Bits

This has been the most difficult Newsletter I have ever had to edit. Not that the material wasn’t in good shape—it was. The only trouble with the H. J. Harrington paper on the effect of the nonlinearities of electrohydraulic control valves was the difficulty of cutting it down to the proper size and level for this non-technical Newsletter. I hope I have succeeded; if not, please be referred to the AIEE article by Mr. Harrington and J. Zahorszky, cited in “Pieces.” And Hideo Mori did his usual good job in his writeup of the Eastern Simulation Council talks on the simulation of jet engines.

The thing which made ye Ed’s job difficult was Suzy’s Christmas present and the La Jolla weather, Christmas and since. The present was a surf board, and the weather has been perfect for trying it out. See my problem? S’a tough life!

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Pieces

CENTRAL S/C MEETING OF NOV. 13 ON ELECTROHYDRAULIC CONTROL VALVES

H. J. Harrington (Missile Engineering Division, McDonnell Aircraft Corp., St. Louis, Mo.) presented a paper entitled “Analog Computer Simulation of Electrohydraulic Control Systems” before the Central Simulation Council, meeting in Kansas City on 13 November 1957. The paper describes analog techniques used in a detailed simulation of single- and dual-stage electrohydraulic control valves and their associated loads. Special emphasis is placed on the simulation of nonlinearities, including detailed descriptions of circuitry used for the following simultaneous nonlinearities in the single-stage system: current hysteresis; Coulomb friction on valve spindle, actuator piston, and load member; square-law damping on valve spindle; Bernoulli force on spindle; quadratic pressure-flow-rate relationship of valve; and special acceleration- and position-dependent damping terms acting on the load member. In addition, the simulation of flapper Bernoulli forces and the nonlinear pressure-flow-rate relationships of the four orifices in the first stage of a dual-stage valve are treated.

Because details of this valuable work are available in AIEE CP 57-780 “Generalized Charts of the Effects of Nonlinearities in Two-Stage Electrohydraulic Control Valves,” only that part of Mr. Harrington’s paper considered to have widest general application to simulation—the mechanization of nonlinearities—will be abstracted here.

Harrington on Nonlinearities

Several years ago McDonnell Aircraft was confronted with two distinct modes of instability brought about by the nonlinearities of servo systems. One of the modes was a hard-type, limit-cycle oscillation occurring at a frequency approximately equal to the natural frequency of the load being driven by the servo.

The mechanism of this oscillation remained a mystery for some time...
until Mr. Harrington and his colleagues again attacked the problem as part of a generalized study contract let by the Applied Physics Laboratory of Johns Hopkins University. Out of this study came an analytical approach to the problem and two separate analog computer studies dealing with both single- and dual-stage valve systems.

The equations were simulated on a Reeves Model C-101 analog computer. About 65 high-gain amplifiers were used for the single-stage simulation and 75 for the two-stage simulation, as well as several diode function generators, multiplying servos, and other associated equipment.

Fig. 1 shows the simulation used for current hysteresis. This circuit was chosen over the simpler two-amplifier, twodiode scheme because of its sharper hysteresis curve, and also because it introduces less phase lag at the higher harmonics.

Fig. 2 shows the circuitry used to generate the orifice (dashpot) damping term of the spindle equation. Spindle rate, \( \dot{x}_c \), is used to position the shaft of a high-speed multiplying servo with \( |\dot{x}_c| \) then picked off the arm of a potentiometer on which \( +100 \) volts exists on both ends. This signal is then inverted twice and appropriately fed across the high and low sides of a second servo potentiometer from which the quantity \( \dot{x}_c \) times \( |\dot{x}_c| \) is obtained.

The Coulomb friction simulation used for both the valve spindle and the actuator piston is shown in Fig. 3. Total acceleration is integrated to give rate, which is then inverted and fed to a high-gain amplifier employing only biased-diode feedback. The output of this amplifier rises at a slope equal to the gain of the amplifier (about 30 million in this case) until it is sharply cut off at the diode bias value, \( V \). This limited output is then properly scaled and fed back as the Coulomb friction force term. This scheme was found to give good performance for very small input signals and did not suffer from relay chatter as do circuits employing differential relays.

Fig. 4 depicts the circuitry used to obtain the spindle Bernoulli force term \( \frac{P_0}{\pi} x_e \) and the valve flow rate. A multiplying servo is driven with spindle position \( X_e \), and one of the potentiometers is energized with \( +P_0 \) on both ends. The arm then is \( \frac{P_0}{\pi} X_e \), the desired Bernoulli term. The quantity \( X_e \) also drives a flip-flop circuit similar to that used in the Coulomb friction simulation. The output of the flip-flop amplifier energizes a differential relay so that either \( +P_a \) or \( -P_a \) is obtained from the relay arm, depending on the algebraic sign of \( X_e \). The sum of this signal and a constant, representing supply pressure, is then the instantaneous pressure drop across the valve. This quantity is fed into a diode function generator, and the square root of the pressure drop is brought out and fed to another potentiometer of the multiplying servo. The output of the arm of this potentiometer is then proportional to valve flow rate, namely \( X_e \) times the square root of pressure drop across the valve.

The only critical item in this circuit is the square root device. A servo square-rooter is not satisfactory because the input function is discontinuous and so demands a faster response than is obtainable mechanically.

Fig. 5 shows the simulation of the load; everything is conventional except the handling of the complex Coulomb friction terms. For these terms, \( \ddot{x}_1 \) was solved for explicitly and then used to trigger a flip-flop circuit which, in turn, tripped a differential relay which switched algebraic signs of \( \ddot{x}_1 \) to give the absolute value of \( \ddot{x}_1 \) out of the arm. This quantity was then properly scaled and fed into a summer along with a similarly derived value of \( F_1 \) times \( |\ddot{x}_1| \) and also the constant term, \( F_1C_1 \). The output of this amplifier was then once more sent through a sign-switching relay, which was triggered by load rate, \( \dot{x}_1 \). The output of the arm of this latter relay is then the desired total Coulomb friction force.

The instrumentation of the first-stage equations of the two-stage valve represented the most serious problem in the over-all simulation. The equations were algebraic and the resultant analog circuitry did not possess the low-pass filter characteristics common to most feedback systems. Therefore the entire first-stage simulation tended to go unstable at a frequency of several kilocycles due to accumulated phase lag in the several high-gain amplifiers and nonlinear function generators. This was cured by holding the number of amplifiers to an absolute minimum, by using parasitic filters at various stra-
egic points, and by performing the squaring operation of the fixed-orifice flow equations by means of nonlinear Thyrite resistors working into high-gain amplifiers. The final circuit configuration evolved only after many frustrating hours of trial-and-error attempts to eliminate the troublesome oscillations.

Although the instrumentation behaved quite satisfactorily for the limit-cycle stability study, it should be pointed out that other simulation techniques might be more nearly optimum for a transient performance analysis.

**EASTERN S/C MEETING OF OCT. 14 ON SIMULATION OF JET ENGINES**

About 65 members representing 25 different groups attended the seventeenth Eastern Simulation Council meeting at the Small Aircraft Engine Department of the General Electric Company, Lynn, Mass., on October 14th.

Five study groups met before lunch; however, the group led by Herb Wexler (AVCO) is the only one on which we have a report. At this meeting, fourteen members, representing six companies, discussed the generation of linear accelerations to test devices such as accelerometers, and reviewed techniques— including the use of electromagnetic and electrostatic forces—which they had talked about in the past. They then discussed two of the more promising techniques in detail. One of these makes use of the earth's gravitational field to test accelerometers with a range below one g. In this case, a simple servo would position the sensitive axis of the accelerometer relative to the one g vector. The other method, similar in principle, makes use of a centrifuge with a servo. In the latter case the servo would have to be insensitive to the accelerations exerted on it.*

This discussion led to a consideration of the simulation of atmospheric sensitive devices in which it was pointed out that physical simulation at AVCO will lead to mathematical simulation, which is a reversal of the usual procedure.

After an excellent lunch, courtesy of General Electric, the technical session—"Simulation As Applied to the Design of Jet Engines"—was opened by Bob Fraser, who welcomed the group on behalf of the host.

**Edkins on Design Specs**

The first speaker (all speakers went from G-E) was Denis Edkins, who spoke on preliminary design specifications for aircraft engines. This area is one in which a large number of engine and aircraft variables must be taken into account to produce an optimum design. Typical problems involve optimizing such variables as operating costs, take-off and climb rates, fuel consumption, etc. Most of these calculations are tedious to do by hand, but not difficult. Once set up, an analog computer takes only about two minutes to plot the various functions.

An interesting trick that the GE people have done on the analog equipment (which would be difficult to do by hand) concerns the cruising environment of an airplane. The economics of the problem involve three boundary conditions. One of them is drag on the aircraft, which makes it uneconomical to cruise above some critical speed. There is also a minimum speed below which aircraft cannot be controlled and flown comfortably. The third boundary is the cruising ceiling. A perfect airplane would meet all three conditions simultaneously. G-E uses the analog computer to optimize a realistic compromise.

Mr. Edkins described, as an example, a military aircraft which climbs at a certain rate and then turns on its afterburner and accelerates to supersonic speed. After a limited combat time it descends, turns back, and tries to ascend. During all of these maneuvers the weight is changing because fuel is being consumed. The problem of optimizing the climb is very difficult by analytical methods. Instead, GE simulates a large number of climbs to find where an optimum occurs.

The engine was simulated by a function-of-two-variable generator, but simulating the pilot gave them considerable trouble. It was difficult to make the operation stable and also fast enough.

In answer to a question from Ro Favreau (Electronic Associates, Princeton, N. J.), Mr. Edkins explained that the reason an engine manufacturing company is interested in making these optimization studies is that it takes longer to develop an engine than an airframe.

**Spring on Fuel Flow**

The next speaker was Richard Spring, who described a nonlinear
control system which was studied by simulating the control and the engine together. He explained the operation of a very simple turbojet engine and said that the primary purpose of the control system is to control fuel flow so that neither the temperature limit nor the maximum rate speed will be exceeded. At the same time, the control system must allow as high a temperature and speed as possible to obtain maximum power and efficiency.

Mr. Spang pointed out the complexities of a turbojet engine, which include a large number of nonlinearities. In fact, many of the significant nonlinearities are functions of two variables, namely fuel flow and speed. Another complexity is that the control circuit does not limit temperature during the acceleration period of the engine.

Katz on Control Evaluation

Herb Katz, who spoke next, talked about the dynamic control analyzer, a fancy term given to a closed-loop test stand for evaluation of control; a jet-engine simulator which he said should not be confused with the three megabuck simulator at Evendale.

The Aircraft Gas Turbine Division of GE, Herb said, more or less pioneered the use of analog computers. He reminded that not many years ago they used mechanical differential analyzers with stenographers cranking in functions. They have evaluated controls by simulating the engine and putting the actual control system on a test stand. They have also used analog computers to simulate control systems with an actual engine on a test stand.

As mentioned, beside controlling thrust (called for by the pilot or flight-control system), the function of a control system is to protect the engine. As it is usually not practical to wait for the engine to be developed to determine what the control requirements will be, analyzers use function generators to simulate the engine. Torque is a function of speed and fuel flow. In most cases engine controls are speed control systems. If the speed is not correct, they change the fuel flow to correct the error. Using the fuel flow and speed, and appropriate function generators, the torque is simulated. The unbalanced torque is then integrated to produce a change in speed. High-respond flow sensors are necessary to maintain a one-to-one-time scale. A high-response forward-drive system, as well as pressure measurements, are necessary.

The usual device for measuring pressure is a fast servo operating a bellows. A special 15-hp hydraulic drive system, used at GE, covers the range from 2 to 300 psia, and is flat within 3 db from 1/10th to 40 cps. The aerodynamic lag is negligible; when the fuel flow is changed, the heat value related to the pressure changes almost instantly.

As stated by Herb Wexler about the accuracy of the pressure system, Mr. Katz replied that it was within plus or minus 1% in a 6 cu ft chamber.

Dumont on Compressors

Lincoln Dumont next spoke on the applications to compressor design of an analog computer at GE. Mr. Dumont gave a brief description of what a compressor does and where it fits into an engine. The compressor draws in air at a very high rate and compresses it by a series of rotating and stationary blades.

In the design of a compressor, certain facts (like rate of air flow, the pressure rise required, and over-all dimensions) are known. From these, the number of stages and the pressure rise per stage for the flow and speed conditions can be calculated. Mr. Dumont pointed out that in designing the turbine blades, the first step is to determine the direction and velocity of the air flow into and out of a typical blade row; usually then can the design of a blade having appropriate aerodynamic characteristics be started.

Mr. Dumont said that an analog computer can be used to figure the required velocities. In determining the axial velocity in a blade row, solution of an integral equation is necessary, and the limits are the minimum and maximum radii of the blades. Different values are assigned to the unknown until the desired result is obtained. In the computation it was necessary to evaluate the function:

$$V = V_{n} (R/R_{n})^{*}$$

The $V_{n}$'s are axial velocities. The $R$'s are radii. The subscript $H$ refers to the hub or minimum blade radius.

The only variables are $V_{n}$ and $R$. The first inclination might be to obtain $V_{n}$ by using a function generator, but the following equation can be instrumented to obtain it directly:

$$d(V_{n}/V_{m}) = n (R/R_{n})$$

Gibson on Heat Transfer

The next speaker, Dave Gibson, told how heat transfer and temperature analysis problems can be solved. He pointed out the similarity between electrical and thermal circuits, and showed how the similarity is used to solve heat-transfer problems in turbo machinery.

Most heat-transfer problems involve a determination of the temperature profile required to evaluate thermal stresses. This, in turn, requires a determination of the heat-transfer coefficients. In a thermal circuit, thermal resistances, which are related to heat-transfer coefficients, may be the result of metallic conduction, convection, or radiation. The heat-balance equations which must be solved merely state that the heat flow in, minus the flow out, is equal to zero.

A resistive network is sufficient to solve steady-state heat-transfer problems. But to solve a transient heat-flow problem, capacitors must be added to simulate the ability of the material to soak up heat. Mr. Gibson showed how a turbine wheel is analyzed from a heat-transfer point of view. A big problem is the determination of the nodal points for the resistance network used for simulation.

The transient problem involves the calculation of clearances and temperatures between a rotating and stationary member in which the designer must consider the conditions during both acceleration and deceleration. If one of the members increases in temperature faster than another, clearances may change and a rub occur. A rub results in a point source of heat generation which, in turn, causes an accelerated failure.

During the question period Mr. Gibson stated that their analog model has been limited to about 30 nodal points, but that they have handled up to 200 on their 704 or 650. He also said that they used some nonlinear elements of a general-purpose computer for their temperature transfer study.
Information (Without theory)

So much material this month that we have had to hold the report on the joint meeting of the Western Simulation Council, the DDA Council, and the Los Angeles chapter of the Association for Computing Machinery on "Interrelationship of Analog and Digital Computers," and the combined analog and digital demonstration of a simulation, held at Ramo-Wooldridge on the 8th of January, until next month. We then also hope to be able to report on a paper that Mr. Fineberg presented at the November Central Simulation meeting.

More correspondence from abroad indicates that interest—and progress—in simulation are by no means confined to the U. S. Excerpts from two of these letters are given below.

(Wish we knew what the Russkies are up to!)

Mr. J.G.L. Michel, National Physical Laboratory, Teddington, Middlesex, England, writes in part:

"... As you probably know, we maintain in this Laboratory a digital computer (DEUCE)—with a further large-scale machine in construction—a servo-connected mechanical differential analyzer, and electronic simulator."

J. Kuntzmann, Director of the Laboratoire de Calcul, Institut Polytechnique, Université de Grenoble, France, writes us that his laboratory has an analog computer built by the Société d’Electronique et d’Automatisme of 24 amplifiers which permits resolution of a system of 12 linear algebraic equations with 12 unknowns, of a system of 12 linear differential equations of the first order, or of any other equivalent differential system.

Nearer home, we hear from George Bekey of the Beckman Computation Center at 305 Parkman Avenue, Los Angeles 26, who states (among other things) that:

"We have been offering a one-week course in theory and application of analog computers here at the Beckman Computation Center approximately once every two months. The courses have been directed to people with limited experience in analog computing and have included lectures, discussions and computer operation by the participants."

"Beginning in January 1958 we will be offering two separate courses. One of these will be directed to persons with limited analog computer experience and will cover theory and applications. The second course, which is entitled "Advanced Applications," will cover such topics as frequency analysis, adjoint computation, solution of partial differential equations, simulation of servo systems and error analysis.

"Both courses are offered at no charge as a public service."

We note that Andromeda, Inc., 3742 Howard Avenue, Kensington, Maryland, is in the conversion field with an Analog-to-Digital Encoder and a Digital-to-Analog Decoder.

So is Packard-Bell, with their Multivertex, which goes both ways and throws in some free multiplication and division to boot. We have seen a demonstration of this gadget and were favorably impressed with both construction and performance.

We have received the following announcement from Lou Wadel, Acting Chairman of the 1958 National Simulation Conference: CALL FOR TECHNICAL PAPERS—NATIONAL SIMULATION CONFERENCE


Technical papers in the general field of simulation are hereby solicited. Papers submitted must not have been presented previously at a meeting of national scope nor published previously in a nationally circulated journal. One-hundred-word abstracts and 500-word summaries to aid in paper selection should be transmitted in duplicate to the Technical Program Chairman:

Mr. D. J. Simmons
Route 8, Box 447
Forth Worth, Texas

The deadline is 25 June 1958.

In addition to topics such as the analog and/or digital simulation of mathematical, physical, logistic, economic, biological, and chemical systems, papers are desired covering advances in analog computer system and component design, techniques, and applications, as well as new methods of determining and improving the accuracy of analog solutions.

No "proceedings" volume will be published as such, but authors of papers accepted for the conference will be expected to submit the full text of their papers to the IRE Transactions on Electronic Computers for consideration for publication in that journal.

He Went Thataway!

Tim Sutton to GPS Instrument Company (high-speed analog computers). Bob Franzel to Boeing (Bo-mark).

Computer Events

Western Simulation Council

Date: Thursday, 13 March 1958
Place: U.S. Naval Air Missile Test Center, Pt. Mug, California

Subject: "The Use and Usefulness of Flight Tables in Simulation" A discussion of this topic by people who have had actual experience with various designs of flight tables will comprise the technical session, which will be unclassified.

There will be two tours: one in the morning of NAMTC in general, and one in the afternoon (following the technical session) of the Simulation Facility only. Both these tours will require security clearance of confidential.

For further information write with Willard Uplinger, Simulation Laboratory, USNAMTC, Pt. Mug.

DDA Council

Date: Monday, 5 May 1958
Place: Los Angeles, California

Details as to place and subject will be announced later.

Western Joint Computer Conference

Date: May 1958
Place: Los Angeles, California

Details will be given next month.

1958 National Simulation Conference

Place: Dallas, Texas

The conference will be sponsored by the IRE Professional Group on Electronic Computers and the Dallas Section of the IRE.

For information write Louis B. Wadel at 3905 Centenary Drive, Dallas 25, Texas.