the information is input and stored in a central data base. The information stored in the data base must be replenished after completing a step in the iterative design process.

We might note that the structure of the CAD system is just like the structure of a real designer group. The information flow moving among the CAD subsystems is just a simulation of the flow among the individual designers of the group.

As long as the CAD system is considered as a physical simulation of the human designer group working without computers, we can invoke the concepts and notions of simulation (as has been stated by Gordon, 1978) to describe the CAD system. We can thus define all the subsystems here as the "entities" of the simulation system, and define the information produced by every such subsystems as their "attributes", while the design processes occuring in them as the "activities". The "events" are the circumstances of the batch of new data being output from the subsystems and input to the central data base.

The process goes on during any one of the iterative steps and can be considered as a continuous process. But the process including several iterative steps may be considered as a discrete one.

The following two principles should be considered in the buildup of the CAD system;

(1) In order to adapt itself to the manifold requirements of a design mission, the CAD system must be flexible enough, and well integrated as a whole. The internal structures of the overall system and each of the subsystems ought to allow each CAD subsystem to be developed independently and/or run independently.

(2) In order to adapt itself to the rapid progress of science and technology, the CAD system must be able to be modified, renewed or replenished whenever necessary. It should be able to absorb into itself various commercial softwares as well as special purpose package.

The above principles are nothing but what is actually followed in the design processes implemented by human designer groups working without computers. These principles will allow the CAD system to improve and develop further. For example, it is reasonable to imagine, with the appearence of a pertinent and practical expert system, then we might embeded it into the corresponding CAD subsystem as a mathematical model to replace, or to simulate, the physical model of the human designer.

3. SIMULATION TECHNIQUES IN THE FLIGHT VEHICLE CAD

The above section has given some basic concepts of simulation for building a CAD system. Now we will turn to the application of simulation techniques in CAD. Given below are only some examples to reveal the possibility of this kind of applications.

3.1. Flight Dynamics Simulation Module in the CAD System

Any mission of a flight vehicle design will first need to evaluated the flight performance of the vehicle being designed. Several special purpose softwares are now available to meet such needs. Some of them are widely used because of their flexibility. They can be used to simulate flight processes not only under conditions similar to an environment having a series of random disturbances, but also under conditions including a pilot's steering action which is described by a model of fuzzy controller. Some of the flight simulation softwares are developed in assembly languages, so they can readily be used for real time simulation.

The flight performance of a vehicle is usually evaluated by a multiple criteria objective function. As the design variables which might influence the flight performance are very complex, so that it is virtually impossible to build an explicit relation as the mathematical model for evaluating the performance. Thus, to experiment on computers with a flight simulation module is a practical approach. With the results of a number of simulation experiments, it is possible to analyse the relationship between the flight performance and the design variables. To reduce the amount of computation necessary, it is found that the factorial experimental method (see, for example, Montgomery, 1984) is favorable in its effectiveness.

3.2. Simulation in the Design of a New Type Navigation Subsystem

Suppose that a new type strapdown inertial navigation subsystem is to be designed for a flight vehicle system. The problem is that the feasibility of the design concept of the navigation subsystem must be verified, and the basic parameters of the subsystem must be decided.

The navigation subsystem's function is such that the sensors of the subsystem ought to sense the linear accelerations along the three principal inertia axes, i.e. OX, OY and OZ, of the flight vehicle as well as the angular accelerations about them. Then the microcomputer on-board ought to convert the acceleration information into the velocity and displacement information. Further-more, the autopilot outputs a series of steering signals to correct the flight course. The first question is to predict for the navigation subsystem the errors' magnitudes and direction. The second question is to find out how to minimize the errors.

A simulation module is then developed to answer those questions. The mathematical model of the navigation subsystem is relatively simple. But it must be run under near-to-real environmental conditions. This is the very key point to consider and it decides the feasibility of the design concept, especially owing to the fact that the navigation subsystem is a strapdown one.

The approach to simulate the environmental conditions of the navigation subsystem is to call on the six freedom flight dynamics simulation module. The flight dynamics simulation module outputs the information about the linear and angular acceleration of the vehicle during the flight course under a set of random disturbances. This information is just a full description of the environmental conditions on-board. The sensors module transfers the information into measured signals and the microcomputer module converts the signals into velocity and displacement parameter components (Vx,Vy,Vz,X,Y,Z), measured by the navigation subsystem. Obviously, as a result of influences from the systematic error, dynamic error and the random error effected on the navigation system model, there must appear some differences between the (Vx,Vy,Vz,X,Y,Z) values measured and the values output directly from the flight simulation module. These differences are just the error of the navigation subsystem, which is what we want to predict. A flow sheet showing the simulation is illustrated in Figure 3.

As the navigation subsystem's error can be found through simulation under each special case, it is possible to run the models repeatedly with various design parameters and various disturbance factors. So the optimal set of the design parameters can be found and the necessary limiting condition for the disturbance factors can be determined. Then the feasibility of the design concept can be evaluated on a computer.

3.3. Simulation in the Design of an On-Board Seeking Subsystem

Suppose that an on-board seeking subsystem is to be designed for air-to-surface searching. The goal is to detect and acquire some particular types of targets with a high probability.

The sensor for detecting on-board is to be

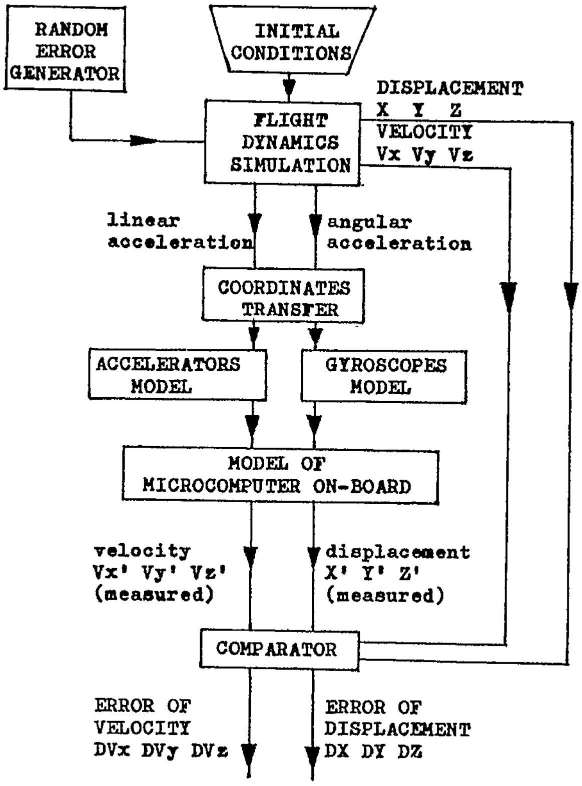

Figure 3 Simulation of a Strapdown Navigation Subsystem

scanning during the flight searching processes (see Figure 4). And the probability of detection is dependent on the "effective search time", that is the duration of time during which the target is located within the effective viewfield of the scanning sensor (See Wan, 1984). But the effective search time is dependent in its turn on a series of factors including the vehicle's flight speed, altitude and flight course as well as the scanning sensor's design parameters, such as the viewfield's angular boundary, the effective detection range and the scanning schemes adopted.

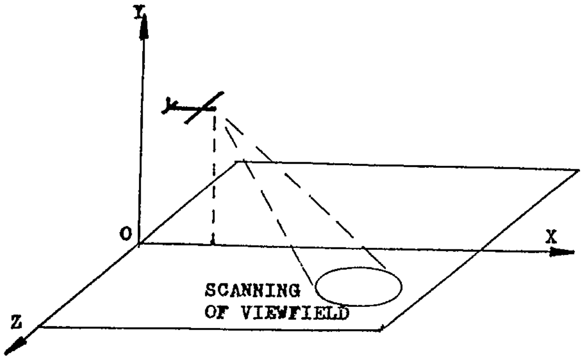

Figure 4 Scanning and Detection of Targets during Flight

It appears that we cannot find an explicit solution for the probability of detection, although we can derive a set of recursive formula for the probability if we know the effective search time. So we have to pay attention as to how to determine the effective search time during the flight process. To do this, we can build a model to describe the scanning process during the flight. Running the model on a computer repeatedly and changing the parameters interested, we can find out a satisfactory alternative.

4. CONCLUSION

The idea and concept of simulation is of use to suggest a CAD system for solving the complicated design problems for flight vehicle· systems. Simulating the knowledge structure and the reasoning processes of a human designer group, we can develop a CAD system integrated as a whole, yet still flexible enough for further changes and improvements.

The simulation technique is found to be very useful as a tool to solve various difficult problems encountered in the CAD of flight vehicle systems.

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