Analogue Computer for Flight Simulator

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IN THE FIELD of dynamics, problems concerned with aircraft motion are noted for their complexity. The ordinary differential equations which generally can be used to characterize the problems commonly are of order between 20 and 30 and, unless drastic assumptions are made, contain many nonlinear terms. Important nonlinear effects are introduced by the trigonometric effects associated with the motion of a rigid body with six degrees of freedom as well as by the nature of the aerodynamic forces and moments acting upon the aircraft. Also, if the aircraft is controlled automatically, the nonlinear properties of the controlling equipment are significant. The complexity of the problems is such that computing machines are required for their solutions.

Because of the fact that no machine was available well adapted to handle problems in this field, a generalized analogue computer has been developed for particular application to the solution of this type of problem. The machine is known as a flight simulator; however, in order to handle the diverse nature of aerodynamic problems, the computer had to be of such scope and flexibility that it is expected to have applications to other problems in the general field of dynamics.

The flight simulator was designed to apply specifically to aircraft problems of two general types: those problems that can be adequately represented by ordinary nonlinear differential equations with time-varying coefficients; and aircraft stabilization problems in which the control equipment is available and requires test, but the mathematical representation of which is either unknown or highly complex. The computer is arranged to handle problems ot the first type in much the same way as existing differential analyzers. Problems of the second type are studied by employing an auxiliary device known as a flight table that orients the control equipment in a fashion similar to that occurring in actual flight. Signals from the control equipment are connected into the computer in a way analagous to that in which it is used in flight, thus permitting the control equipment to be tested under circumstances almost identical with actual flight conditions. Use of the simulator to test actual aircraft control components requires that it operate on a one-to-one time scale. Thus, if a particular phenomenon requires two seconds to occur in flight the same phenomenon must be computed by the machine in two seconds. The rapidity of occurrence of many flight motions required that special attention be paid to the speed of operation of the computer.

The variety of problems requiring solution led to the choice of an electric computer primarily to gain flexibility but also to obtain the necessary computing speed. The computer is of the a-c type, and dependent variables in the mathematical equations being studied are represented in the machine by 400-cycle-per-second voltages. The amplitude of the voltage is proportional to the magnitude of the variable being represented, and the phase of the voltage is either zero or 180 degrees depending upon the sense of the variable. The use of a-c signals in the machine provided freedom from grounding difficulties and permitted trigonometric transformations to be handled readily. Considerations such as speed of computations determined the frequency employed, and 400 cycles per second seemed to be the lowest frequency feasible. Phase shift in the signals was troublesome, and it was necessary to limit the phase shift introduced by each element of the computer to 0.05 degree. In addition, it was necessary to make use of quadrature rejection circuits.

The high speed of computation needed and the large number of effects that required representation made it necessary to develop almost all the various types of computing components used in the machine. These include summing networks, repeater amplifiers, multipliers, integrators, vector resolvers, and arbitrary function generators. Accuracy specifications on each computing element of 0.1 per cent of full scale output were met. The time constant associated with the operation of each computer element is about one millisecond except for operations such as summation and multiplication by a constant where, because of the frequency of occurrence of these operations, the time constant had to be well below 0.1 millisecond.

When the simulator is used to test flight control components, a servo-driven table must be employed to orient those components of the control system that respond to angular motions of the aircraft. The table that simulates the aircraft motion is called the flight table, and its design and characteristics are important considerations in the analogue computer. When the complete flight problem is studied the table must have three degrees of freedom in order to simulate the pitch and yaw as well as the roll motion of the aircraft.

The analogue computer has been in operation for about one year and has been used largely on trajectory problems although some aircraft stability problems have been solved. In the year's operation over 5,000 solutions to trajectory problems and several hundred solutions to stability problems have been computed by the machine. The problems were such that each solution would require 100 to 1,000 hours to solve manually with a desk calculator. A typical stability problem required 9 integrators, 10 vector resolvers, 20 summing networks, 20 multipliers, 30 coefficient potentiometers, and 70 repeater amplifiers.

Operation thus far has proven the value of the simulator to aircraft dynamics and related problems.

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