SP 184

Trice/440

An all-digital hybrid computing system

RAYTHEON

RAYTHEON
COMPUTER

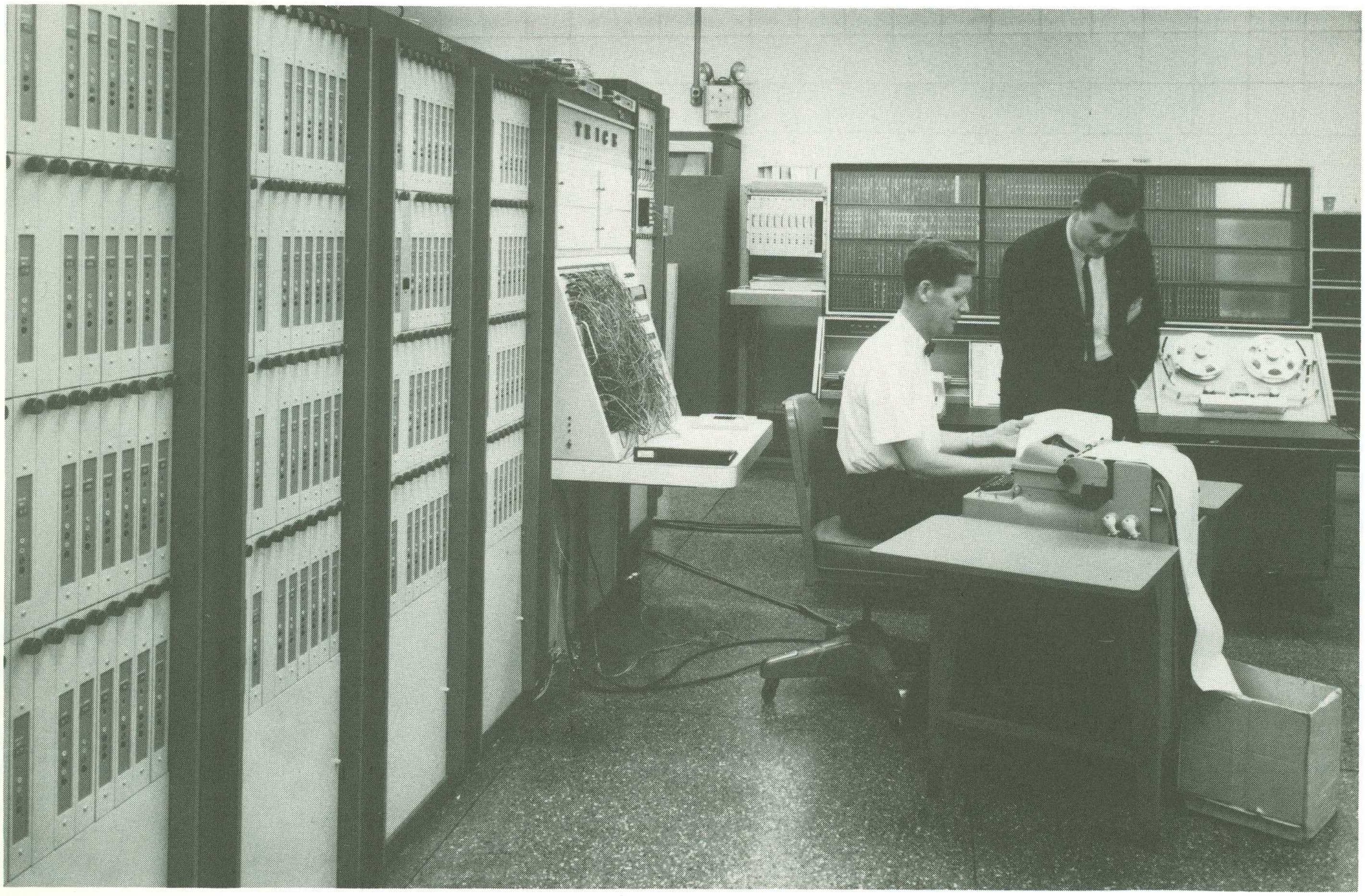
The Trice®/440 Hybrid

. . . a different kind of hybrid system with unequaled computing power and versatility

When the TRICE digital differential analyzer was first introduced several years ago, it represented a breakthrough in computer technology whose benefits are just now being fully recognized. Even at its introduction, however, the need, in the aerospace field especially, for a computer that could perform simulation studies with the flexibility and ease of programming of an analog computer yet offer the accuracy and repeatability of a digital computer was well defined. The first TRICE computers offered this combination. Since then there has been continuous evolutionary improvement in TRICE, brought about jointly by the users who have pioneered in new and unique applications and the definition of new problems and TRICE designers who have steadily added to the computer's capability by development of new concepts and new hardware.

Since it successfully combines certain features of both analog and digital computers, TRICE has been considered one of the first "hybrid" computers. Its hybrid characteristics and capabilities were further extended and improved when the PB250 digital computer was added to it. This provided memory, decision-making and digital computer programming features within the limits of the PB250, a small microsecond speed machine.

TRICE/440 All-Digital Hybrid Computing System in use by the Computation Division, NASA's Marshall Space Flight Center, Huntsville, Alabama. Applications include simulation of meteorological conditions and studies of their effect on rocket engine sound refractions, orbital studies and other complex aerospace investigations.



Computing System

A number of large TRICE/PB250 systems which have been operating for several years have proved — and improved — the benefits of the TRICE/general purpose digital computer approach to hybrid computing.

Now, with the availability of the 440 digital computer and its microprogramming flexibility, its logical decision capability and its enormous input/output power, this special type of hybrid computing system takes on a completely new dimension. TRICE/440 systems are already in operation at NASA's Marshall Space Flight Center in Huntsville and the Manned Spacecraft Center at Houston solving some of this century's most sophisticated and demanding scientific and engineering problems.

The addition of the 440 general purpose digital computer to the TRICE adds tremendous computing power and convenience to the system. The 440 is powerful enough to handle most sophisticated hybrid problems in real-time. Stored logic provides commands for TRICE input/output and control functions.

Thus, on a large problem, the dynamic portion of the problem involving differential equations can be programmed on the TRICE while the algebraic computations and logic decisions can be done on the GP digital computer. This combination allows the use of each machine in the function for which it is best suited.

Since both are digital machines, no analog/digital or digital/analog converters are required. There is no limit to the number of variables that may be exchanged between the two computers, since each computing element in TRICE may be accessed by the 440 in either direction.

There are no limitations on accuracy imposed by the communication system as the full word length used in TRICE is communicated to and from the 440.

The connection is a simple digital device, which reduces cost, improves reliability and decreases maintenance problems.

Control programs are available which allow the 440 to be used as a convenient high speed input/output device for TRICE. These programs provide an abstraction which convert decimal numbers to binary numbers and insert them into the proper elements in the TRICE, control all operations of the TRICE, read selected results from the TRICE, convert them to decimal and output them. This makes all the high-speed peripheral equipment of the GP computer available to the system.

APPLICATIONS

Aerospace Simulation

In aerospace science, two of the most useful and significant applications of hybrid computing are in studies of space vehicle guidance control and space vehicle trajectories. In the design of space vehicles, the two types of problems most effectively solved by computers are (1) computations which require either considerable logic or a large memory, and (2) differential equations in which high frequencies and nonlinearities are present yet which require precise solution to accurately determine trajectories. Because these two types of problems are so closely interrelated in many steps of space vehicle design and the solution to one may be the conditions of the other, hybrid computing is clearly indicated. The computations of (1) above can be handled on a digital computer, and the computation of (2) by means of the TRICE.

In general, equations of a space vehicle problem can be divided so that the dynamics and kinematics are studied on the TRICE, while the guidance equations are studied on the digital computer. The digital computer may also generate the aerodynamic functions and solve the force and moment equations.

If an airborne guidance and control computer is also part of the system, it can be simulated with the PB440 on a *command* and *format* basis.

One area which requires a parallel logical decision capability not found in either the analog or digital computer is the simulation of the reaction controls of a space vehicle attitude control system. Here the translation of the attitude commands to jet pulses is most aptly done by a system of parallel logic. This is provided in the TRICE/440.

In general, in any system where a large number of discontinuities occur, the handling of these discontinuities by relay logic on an analog computer becomes cumbersome because of problems in switching time of the relay logic. This type of simulation can be handled more efficiently and economically by solid-state digital circuit elements.

When the operation becomes sequential in nature, that is, where memory is required to store past conditions, it is advantageous to handle the simulation of digital computers directly. Memory, arithmetic, and logical operations are readily available and the problem can be solved by digital computer programming, making use of a flow chart which is itself sequential in nature. This method is preferable to use of a special purpose computer with patched logical elements.

Sampled Data Systems

A valuable application of TRICE/440 hybrid computation is in the design of sampled data systems. These are systems in which the data signals can change or are available for manipulation only at discrete intervals of time. Usually both discrete and continuous signals are involved. Examples of sampled data systems are the digital guidance computer of a space vehicle, chemical process digital control computers, machine tool control and many other control applications involving fluids or solids such as pipeline control, steel rolling mills, etc.

The space vehicle guidance computer application is typical. Here, either the continuous values of errors in parameters such as attitude are sampled and digitized, or the commanded and actual values are sampled and digitized (the commanded value may already be in digital form). The digital control computer solves a set of control equations to generate signals which control vehicle thrust jet power, duration, direction or some combination of the three. The control elements may require a continuous signal, necessitating desampling of the control computer outputs.

Use of a hybrid computer system is obvious. The system consists of analog elements, digital elements and sampling elements, and each of the three is simulated by its counterpart in the hybrid computing system with TRICE handling the analog portion of the problem. However, the simulation is not as straight-forward as it might appear. The average digital computer will not have the same characteristics as the airborne computer. Speed, word, length, commands, command and data format, are characteristics in which the two may differ.

The 440 stored logic computer eliminates difficulties in the simulation because of computer differences. The command list, command and data format, word length and execution times of a control computer may be duplicated so precisely that even the finalized programming for the actual system may be done on the TRICE/440 hybrid computing system.

Man-Machine Systems

An important area of application in simulation methods is the study of systems in which a human being participates as a system element. Since mathematical modes for human performance are not available, except for simple tasks, it is necessary to run such simulations in real-time. It is the requirement for real-time simulation of sophisticated and complex man-machine systems which has been responsible in large part for the growth of interest in hybrid computer techniques.

Where a human pilot performs control or guidance functions in the operation of a system, some form of simulation is essential, both during the design phase and for the purpose of training and evaluation. The simulation may be entirely an analog simulation or it may be partially or entirely digital simulation. Here, the ease and accuracy of communication between TRICE and the 440 becomes important.

In the design of flight control systems, the simulation is generally some form of physical simulation in which there is an interrelationship between a human pilot, an actual or simulated portion of a vehicle control system, and a general purpose computer (analog, digital, or hybrid) which provides inputs to the cockpit and operator. These inputs represent the variation of environmental characteristics as well as vehicle dynamics during a particular flight mission.

In connection with orbital and space missions, hybrid computation becomes imperative because:

1. Real-time operation is essential when there are human pilots. This presents no problem to the TRICE digital differential analyzer; however, only the largest, fastest digital computers, programmed in machine language, can even be considered if the simulation is to be done all digitally.
2. Inherent variability of human performance as well as random or stochastic elements in the pilot's responses requires each experiment to be repeated with a number of different operators. This means that long periods of computing time will be required — prohibitively expensive for large scale digital computers.
3. Duration of even sub-orbital missions will be in the order of hours, and simulations requiring hours or days of real-time operation may become necessary. This requires full time use of the computer system — again prohibitively expensive for a large-scale digital computer.

   Use of large-scale digital computers in hybrid systems on an interrupt basis has been proposed. In this case, the digital computer is limited to such operations as described (4.) below. Interrupt operation has to be considered in the light of the amount of memory required and therefore the amount of time that may be spent loading and unloading the main memory to auxiliary memory.
4. Digital computers are present "on-board" space vehicles in order to perform guidance computations which would be extremely difficult or excessively time-consuming for the pilots themselves. For example, in the Apollo mission the pilot must obtain sightings with respect to certain stars at particular times during the flight. These sightings are then used as inputs to the on-board digital computer which must determine the precise trajectory of the vehicle as well as the necessary corrections to insure arrival of the spacecraft at the desired location. Thus, the pilot has available a keyboard or similar device for direct entry to the digital computer and he receives information back from the digital computer. Such a facility must be available in connection with the simulation. This requirement precludes the use of all-analog simulation. A stored logic digital computer such as the 440 is ideal for this application.
5. Display generation for simulated flights requires the availability of a digital computer. The displays seen by the pilot of a complex spacecraft can no longer be represented by means of simple dial movements but will in general include cathode ray tubes and other visual presentations which give the pilot a complete indication of his position in space, predicted position, necessary corrections and a great deal of additional information. The generation of the signals for driving the displays requires a multitude of logical operations and computations which can be carried out most conveniently by means of a digital computer.
6. Vehicle dynamics, simulation of attitude control systems, and similar problems can be handled conveniently by means of the TRICE computer.
7. Some aerospace vehicle simulators must also have the capability of representing the boost phase of the flight and re-entry into the earth's atmosphere. Consequently, computational tasks requiring both drift-free high accuracy computation and simulation of non-linear systems with high frequency are accommodated by TRICE.

Optimization of Multiparameter Systems

Optimization of system parameters is one of the most important phases of system engineering. It is the process of adjusting parameters so that system performs as close to optimum as possible, optimum performance having been determined by some preselected criterion.

In analog simulation this process has advanced from the manual adjustment of a few parameters between runs on a "one shot" analog computer, through the repetitive operation machine with continuous adjustment of parameters as runs are repeated at high speed. When it is necessary to adjust more than just a few parameters, the task becomes impossible for a human operator because of his limited capacity for remembering past adjustments and their effects. Moreover, an intuitive approach to deciding the next adjustment to be made will not suffice for a complicated system.

It also becomes evident that even if all parameters were limited to some finite number of values, the time required to investigate all of the possibilities under manual control would be prohibitive. For all but the simplest problems then, the memory and logical decision capability of the general purpose digital computer can be used to good advantage.

In order to use the digital computer to optimize the system parameters, we must have a mathematical statement of the performance criteria, a group of parameters on which adjustment is permitted, and an organized method of adjusting the parameters. The statement of performance criteria is called the criterion function. It is frequently stated in terms of the square of the error between the value of a pertinent system variable and the optimum value of this variable. For dynamic systems quite often the criterion function is the definite integral of the error squared, over the interval of interest. Both the criterion function and the list of parameters which may be adjusted are determined from a knowledge of the system.

The general purpose computer must search for either a maxima or minima of the criterion function depending on how the function is formulated. It should be pointed out that the criterion function may have more than one maxima or minima, so that only a relative maximum or minimum may be found.

There are two general types of systems in which optimization problems occur, static and dynamic. Static systems have no energy storage and can be represented by algebraic equations rather than differential equations. Profit optimization, scheduling, and transportation problems belong to this group. Mathematical problems including the solution of linear algebraic equations and the finding roots of polynominals can also be handled by the optimization approach. The method of steepest descents can be employed to solve these problems in a continuous manner on the TRICE.

Optimization by the continuous steepest descent method is not possible in dynamic systems which include energy storage and are represented by differential equations. Iterative techniques consisting alternately of a time solution of the dynamic system and a computation of the parameter adjustments must be used. These techniques may be implemented accurately and efficiently with a hybrid TRICE/440 system.

The Trice Digital Differential Analyzer...

unparalleled speed and accuracy at incredibly small programming cost.

Use TRICE for—

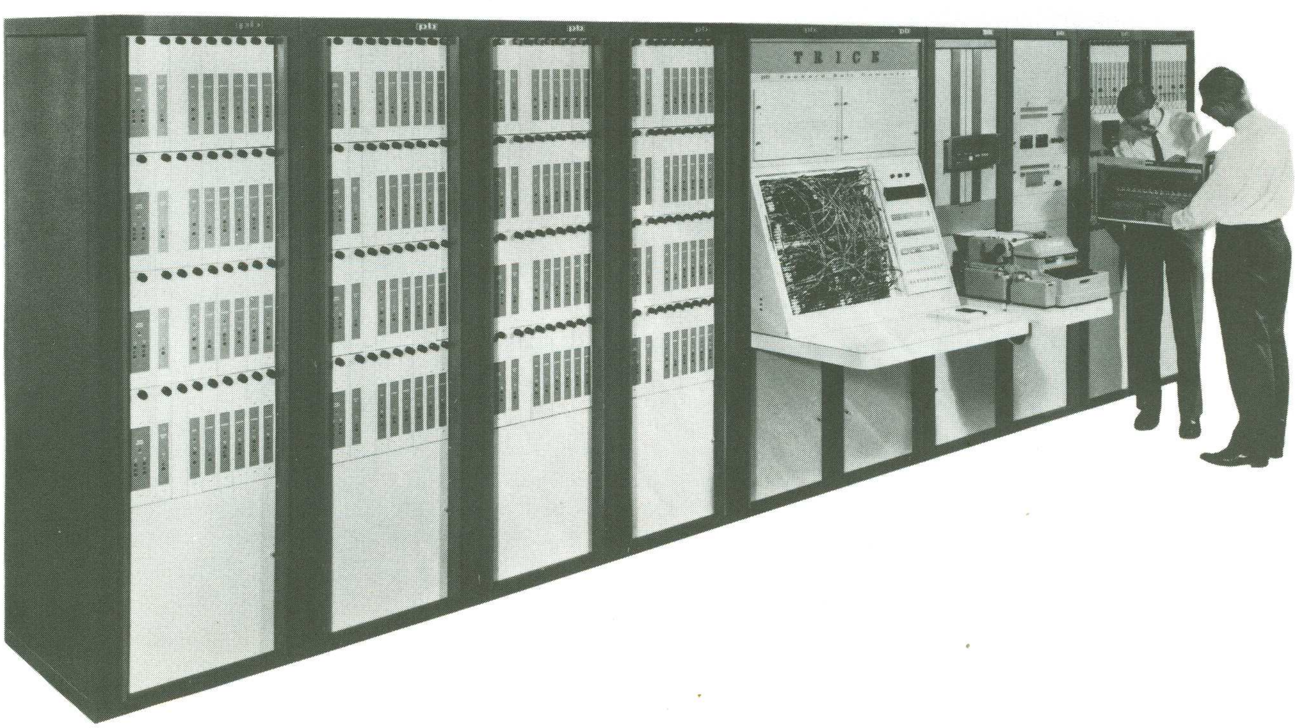
* Solving all problems which are properly formulated in differential equation form.
* Real-time simulation at speeds commonly associated with electronic analog computers. The accuracy and repeatability of digital computations can be applied to dynamic system problems, such as space vehicle simulations, multi-body orbit problems, and axis transformations.

For these and many other applications, TRICE outperforms both analog and large general purpose digital computers.

Compared to a large-scale digital computer for solving differential equations, TRICE provides substantially reduced setup and execution times with no loss of accuracy. Because TRICE module algorithms are identical to the mathematical operators, it can be programmed by engineering personnel after a short training period. No programming staff is required to utilize the extensive capabilities of this powerful computer, thereby saving many thousands of dollars in programming costs and engineering time. Literally man-years of programming effort are eliminated. The engineer with the problem can communicate directly with TRICE, observe problem solution, change parameter values and/or the mathematical model to obtain the desired results.

Control system design studies may be carried out by direct representation of Laplace transforms on TRICE.

One TRICE can do the work of a room full of analog computers while providing flexibility and versatility not possible with such equipment. Consider these advantages offered by TRICE.



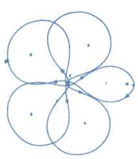
A fully expanded TRICE Digital Differential Analyzer. This unit utilizes the smaller 250 general purpose digital computer for hybrid capability.

- Analog speed with digital accuracy
- Open loop integration without drift
- Stability—periodic functions remain stable over any period of time
- Programming ease — differential equations are solved directly without recourse to numerical analysis
- Integration with respect to any variable —trigonometric, logarithmic, hyperbolic and other functions are generated directly from their differential equations
- Servo unit permits instantaneous solution of transcendental equations by servo methods to high accuracy
- Absolute repeatability
- Dynamic range of $\pm 2^{26}$ (67 million)
- Fast setup because of digital input/output
- Scaling computations performed automatically

TRICE may be used independently, or in hybrid combination with an analog computer, a digital computer, or both analog and digital computers, simultaneously.

Features of the TRICE/440 for Hybrid Computation are:

- The system is all digital
- Data transfer between all TRICE modules and the 440 computer is accomplished by a simple digital buffer at a 50KC (440) word rate
- Each module is individually addressable under program control from the digital computer
- For repetitive operation, all constants and initial conditions are rapidly accessable
- The full 30-bit TRICE word is transferred
- The high-speed, high-accuracy capability for differential equation solution is complemented by the high-accuracy arithmetic, logical decision, and memory capabilities of the digital computer
- A complete input/output software package provides input/output to the TRICE from any of the 440's peripheral equipment in decimal and engineering units. Scaling computations are performed automatically.
- Automatic re-scaling of TRICE for dynamic ranges exceeding 2^{26} based on an over-range indication of any one of eight parameters accomplished on an interrupt basis at speeds too fast to be noticed by a human participant in a real-time simulation
- High-speed analog readout for qualitative analysis on standard xy plotters, strip chart recorders or oscilloscopes
- Function generation for functions of one, two or more variables provided by the digital computer with first or second order continuous interpolation provided by TRICE
- Automatic verification of all entered data



TRICE Specifications

Clock Frequency	*3 megacycle*	*or*	*3.145730 Mc*
Iteration Rates	*10^5 per sec*		*2^{17} per sec*
Word Length	*30 bits*		*24 bits*
Maximum for programming	*26 bits + sign*		*20 bits + sign*
Equivalent decimal, approx.	*8 digits*		*6 digits*
Computing Modes — Choice of - - -	*Rectangular Integration* *Extrapolative Trapezoidal* *Interpolative Trapezoidal*		*on each integrator individually*
Manual Controls	*35-Key Keyboard* *22 Function Switches*		
Displays	*30-bit Buffer Register* *9-bit Element Address* *11-bit Overflow*		*Binary Indicators*
Fully Expanded Machine	*4 Module Bays*		
Capacity	*64 Integrators* *16 Constant Multipliers* *16 Variable Multipliers* *16 Servos* *16 Summers* *16 Function Units*		
Power Requirements	*3 phase, 60 cps, 120-208V* *10 amp per module rack* *6 amp control console* *20 amp per phase, expanded machine*		
Control Console	*500 Pounds* *72″ high, 48″ long, 52″ deep*		
Module Bay	*700 Pounds* *72″ high, 24″ long, 30″ deep*		
Air Requirements per Module Bay	*200 cu. ft./min. flow* *60°F in* *85-90°F out*		

Just What is TRICE?

TRICE is a solid-state, digital differential analyzer, utilizing binary arithmetic and digital logic and operating at three megacycles. TRICE is organized in a modular fashion with individual computing elements capable of performing integration, multiplication and function generation. To program a problem solution, these elements are interconnected via a removable patch panel.

Computation is done in parallel with all elements operating simultaneously, and transfer of information between elements is done on an incremental basis. Two lines, existence and sign, are used to transfer increments between elements in what is known as ternary transfer, i.e., there are three possibilities of transfer, during any iteration cycle; +1, 0 and −1.

Operational memory and constant and initial condition storage are provided by magnetostrictive delay lines. These lines, with associated read-write electronics, are packaged as sub-modules which plug into the appropriate computing elements.

A keyboard provides manual control of all TRICE operations. This includes operation modes, addressing of elements, and data input. Monitoring the state of the control system or individual elements is provided by the keyboard and displays on the console.

Two pieces of optional equipment, a Decimal Code Converter and a Paper Tape Reader-Punch unit are available as additional aids when operating TRICE as an independent computer. The Decimal Code Converter provides decimal input and output. The Reader-Punch provides paper tape input-output at 60 characters per second.

TRICE Computing Elements . . .

The Integrator

The basic computing element in TRICE is the integrator. Integration is accomplished by summing incremental areas. The sum of these incremental areas approximates the exact area. While the computation is actually done in the incremental form, Δx, Δy and Δz, the differential forms dx, dy and dz are used for schematic and programming simplicity. Thus, the operation of the integrator is represented by the formula: $dz = ydx$.

The integrator has three registers – the "I" register to store initial conditions, the "Y" register to accumulate the whole value of the variable, $\Sigma \Delta y$, and the "R" register containing the partial value of Δz. Each iteration cycle of the TRICE, the increments of dy (if any) are added to the "Y" register, the dx pulse (if it exists) causes the new contents of the "Y" register to be added into the "R" register. A dz output pulse occurs when the "R" register overflows.

In order to get the incremental area represented by dz to be the best approximation of the exact area, each integrator has three algorithms available for regulating the change in R. These changes are represented empirically as follows:

Rectangular $dR_n = y_n dx_n$

Trapezoidal Extrapolative

$$dR_n = y_n dx_n + \tfrac{1}{2}\, dy_n dx$$

Trapezoidal Interpolative

$$dR_n = y_n dx_n - \tfrac{1}{2}\, dy_n dx$$

If the sum of dz outputs of an integrator is accumulated in the "Y" Register of another integrator, it forms the integral:

$$z = \int dz = \int ydx$$

Both signs of dz are available at the patchboard.

The Constant Multiplier

If the dy inputs of an integrator are not used, the number in the "Y" Register remains constant and the operation of the element can be represented by the formula:

$$dz = kdx$$

In a constant multiplier this is done with the saving of one register by combining the functions of the "I" and "Y" Registers into one unit.

The Variable Multiplier

Variable multiplication can be done by means of two integrators using the identity $d(uv) = vdu + udv$. This operation is done in the variable multiplier, thereby eliminating one "R" Register and providing the product output in incremental form. This operation is represented by the formula:

$$dz = d(xy)$$

where the inputs are dx and dy.

The Servo

The servo is a specialized type of computing element that is generally used as a nulling device in the implicit solution of differential equations, or as a decision element in the generation of discontinuous and nonlinear functions. The servo uses the "I" and "Y" Register in the same manner that the integrator does, but has no "R" Register. It has two modes of operation. The output is determined as follows:

Normal Mode:

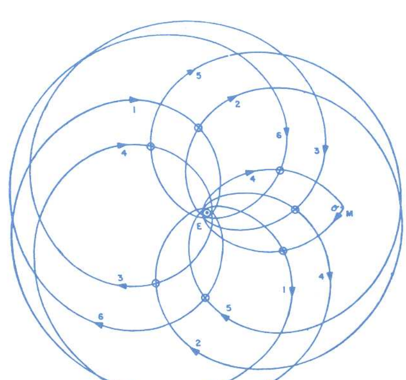
$$\begin{aligned} &\text{If } Y > 0, \text{ then } && dz = +dx \\ &Y = 0, && dz = 0 \\ &Y < 0, && dz = -dx \end{aligned}$$

Decision Mode:

$$\begin{aligned} &\text{If } \tfrac{1}{2} \le Y < 1 \text{ then } && dx = 0 \\ &0 < Y < \tfrac{1}{2} && dx = +rx \\ &Y = 0 && dx = 0 \\ &-\tfrac{1}{2} \le Y < 0 && dz = -dx \\ &-1 \le Y < -\tfrac{1}{2} && dz = 0 \end{aligned}$$

The Delta Y Summer

The ΔY Summer is used to sum as many as six dY inputs before they are gated into the "Y" Register of the integrator or servo to which it is connected. The summer has no registers and is used whenever more than the two available dY inputs to servos and integrators are needed.



Decimal Code Converter Specifications

Word Length	*9 digits + sign* *30 binary bits*
Conversion Time	*5 milliseconds maximum*
Display Rate	*100 per second approximately*
Displays:	
Decimal Register	*9 digits + sign*
Decimal Exponent	*6 bits + sign*
Scale Exponent	*7 bits + sign*
Register Length	*5 bits*
Power Requirements	*Included in control console*
Space Requirements	*Fits into the control console*

The Decimal Code Converter can be an integral part of the Control Console; it provides decimal input-output capability for the TRICE. The Decimal Code Converter will accept inputs from the TRICE keyboard or from the Reader Punch unit. It will convert the decimal number into a binary number, in accordance with the information stored in the Decimal Exponent and Scale Exponent registers, truncate and insert scale bit in accordance with the Register Length register and insert the resultant into the binary buffer register from which it can be entered into the desired TRICE element. For output, this process is reversed and the equivalent decimal number is displayed in the Decimal Display Register from which it can be viewed directly or punched out onto paper tape by the Reader-Punch unit.

Reader Punch Unit Specifications

Tape	Eight Level Paper Tape
Reader Speed	60-Character per second
Punch Speed	60-Character per second
Power Requirements	120 volt, 60 cps, 4 amp
Size	24″ wide, 30″ deep, 33.5″ high
Weight	250 Pounds

The Reader-Punch unit permits paper tape control of TRICE and provides TRICE with paper tape input-output. The Reader-Punch unit can also be used as a tape duplicator or as a peripheral device for the 440.

The 440 for Hybrid Computation

The 440 is ideally suited to hybrid computation because of its stored logic capability. With stored logic, the 440's command list may be designed especially for hybrid computation so the machine has exactly the desired characteristics for the combined problem solution.

For hybrid computing, these characteristics are:

1. *Rapid input/output* to and from TRICE, easily programmed, flexible, and requiring a minimum of housekeeping functions. Uses commands specifically designed for this purpose.
2. *Floating point* operation at speeds useful in the fastest real-time applications in order to minimize scaling.
3. *A varied list of arithmetic operations* plus logarithms, power, roots, and transcendental functions. All execute rapidly to supplant TRICE where more accuracy is needed in real-time.
4. *FORTRAN* — Completely documented and IBM-compatible so that existing programs may be used directly, as in the case of check solutions.

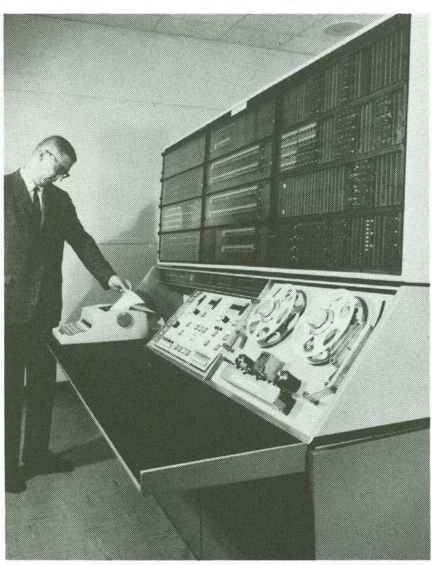
   For example, it can be used in hybrid computation problems and is fast enough in execution speed to be used in a large portion of the real-time requirements. When not fast enough for a specific real-time application, it can be used to check out the mathematical model of the system at a reduced time scale with programmed inputs replacing inputs from actual hardware.

   After the model is developed to a satisfactory state, the FORTRAN program can be translated to machine language to gain the necessary speed for real-time operation. Statements for use with the hybrid system are included in the FORTRAN package so that the FORTRAN programmer need not know anything about machine language programming to use the hybrid system.
5. *Simulation of other computers* is easily facilitated so that the operation of existing or proposed computers in a control system can be studied. Capability of simulating other computers on an individual command, command format, and word length basis. By such simulation, the validity of a proposed control computer design can be established before the computer is built. Similarly, the suitability of an existing computer for a particular control application can be determined before the computer is purchased.
6. *Direct memory access capability* is available as a standard option. This mode of operation is used where the amount of data transferred in and out of the digital computer under program control becomes large enough to require an appreciable part of the computation cycle time. Large-scale simulators are an example of this requirement.

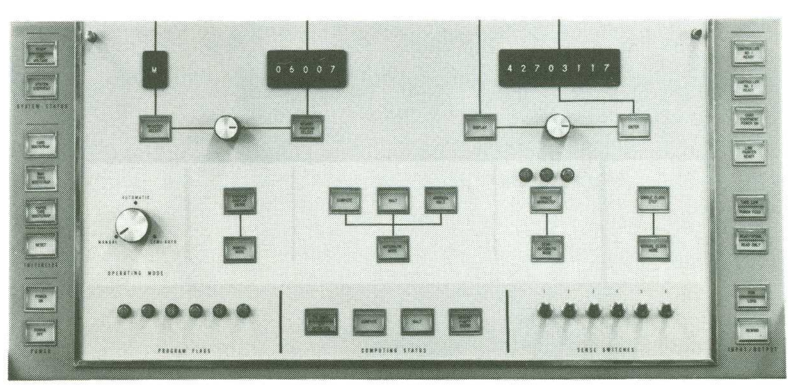
   Here, large amounts of data must be up-dated and sent to numerous displays periodically, in addition to the transfer of dynamic and kinematic data to and from the TRICE and simulator. Some combined problems require use of mass memory such as magnetic tape or disc file. Communication with these devices under program control may be impractical because of the amount of program cycle time required. In this case, communication via direct memory access becomes extremely useful.
7. *Expandability* is an important requirement for a hybrid computer, because all potential uses for such a system cannot possibly be anticipated at the time of purchase. Expandability is provided by a sufficiently large addressing scheme in the 440. Large-scale computers often provide 32,000 words or more of memory and problems which require that much memory are not uncommon. While this much memory will not normally be required initially in a hybrid facility, the capability for adding it later on should be specified.

   Real-time computation may also require an expansion of the program to the extent that the program cycle becomes excessive. In such cases, the capability for easily adding an additional main frame to the system so that the program may be divided between two or more simultaneous processors is important. This capability is built into the 440. No additional engineering changes are required and the expansion can be accomplished in the field.
8. *The computer console* is another important consideration. Features which make the 440 easier to use, especially for the engineer-programmer to whom programming is a means rather than an end are:
   a. Console selection of registers and memory locations for entry or display of information.
   b. Display of register and memory contents in octal arabic character as well as binary format.
   c. Manual control of program advance one step or one clock cycle at a time.
   d. Built-in boot strap loader.
   e. Indicator light display of the state of *all* arithmetic and control unit flip-flops.

The 440 stored logic general purpose digital computer. Its programming and command flexibility makes it a powerful partner to TRICE for all-digital hybrid computing.



The 440 control console gives the operator complete and flexible control over normal operation, debugging of macro and micro programs and test and maintenance procedures. Special features in-register and memory display and load provisions and single-step operation at the micro level. A special feature enables programmers working out complex routines to observe condition of all flip-flops in the arithmetic and control unit.



TRICE in Other Hybrid Combinations

Analog-TRICE-Computing System

The high speed of the TRICE makes it ideally suited for connection to an analog computer, especially where greater accuracy is needed or long time open loop integrations are desired. TRICE is no more difficult to program than the analog computer, so various versions of a given mathematical model are readily examined at low cost.

The speed of the TRICE requires individual conversion channels and allows it to be connected to the analog computer without regard to sample data theory. The sampling (analog-to-digital conversion) is done at the TRICE iteration rate. The transport delay, before the data is returned in a closed loop operation, is equal to the number of elements in the loop times the iteration cycle. This period is so short that it causes no more phase shift than a precision potentiometer and the TRICE appears functionally the same as another analog console.

Raytheon Computer supplies A/D and D/A incremental converters especially designed for TRICE/Analog Systems. They are mounted in a module bay similar to TRICE computing elements.

Each of the A/D converters is provided with a switch which allows it to be operated as a D/A converter. Each converter contains a buffer which can be used for whole-number input/output to the module. The converter buffer can be used to communicate directly with the TRICE binary buffer and thence to the 250 or 440, if also associated with the system.

Digital-TRICE-Analog Computing System

This three-way combination forms the most powerful computing system possible today. The TRICE provides an efficient interface between analog and digital computers as well as being able to perform many of the calculations better than either of the other machines.

In this system, each computer performs those computations for which it is best suited, i.e., digital computer — arithmetic, logical and memory operations; TRICE — high-accuracy open loop integration, implicit functions, transcendentals; analog computer — moderate accuracy closed loop integrations.

Current TRICE Installations

* *North American Aviation, Los Angeles Division, Los Angeles, California*
* *North American Aviation, Space and Information Systems Division, Downey, California*
* *National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama*
* *National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia*
* *National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas*
* *Naval Ordnance Laboratory, Simulation Laboratory, Corona, California*
* *Holloman Air Force Base, Analysis and Computation Division, New Mexico*
* *White Sands Missile Range, Flight Simulation Laboratory, White Sands, New Mexico*

RAYTHEON COMPUTER
2700 S. Fairview Street • Santa Ana, California 92704

PRINTED IN U.S.A.—10-64