Westinghouse ENGINEER

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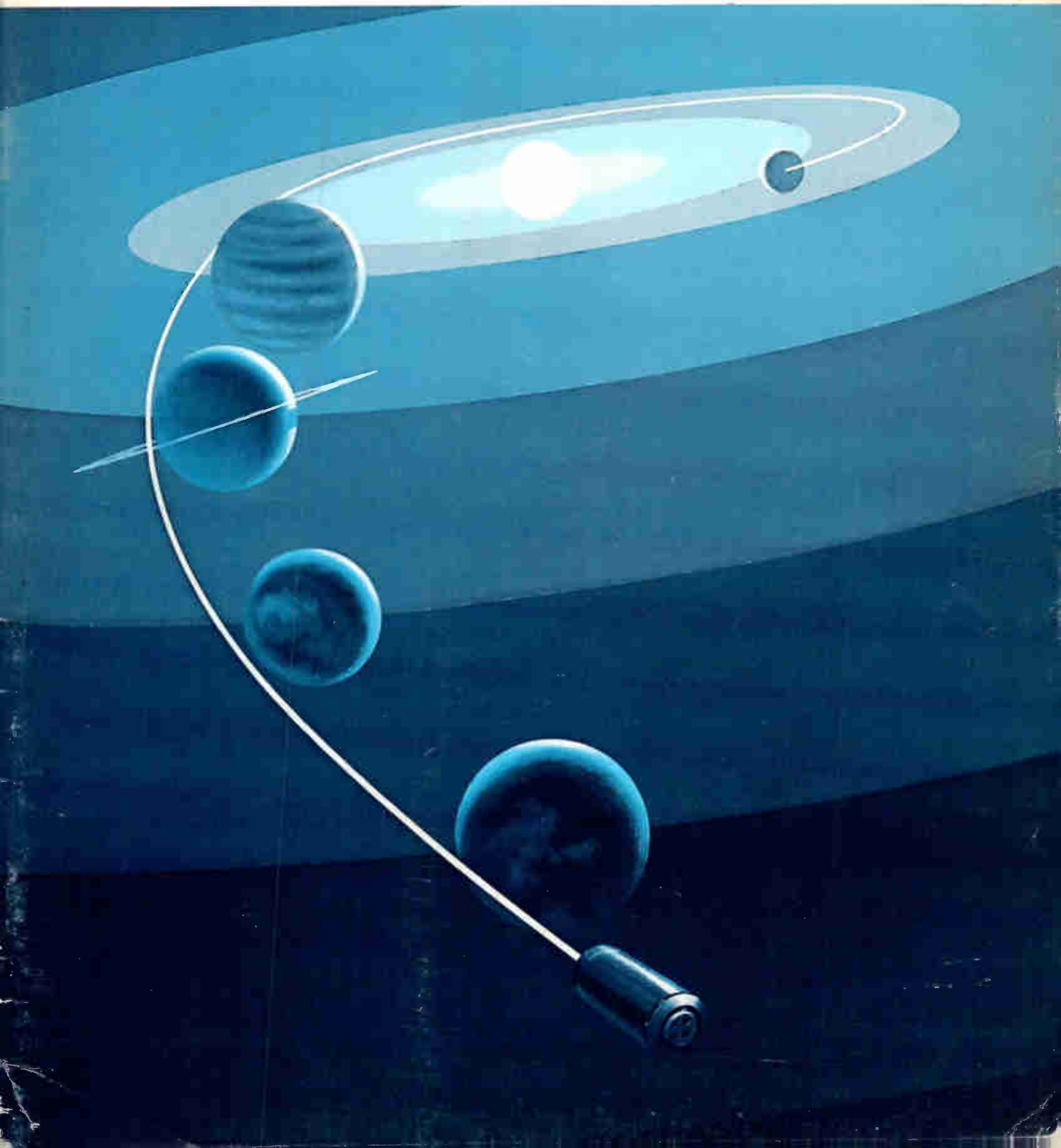

Nuclear Reactor Internal Components Produced by Modern Plant

Westinghouse Nuclear Energy Systems has recently completed its Pensacola Division manufacturing facility near Pensacola, Florida, to produce internal components for the pressurized-water nuclear reactors used by electric utilities for power generation. The major components are core barrels; plates, supports, baffles, formers, and other structural members that fit inside the barrel; control-rod guide tubes and support columns; in-core mechanical instrumentation; and reactor ancillary equipment such as lifting rigs, remote handling tools, fuel-element storage equipment, and refueling equipment. Secondary products include other large precision-machined components whose manufacture requires the division's engineering, fabricating, and joining technology and its large machine tools.

The facility has an air-conditioned factory building and an office building at a wooded site on Escambia Bay (*Photo 1*). The largest machines are three vertical boring mills; two can mill, drill, turn, and grind core barrels 16 feet in diameter and 19 feet high (*Photo 2*), while the third is a standard machine for general use (*Photo 3*). Numerically controlled machine tools used for efficient production and high quality include the horizontal boring mill seen machining a core plate in *Photo 4*. The facility also has electrochemical and electric-discharge machining centers for making complex shapes.

Internal support columns are made from tubing of ¾-inch wall thickness (*Photo 5*). Water flow holes are machined in the sides of the columns in a vertical mill with a pantograph attachment, which assures that the holes are machined exactly to pattern.

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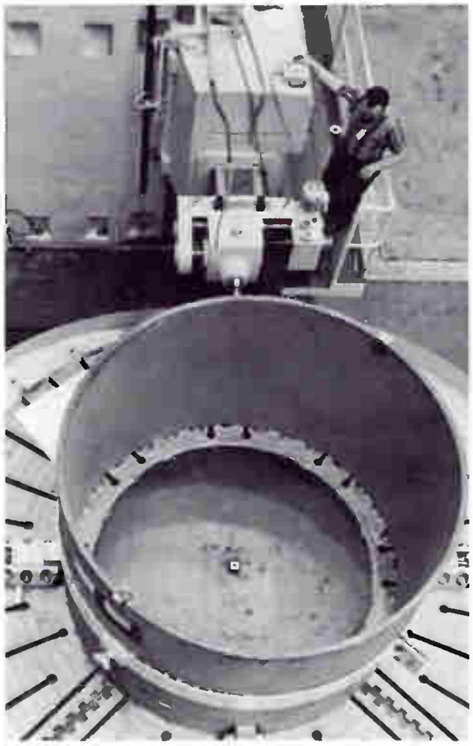

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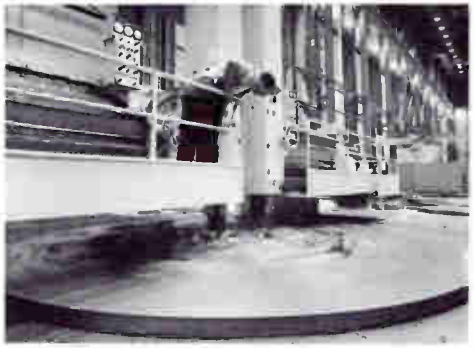

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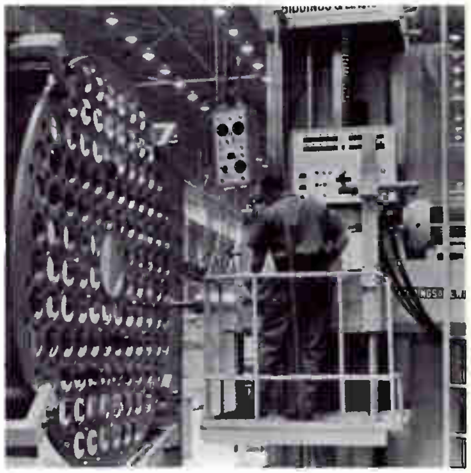

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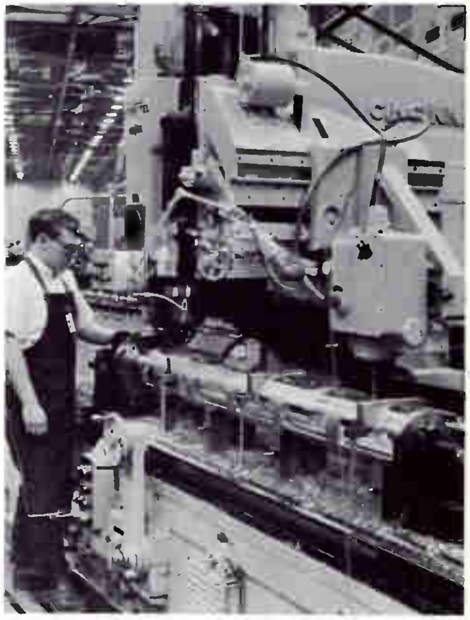

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Front cover: The high performance of a nuclear rocket engine could make "Grand Tour" probes of the outer planets possible, as suggested symbolically in Tom Ruddy's cover design. An article on the nuclear rocket begins on the following page.

Back cover: Divers survey a coral reef in the Pacific Ocean for evidence of "crown of thorns" starfish, which are destroying large areas of reef and thereby disrupting the natural ecology. (More information on page 62.)

The NERVA Nuclear Rocket: A Status Report

W. H. Esselman
M. R. Keller

The potential performance capabilities of the nuclear rocket engine greatly exceed those of chemical rocket engines. Successful testing of several models shows that the basic technology of nuclear rocketry is ready for exploitation in the form of a NERVA flight engine.

The enormous energy of nuclear fission is being combined with the ability of rockets to travel in space, the basic reason being to improve the performance of rocket engines. This improved performance will give space vehicles more mobility and operating flexibility for scientific and domestic missions than can be provided solely by chemically fueled engines. Producing more thrust from a given weight of propellant, the nuclear engine could push a larger payload the same distance or the same payload much farther.

The difficulty of the development has been stated colorfully but accurately by Dr. Glenn T. Seaborg, Chairman of the U.S. Atomic Energy Commission: "What we are attempting to make is a flyable compact reactor, not much bigger than an office desk, that will produce the power of Hoover Dam from a cold start in a matter of minutes."

Intensive development in the past few years has produced such reactors, justifying the high expectations of the earlier years.[1] The latest one built was in the NERVA-XE engine tested successfully last year at the Nuclear Rocket Development Station at Jackass Flats, Nevada. The engine was run for 3½ minutes at full thrust of about 55,000 pounds and full power of 1100 MW, and also at intermediate power levels. No major problems developed in 28 test runs over eight days. Total running time was about 3 hours and 48 minutes.

The next step, now in progress, is development of a flight-rated engine to be flown in 1977. Present plans are to make the engine compatible with the Saturn V rocket (on which it would be used as a third stage) as well as with other advanced systems.

Nuclear and Chemical Rockets

In any rocket, thrust is the reaction produced by a stream of hot gas expanding out through an exhaust nozzle. The force of the thrust is computed from the equation $F=\dot{m}v$, where F is thrust, $\dot{m}$ is mass flow rate of the gas particles, and v is the average exhaust velocity. Thus, the thrust produced per unit of mass flow rate is equal to v.

Thrust produced per unit of mass flow rate is a convenient standard for rating and comparing rocket engines. In practice, rocket engineers use a term called specific impulse, which is the thrust per unit weight of propellant flow. ($I_{sp}=F/\dot{w}$, where $\dot{w}$ is propellant flow rate in pounds per second.) Specific impulse is expressed in seconds because it can also be thought of as the period of time during which one pound of thrust is provided by one pound of propellant. The greater the specific impulse at any specified thrust, the greater the power produced, since power is proportional to specific impulse times thrust.

A nuclear rocket can produce about twice the exhaust velocity of the best chemical rocket and, therefore, twice the specific impulse. That is its main advantage—it can accomplish a given space mission with less propellant and therefore more payload, or it can go farther, go faster, or maneuver more with a given amount of propellant, or it can provide some optimum combination of those abilities.

The reason exhaust velocity (and thus specific impulse) can be higher in a nuclear rocket is seen in the proportionality

$$v \text{ (or } I_{sp}) \sim \sqrt{T/M},$$

where T is temperature of the exhaust gas and M is average molecular weight of the gas. Today's chemical rockets already operate near the limiting temperature of the available structural materials, so little improvement in exhaust velocity is imminent from increasing T. A hydrogen-oxygen engine, for example, operating at 5100 degrees F provides an I_{sp} of 456 seconds; even developing a fluorine-hydrogen engine operating at 6840 degrees F would increase the I_{sp} by only 20 seconds.[2]

However, M is greatly reduced in a nuclear rocket, resulting in a significant increase in v and I_{sp} without an increase in temperature. The nuclear rocket simply heats hydrogen propellant, which has an M of only 2. Chemical rockets, on the other hand, must rely on combustion gases, which are heavier. Even in advanced rockets burning hydrogen with oxygen, the molecular weight of the combustion product (H_2O) is 18.

Thus, the theoretical exhaust velocity (and specific impulse) of a nuclear rocket is three times that of the best chemical rocket for the same temperature. A hydrogen-oxygen engine provides a specific impulse in vacuum of about 456 seconds, while a specific impulse of more than 900 seconds is attainable eventually in a nuclear engine operating at a lower temperature than that of the hydrogen-oxygen engine.

Doubling of the rocket exhaust velocity doesn't come free of charge; it requires twice as much power. That is no problem, however, because nuclear fuel contains a great deal of energy in a small package. Thus, the second major advantage of the nuclear rocket is its ability to convert the vast potential energy of nuclear fuel into high exhaust velocity.

A related advantage is the "storability" of nuclear energy. The solid fuel is physically and chemically stable, so a nuclear engine could readily be boosted into earth orbit and then supplied with propellant delivered by another booster. Moreover, a vehicle could be reused many times by resupplying it from a propellant station. Resupply of a nuclear rocket would be much simpler than that of a chemical rocket because the latter requires two propellant materials and, due to its lower specific impulse, uses them less efficiently.

The NERVA Engine

The main components and the operating cycle of a typical engine used in the ground test program are shown in Fig. 1. Propellant (liquid hydrogen) is pumped from the storage tank to engine operating

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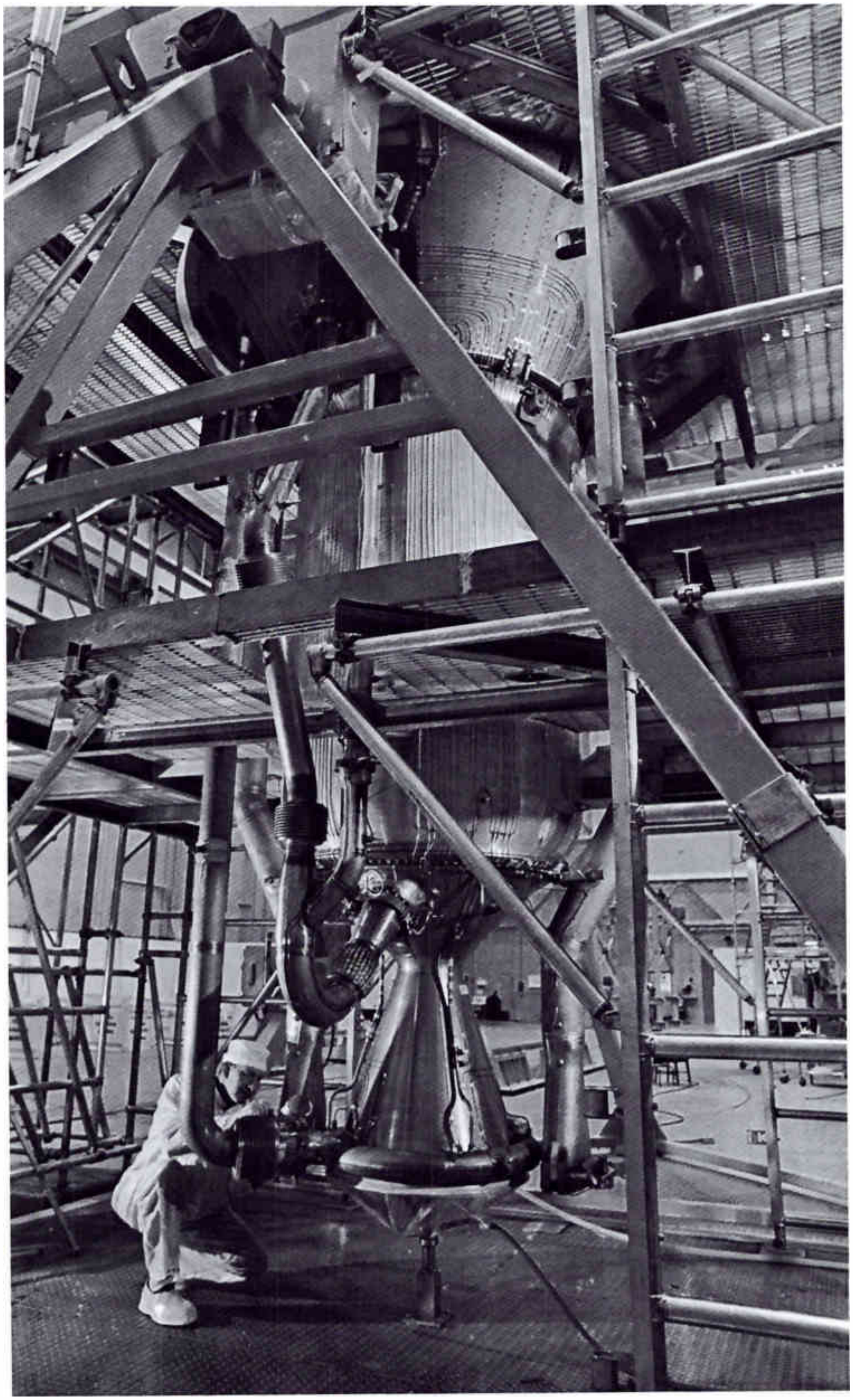
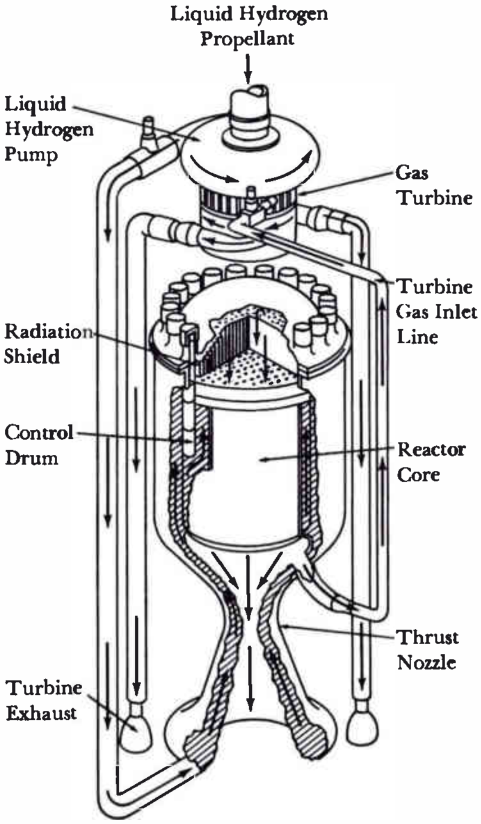




1—Typical component arrangement and operating cycle of engines tested so far are illustrated in this simplified diagram. Hydrogen propellant is preheated by cooling the thrust nozzle and other components, and then it passes through the reactor core to be heated and expanded out through the nozzle. Some hot gas is bled off to power a turbopump that delivers hydrogen to the engine.

Left—NERVA-XE engine was photographed during preparation for testing at the Nuclear Rocket Development Station in Nevada. Its successful operation, and that of previous reactors and engine systems, provided data being used to develop a flight-rated engine.

pressure by a turbopump. The hydrogen passes through tubes in the exhaust nozzle, cooling the nozzle and getting preheated in the process, and then passes through the reflector and radiation shield and into the reactor core where it is heated. The hot hydrogen expands out through the exhaust nozzle, accelerating to produce thrust. A small amount is bled off to power the turbopump.

The reactor core is made of graphite impregnated with uranium. It contains many channels for hydrogen flow.

The Nuclear Rocket Program

The Nuclear Engine for Rocket Vehicle Application (NERVA) program is administered by the Space Nuclear Propulsion Office, a joint office of the United States Atomic Energy Commission (AEC) and the National Aeronautics and Space Administration (NASA). Aerojet-General Corporation is prime contractor for the engine system, and Westinghouse Electric Corporation is principal subcontractor responsible for the nuclear subsystem.

The nuclear rocket program was initiated in 1955 as a joint effort, called Project Rover, of the AEC and the U.S. Air Force. When NASA was established in 1958, the Air Force's responsibilities were transferred to it because of the considerable potential of a nuclear rocket for space missions.

Because the key component of the nuclear rocket is the reactor, the AEC's early research programs at Los Alamos Scientific Laboratory and the Lawrence Radiation Laboratory concentrated on the conceptual reactor design and the development of a fuel element that would operate at the high temperature necessary in the nuclear rocket (greater than 4000 degrees F). In March 1957, a specific research and development approach was selected and the AEC decided to proceed with fabrication and testing of research reactors using uranium-loaded graphite fuel elements to heat hydrogen to the temperature useful for rocket propulsion. Development responsibility was assigned to Los Alamos Scientific Laboratory. The first experimental reactors, called Kiwis, were built to demonstrate feasibility and proof of principle of the nuclear rocket engine reactor. With success in the Kiwi tests, the NERVA program was started in 1961. Kiwi and NERVA programs have been closely meshed, each reactor experiment building on knowledge gained in the preceding tests to evolve a continuing improvement in technology.

A reflector surrounding the core prevents the escape of too many neutrons from the core and so helps sustain the controlled chain reaction of nuclear fission. It contains control drums, which are cylinders made of neutron-reflecting material on one side and neutron-absorbing material on the opposite side. The drums can be rotated in unison to maintain the desired neutron flux in the core; their position thus determines the rate of fission and thereby the rate of heat production.

The NERVA flight engine now being designed will be similar to the one just described except that instead of the "hot-bleed" cycle it will employ a "topping" cycle: almost all of the preheated hydrogen passing through the reflector and shield will be channelled through the turbine before entering the core. Because no hydrogen is bled from the outlet of the core to provide turbine power, this cycle enables a slightly lower core temperature to yield the same specific impulse. Average core temperature will be about 3800 degrees F, thrust 75,000 pounds, reactor power more than 1500 MW, and specific impulse 825 seconds.

Feasibility Demonstrated

To assess the progress made on the many difficult problems that have had to be resolved, a base point of early 1964 is used in this article. At that time, no reactor had been operated at the high power and temperature conditions essential to achieve the desired rocket performance. In fact, there were still a number of basic feasibility questions.

The main question concerned structural integrity—whether a reactor could be designed and constructed to remain physically intact during the high-temperature and high-power operating conditions. The reactor would have to operate at white heat and still not fail in any of its parts. (Severe vibration during a Kiwi-B test in 1962 had resulted in a gross reactor failure, in which many fuel-element parts were ejected through the nozzle.) A goal of 20 minutes of operation was established in May 1964.

Another key question was whether the engine would have restart capability, including ability of the reactor to be heated white hot a number of times without failure. Restarting is necessary because most of the time in a mission is spent "coasting," with infrequent operation of the engine. In a round trip between earth and moon orbits, for example, the engine would be started for translunar insertion, perhaps a midcourse correction, braking into lunar orbit, transearth insertion, perhaps another midcourse correction, and braking into earth orbit. Each start probably would be from zero to full power, with duration depending on the payload being transferred.

The third key question concerned predictability, controllability, and reliability of operation. In 1964 we had not demonstrated that the NERVA system could be controlled reliably enough for the requirements of rocket propulsion. Moreover, in order to obtain the full benefit of the high specific impulse and thus provide optimum economy of operation, the engine had to be capable of achieving the necessary power and thrust in a very short time. A nuclear rocket must reach full power in the order of a minute, while many commercial reactors take hours to reach full power.

Tests conducted since early 1964 have resolved all of the questions.

Structural integrity and performance have been demonstrated by successful operation of 15 reactors (Table I). The Kiwi and Phoebus reactor tests were conducted by the Los Alamos Scientific Laboratory, while the NRX (Nuclear Reactor Experimental) tests were part of the NERVA program. In early 1964, the serious vibrational problems encountered in the 1962 Kiwi-B test were not completely resolved, and the structural integrity of the reactors was in doubt. Tests later in 1964 by Los Alamos Scientific Laboratory and the NERVA team proved that the difficulty was understood and had been corrected. Confidence then increased sufficiently to increase the goal to 60 minutes of operation.

That operating goal was a staggering engineering requirement as it was almost two orders of magnitude greater than the initial full-power reactor time of one minute. In three years, however, as shown in Table I, the goal was met. In fact, NRX-A6 could have been operated significantly longer, but the test was scheduled for only 60 minutes to preserve data for postoperative examination.

Total operating time at full power is now more than four hours. The tests have demonstrated the high performance capability of the NERVA system as well as its ability to achieve long thrusting periods.

As for restart capability, more than 25 reactor power starts have been made, including many restarts. In the first complete engine system test (NRX/EST), 10 starts to power conditions were planned and successfully executed. The tests have conclusively demonstrated the restartability and reusability of the nuclear system.

The experiments also answered the questions about controllability of the system under the extremes of temperature, flow, and start times dictated by a nuclear rocket. To achieve the necessary control during the fast startup required, reactor operation during the rapid temperature increase must be thoroughly understood and predictable. In 1964, a major concern was that introduction of cold hydrogen into the core during startup would cause instabilities by increasing the moderating capability of the core. Such an increase might cause a higher temperature excursion than could be controlled by the drums. Therefore, a significant part of the program was evaluation of the controllability and predictability of the engine.

In studying controllability, a number of experiments were performed to determine system stability. An experiment on NRX-A2 showed no major problems; the system was operated close to liquid hydrogen conditions at core entrance with no instabilities. The power was increased to some 30 MW with the control drums kept at constant position while hydrogen flow to the reactor was increased. On A3, the power was increased to some 60 MW with drums fixed, and on the NRX/EST to 200 MW. Finally, on the A5, the power was increased to some 800 MW in approximately 2 minutes and then brought to full power by using a temperature control system that adjusted the drums. Because of this test series, the technology of reactor control is now well understood.[3]

The next step was to test the experimental prototype engine called the NERVA-XE. Those tests, successfully completed in September 1969, were run with the engine firing downward into a simulated space environment. They investigated multiple restarts, throttling (changing the engine flow during operation), and automatic startup by use of "bootstrap" techniques. (Bootstrap starting involves bleeding hydrogen from the reactor to start the turbopump and increasing the amount bled as the reactor comes up to full power; it frees the engine from dependence on an auxiliary starting system.) The engine was started 28 times and was operated at various thrust levels for a cumulative time of 3 hours and 48 minutes, of which 3½ minutes were at full power of 1100 MW and thrust of 55,000 pounds. The XE testing again demonstrated the stability of the nuclear rocket.

Much of the present NERVA program consists of incorporating the technology accumulated to date into the design of the nuclear rocket engine for flight, which is to have 825-second specific impulse and 75,000-pound thrust. The associated experimental program at Los Alamos Scientific Laboratory is in development of fuel elements that will operate at even higher temperatures than those now being developed for the flight reactor. (The experiments are conducted on a test-bed reactor called Pewee.)

Mission Capabilities

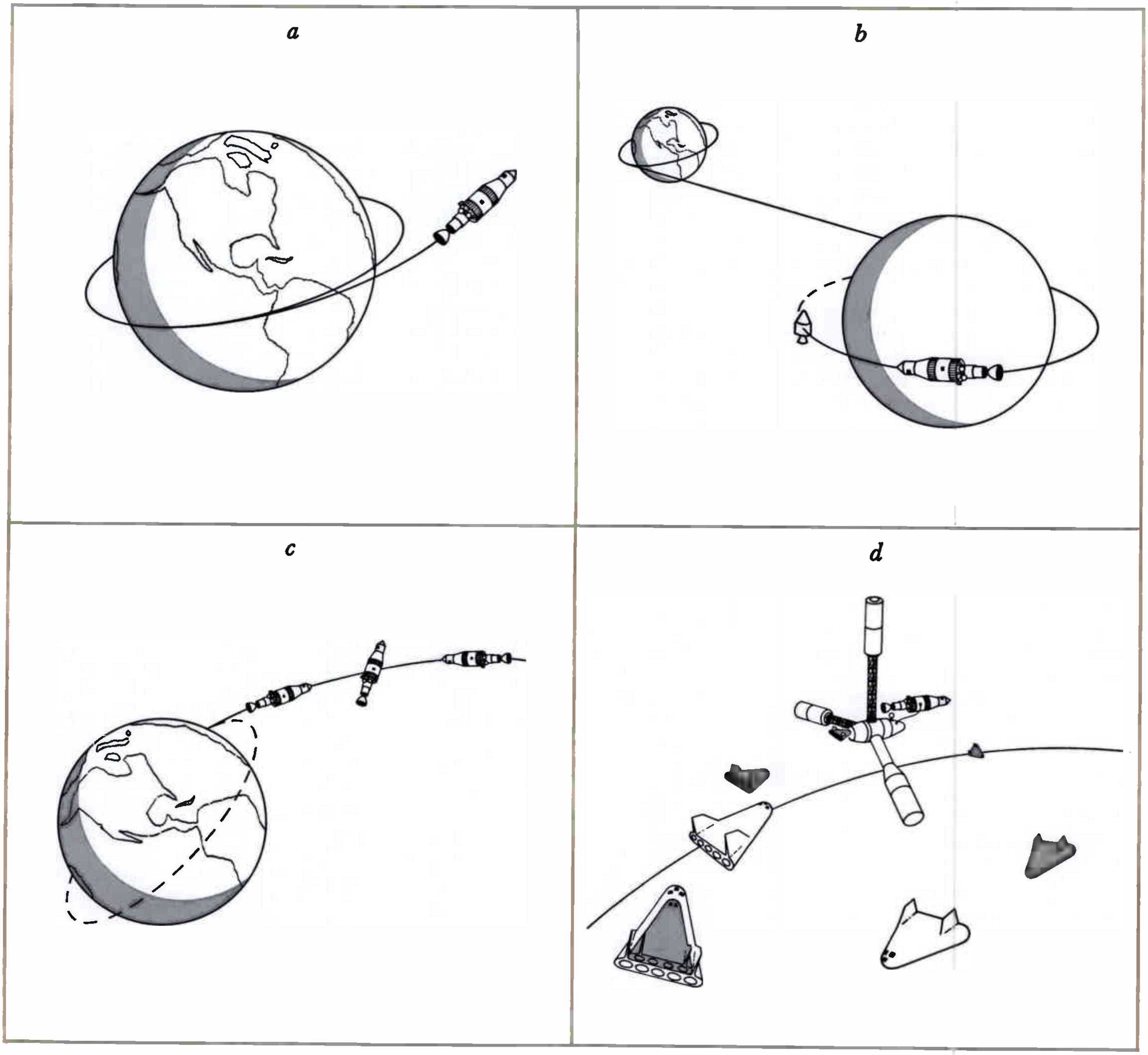
The NERVA's high specific impulse and the reservoir of energy available in nuclear fuels will provide space vehicles with mobility and load-carrying capacity that cannot be matched by any current or future chemical rocket system. As an example, Table II compares a NERVA stage with a chemical stage for various reuse missions from earth parking orbit.[4]

Operations that are especially well suited to the stored-energy advantage of the nuclear rocket are lunar-shuttle and earth-orbital missions. In a typical lunar-shuttle operation, for example, a stage powered by a NERVA of 75,000 pounds thrust would be placed in a 300-mile parking orbit by a Saturn V or by a smaller launch vehicle, and the shuttle (propellant tanks, service module, and command module) would be assembled and supplied with propellant in orbit. The nuclear shuttle would depart from parking orbit on a lunar trajectory and,

Table I. Summary of Reactor and Engine-System Tests

Kiwi-B4D (one power test)	May 1964
Kiwi-B4E (two power tests)	August–September 1964
NRX-A2 (two power tests)	September–October 1964
Kiwi-TNT	January 1965
NRX-A3 (three power tests)	April–May 1965
Phoebus-1A (one power test)	June 1965
NRX/EST (ten starts)	December 1965–March 1966
NRX-A5 (two power tests)	June 1966
Phoebus-1B (one power test)	February 1967
Phoebus-2 (cold flow tests)	July–August 1967
NRX-A6 (one power test)*	December 1967
XECF (cold flow tests)	February–April 1968
Phoebus-2A (three power tests)	June–July 1968
Pewee-1 (two power tests)	November–December 1968
XE (28 starts)	December 1968–August 1969

*Operated 60 minutes at full power (1100 MW).



2—A lunar shuttle is one type of mission that could make good use of the nuclear rocket's ability to "store" energy and to be reused a number of times by resupplying propellant. In this example, a vehicle assembled in an earth parking orbit is accelerated by engine operation out of orbit and into a lunar trajectory (*a*). It goes into lunar orbit (*b*) to rendezvous with a lunar station and transfer its payload. The engine is fired again to accelerate the shuttle out of lunar orbit toward earth, where another engine operation (*c*) puts it into its parking orbit for resupplying of propellant. Resupplying (*d*) could be done by a reusable two-stage vehicle that carries hydrogen, other supplies, and crews into earth orbit to rendezvous with an orbiting space station and the lunar shuttle.

arriving in lunar orbit, would rendezvous with a lunar station and transfer the payload (Fig. 2). The payload could be men, life-support equipment, and scientific instruments for lunar exploration. The NERVA would be fired again to boost the shuttle out of lunar orbit toward earth, and again to insert the shuttle into parking orbit to prepare for resupplying of propellant. The shuttle could be resupplied by a reusable earth-to-low-orbit transportation system. The complex tankage connections associated with bipropellant chemical systems would not be required in the nuclear system.

Moreover, the large payload capacity of a nuclear engine gives a very high probability of mission success. For example, more life support equipment, including redundant equipment, could be provided on each mission, so stay time on the moon could be increased by a factor of 10 over that now possible.

Earth-satellite operations are predicted to become of great value in communications, meteorology, and navigation and to have many other profound social and economic influences. As an example, a recent study for NASA by the National Academy of Sciences postulates a television service that would provide signals directly to home receivers.[5] The system would use either 5800-pound satellites, each of which would supply one channel of 525-line compatible color to home receivers equipped with a receiver adapter kit at a cost of approximately $125, or 20,000-pound satellites that would not require the home adapter kits. The maneuverability and payload capability of a NERVA would certainly be of advantage in placing in orbit, moving, and maintaining such satellites. In addition, propulsive efficiency and system reuse could provide economical operation.

Orbital space stations also are under study by NASA. As space operations with these stations begin to show advantages for our national economy and to the scientific community, payloads will become heavier and energy requirements for orbit changes will increase.

Still other applications made attractive by the greater performance of the nuclear rocket are explorations of our planetary system. A unique opportunity for multiple planetary investigations of the type entitled "Grand Tours" is available in the period of 1977 to 1980, when the planets Jupiter, Saturn, Uranus, and Neptune are so oriented that a single flight could swing by all of them and make scientific observations at each. (See front cover design.) Other swingby possibilities include tours of Jupiter, Saturn, and Pluto and of Jupiter, Uranus, and Neptune.[6]

The basic operation of all such unmanned planetary investigations would be the same. A NERVA would boost the unmanned payload from a parking orbit, separate from the payload, and return to parking orbit. The payload, placed on a planetary trajectory, would come into the influence of the planet's gravitational field and be accelerated by it on its way to the next planet in the tour. (In itself, the flyby interaction with a planet's gravitational field would not add to nor detract from the vehicle's total energy but would act only to change direction; the planet's orbital motion about the sun is what would give the vehicle the additional kick. It is as if a billiard ball strikes a perfectly elastic wall a glancing blow. If the wall is not moving, it only changes the ball's direction, but, if the wall moves, it imparts some of its moving energy to the ball as well as changing the direction of the ball's velocity.)

The data radioed back from the vicinity of each planet would be greatly enhanced, and the chance of success much better, by use of a nuclear stage. Due to the high payload capability, orbiters and probes could be left at the planets, transmitter power and antenna size could be larger, and redundant equipment and additional guidance equipment could be provided.

These are but a few examples of the nuclear rocket's ability to meet the challenge of the space age that started with the flight of Apollo 8, when man first ventured away from Earth. Numerous variations and benefits will evolve once the initial operations show the mobility and versatility of the nuclear rocket.

Piet Hein in one of his poems expressed the purpose of man's drive into space as well as anyone:

"I'd like to know
What this whole show
Is all about
Before it's out."[7]

Table II. Performance Comparison, Reusable Nuclear Vehicle and Nonreusable Chemical Vehicle

	Interorbital Transfer			
Destination Orbit	*Outbound Payload (lb)*	*Inbound Payload (lb)*	*Nuclear Stage Weight (lb)*	*Chemical Stage Weight (lb)*
Lunar	119,000	0	370,000	800,000
	44,000	44,000	370,000	1,130,000
	47,000	0		370,000
	12,000	12,000		370,000
Geosynchronous	102,000	0	370,000	900,000
	38,000	38,000	370,000	1,200,000
	34,000	0		370,000
	10,000	10,000		370,000
	Deep Space Injection			
Reusable nuclear vehicle can inject over 100,000 pounds into Mars trajectory with expendable chemical stage added, over 30,000 pounds into Jupiter trajectory.				

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[7] Piet Hein, *Grooks*, Doubleday & Co., 1969. © 1966, Piet Hein; reprinted by permission.

Guidelines for Selecting Large Synchronous Motors

B. C. Estep
B. S. Strait

The inherent features of the synchronous motor are constant speed, leading power factor, low inrush current, and torque characteristics that can be fitted to the application.

The choice of a synchronous, induction, or direct-current motor should be determined by an evaluation of drive requirements and by economics. The constant-speed synchronous motor has inherent advantages that often make it the logical choice for many industrial drive applications. Torque characteristics of the motor can be varied by design to match the requirements of the driven load and the available power supply. Starting, pull-in, and pull-out torques can be selected over a wide range. Power-factor improvement is available with rated power factor of unity, leading, or even lagging. Experience with many applications indicates that the following general conditions should be considered when selecting a motor.

3600 to 3000 r/min—Synchronous motors are seldom economic for this range because of the high cost of rotor construction. Although large two-pole, 3600-r/min synchronous motors from 2500 to 22,000 hp have been built, slower speed motors with step-up gears or squirrel-cage induction motors are usually a more economic choice.

1800 to 900 r/min—Synchronous motors above 1000 hp are widely used for pumps and for centrifugal compressors with speed increasers. The need for power-factor correction, high efficiency, low inrush, or constant speed may favor synchronous motors below 1000 hp. Other applications in this speed range include fans, pulverizers, rubber mills, banbury mixers, refiners, and m-g sets.

For compressors above 2500 hp requiring speed increasers, 1200-r/min unity-power-factor synchronous motors should be evaluated against 1800-r/min motors. For 1200-r/min loads (pumps, etc.), synchronous motors may be more economical at 1250 hp and above. For 900-r/min loads, synchronous motors should be considered at 1000 hp and above.

Motor requirements below 500 hp in the 900 to 1800-r/min speed range can be handled by standard induction motors.

720 to 514 r/min—Synchronous motors are often selected above 1 hp per r/min; that is, 800 hp at 720 r/min, 700 hp at 600 r/min, and 600 hp at 514 r/min.

Below 514 r/min—The synchronous motor should be considered for sizes down to 200 hp because of higher efficiency, improved power factor, and possibly lower cost. At high voltages (4 kV and above), the synchronous motor becomes more economic at even lower horsepowers.

Beyond these guidelines, more specific considerations are required when applying a synchronous motor to a given load.

Horsepower Requirements

The motor horsepower requirement is usually specified by the manufacturer of the machine to be driven, and his recommendations should be followed. Brake horsepower is determined by the torque requirements at rated speed:

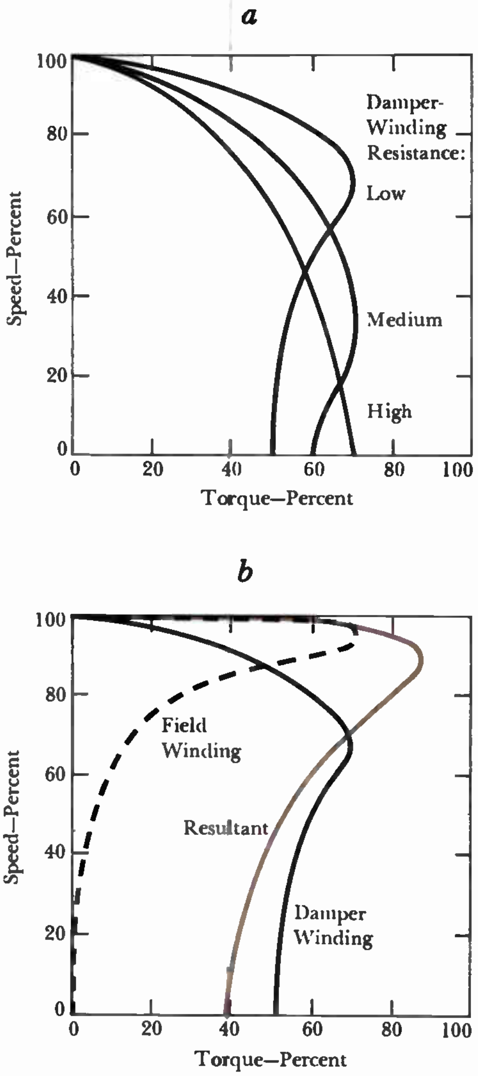
$$bhp=\frac{lb\text{-}ft\times r/min}{5250}.$$

Losses in variable-speed couplings or accessories should be included in the horsepower requirement, along with any anticipated continuous overload plus the desired safety factor. The next larger standard motor rating above the total horsepower requirement should be used.

Full-Speed Torque Requirements

Torque requirements are usually considered in two separate categories—those involved when the motor is operating at full speed (in synchronism), and those encountered during starting.

The maximum torque that a motor can carry at synchronous speed, at rated voltage, and with rated field current is the *pull-out* torque. When selecting pull-out torque, possible voltage fluctuations must be considered because pull-out torque is directly proportional to voltage. (If static excitation is connected to the same power source as the motor, pull-out torque varies as the square of the applied voltage.) Enough torque must be specified to



1—The desired speed-torque characteristics of a synchronous motor are obtained by selecting damper-winding resistance (*a*) to satisfy the starting requirements of the load. For example, the speed-torque characteristic for motors used to drive centrifugal pumps or blowers, which require low starting torque and high pull-in torque (*b*), is obtained with a low-resistance damper winding.

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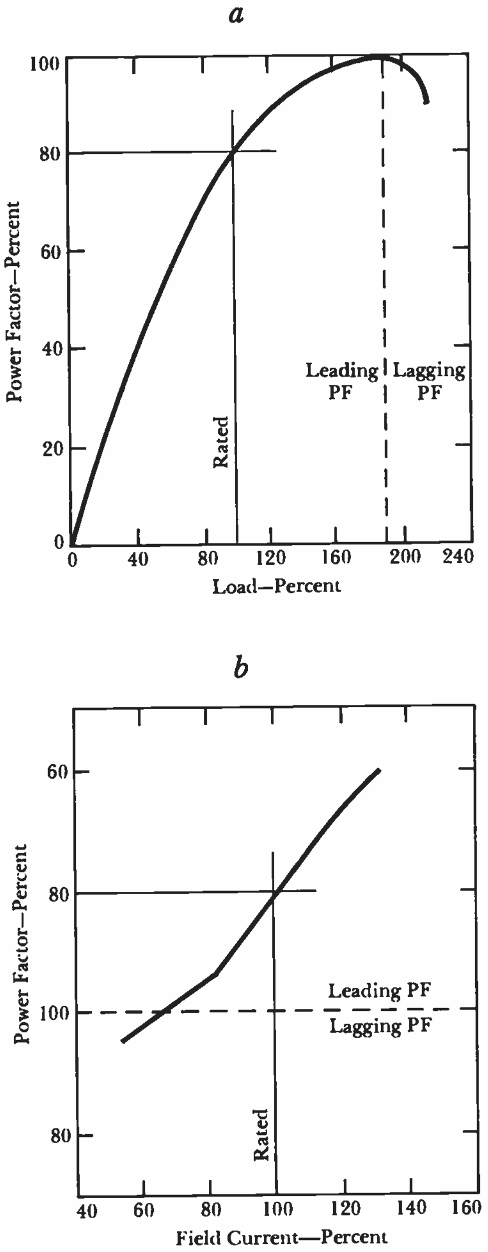
provide ample margin over maximum torque required by the driven machine at the lowest voltage that will be encountered. However, it is not desirable to specify a pull-out torque greatly above actual requirements because high pull-out torque increases the size and cost of the machine and also causes greater inrush current at starting.

Since pull-out torque is also directly proportional to field excitation, most synchronous motors are operated at rated field, even at light loads, if the load is subject to fluctuations. Decreasing field excitation to maintain rated power factor at light loads can cause the motor to pull out of step if the load suddenly increases.

Motors rated at 0.8 power factor (leading) usually have higher pull-out torque than unity-power-factor motors because of the higher field excitation. Therefore, special high-pull-out-torque motors may be less expensive at 0.8 power factor than at unity.

Although a motor with high pull-out torque is capable of handling high momentary overloads, it does not necessarily have greater ability to handle continuous overloads. Motors with high pull-out torque must be larger to increase the thermal capacity of the field, but the thermal capacity of the stator winding need not be increased in the same proportion. Therefore, the stator—unless it has been designed for low-temperature-rise operation—will reach its permissible operating temperature under rated conditions. A continuous overload may cause overheating.

Special consideration must be given to drives for loads with *cyclic torque pulsations*, such as reciprocating compressors. These applications require close cooperation between the motor manufacturer and the compressor manufacturer so that a definite figure for current pulsation can be guaranteed to the user. Current pulsation is defined as the difference between the maximum and minimum current drawn by the motor divided by the rated current. The standard (maximum) value adopted by the National Electrical Manufacturers Association is 66 percent, because experience has shown that this amount of pulsation will give satisfactory operation in nearly all installations without excessive voltage fluctuation and light flicker.



2—Power-factor improvement can be obtained with synchronous motors. Power factor varies with load (*a*) when field current is held constant, and with field current (*b*) for constant rated load.

Starting Torque Requirements

The desired starting characteristics of a synchronous motor are obtained by adjusting the resistance and reactance of the two rotor circuits (damper and field) (Fig. 1). The torque developed by a motor at any instant during acceleration is the resultant (but not the direct sum) of the torques developed by the rotor windings.

The three starting performance characteristics that are normally specified are: *starting torque*, *pull-in torque*, and *inrush* (or starting current). These characteristics are interrelated, so any change in one affects each of the others. The torques are usually expressed as a percentage of the torque delivered by the motor when it is carrying its rated load at synchronous speed; inrush is expressed in percent of full-load kVA or current.

Starting torque is the torque developed by the motor at standstill when voltage is applied. It must be sufficient to break the load loose and accelerate it to the speed where the motor pulls into synchronism when field excitation is applied.

Pull-in torque is the torque developed by a motor when it is operating as an induction motor at the speed from which it can pull into synchronism when the field winding is energized. The speed at which the motor synchronizes is generally a function of rotor and load inertia. Most synchronous motors pull in at approximately 5 percent slip (95 percent speed).

The torque developed by a synchronous motor while it is operating as an induction motor varies as the square of the applied voltage. (*Pull-up torque*, occasionally specified, is the minimum torque exerted by the motor at any speed during startup.) When motors are started at reduced voltage, the control usually is so arranged that transfer to full voltage will be made before the pull-in speed is reached so that maximum torque is available at the time pull-in speed is reached. Field excitation should *not* be applied before the motor is up to pull-in speed.

The pull-in torque capability depends on the inertia of the connected load.

Nominal pull-in torque is the torque against which the motor can synchronize a normal inertia load (as defined by NEMA MG 1-21.42) from 95 percent speed with full voltage and rated excitation. Nominal pull-in torque, used for comparing motors, is a function of the motor alone and is independent of the load characteristics. When the motor is applied to a load, the *guaranteed* pull-in torque, not the nominal pull-in torque, should be used.

Inrush means either kVA or current taken by the motor at the instant of starting. It is the inrush at full voltage even though the motor may be started at reduced voltage.

When a motor is started at reduced voltage, motor current is reduced in the same proportion. Torque varies as the square of the applied voltage (see Table I).

Torque Specifications

Synchronous motors can be built with any combination of torques required for practical applications. Although NEMA publishes recommended values for minimum torques (MG 1-21.41), Westinghouse recommends that the torques specified for each application actually fit the particular drive requirements. For example, if the driven machine can be started unloaded with low starting and pull-in torques, specifying low torque values will permit the motor to be designed with lowest possible inrush.

If the driven machine cannot be unloaded during starting and the torque requirements of the load are higher than standard, the necessary starting and pull-in torques must, of course, be specified. This requirement raises the cost of the motor, and the inrush is also higher. For example, a motor suitable for a crusher drive might require 200 percent starting torque, 140 percent pull-in torque, and 200 percent pull-out torque; a motor with these characteristics costs approximately 50 percent more than a low-torque motor and the inrush is about 2.6 times that of a low-torque motor.

Typical load torque requirements for industrial applications are listed in Table II. These values are estimates, and actual requirements should be obtained for each specific application from the manufacturer of the driven machine.

Load Inertia

Machines such as fans, chippers, and geared centrifugal compressors are high inertia loads, and this fact must be considered when selecting drive motors. The critical effect of high inertia on pull-in torque is especially important in fan and

Table I. Reduced-Voltage Starting

Method of Reduced-Voltage Starting	*Starting Torque*	*Starting kVA*
Reactor	Varies as square of voltage	Varies directly with voltage
Autotransformer	Varies as square of voltage	Varies as square of voltage
Star start, delta run	One-third of delta value	One-third of delta value

Table II. Typical Load Torque Requirements

Application	*Torque—Percent of Motor Full-Load Torque*			*Ratio of Load Inertia to Normal Inertia**
	Locked-Rotor	*Pull-In*	*Pull-Out*	
Banbury mixers	140	120	250	0.2-1
Blowers, positive displacement, rotary—bypassed for starting	50	50	150	3-8
Chippers—starting empty	60	40	250	10-100
Compressors, centrifugal—starting with:				
Inlet or discharge valve closed	40	30	150	3-30
Inlet and discharge valve open	40	100	150	3-30
Compressors, reciprocating—starting unloaded				
Air and gas	40	30	150	0.2-15
Ammonia (discharge pressure 100-250 psi)	40	30	150	0.2-15
Freon	40	40	150	0.2-15
Crushers—starting loaded (ball or rod mills)	160	120	175	2-4
Fans, centrifugal—starting with:				
Inlet or discharge valve closed	40	60	150	5-60
Inlet and discharge valve open	40	110	150	5-60
Generators, dc (m-g sets)	40	10	200	2-15
Grinders, pulp—starting unloaded	50	40	150	1-5
Pulverizers	200	100	175	4-10
Pumps, axial flow, fixed blade—starting with:				
Casing dry	40	15	150	0.2-2
Casing filled, discharge open	40	100	150	0.2-2
Pumps, centrifugal—starting with:				
Casing filled, discharge closed	40	60	150	0.2-2
Casing filled, discharge open	40	100	150	0.2-2
Pumps, mixed flow—starting with:				
Casing filled, discharge closed	40	120	150	0.2-2
Casing filled, discharge open	40	100	150	0.2-2
Refiners, pulp (including Jordans)	50	50	150	2-20
Rolling mills, roughing stands of hot-strip mills	50	40	250	0.5-1
Rubber mills	140	120	250	0.5-1

***For table of calculated normal inertia of load, see NEMA MG-1, Table 21-5.**

compressor applications. Other applications, like chippers, which start completely unloaded, have low starting and pull-in torque requirements, but their high inertia retards acceleration and the heat developed in the damper winding of the motor necessitates a special design.

If load torque is small compared to available motor torque, the heat developed in the damper bars of the motor during acceleration is about equivalent to the kinetic energy of the rotating mass. If the load torque is fairly high, additional rotor heating results. Unless the winding components are large enough, the temperature may become excessive and damage the bars.

In all applications involving high-inertia loads, the motor manufacturer should be given accurate load inertia and torque values so that the proper motor can be selected. If a rotating member of the driven equipment operates at a speed different from that of the motor, its inertia should be multiplied by the square of the ratio of its speed to the motor speed to obtain the equivalent inertia at the motor shaft.

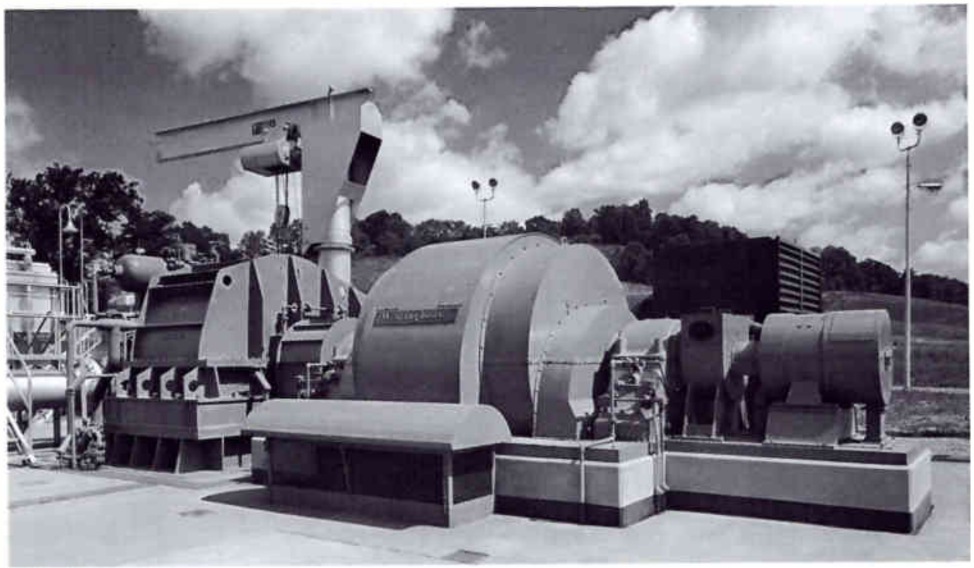
Power Source

Limitations of the power source must always be considered when applying large motors. Inrush current is the most important motor characteristic affecting the power supply because it generally causes a significant system voltage dip.

Full-voltage starting is the most economical and simple form of starting control because the motor is energized by simply connecting it across the line. But when motor inrush is too high for the power supply, other starting methods must be evaluated. Reduced-voltage starting may be used, such as reactor or autotransformer starting, provided that sufficient torque can be delivered at the reduced voltage to accelerate the load fast enough to avoid overheating the motor damper circuit or stator coils.

If reduced voltage cannot be used because of load characteristics, other solutions such as synchronous starting, capacitor starting, simplex motors, or synchronous-induction motors should be investigated.

1



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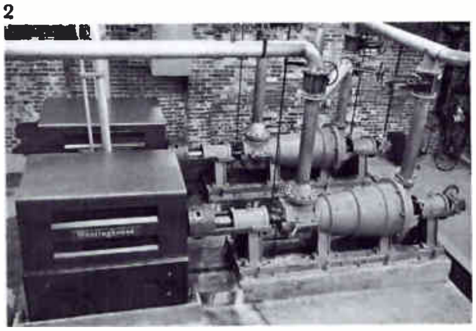

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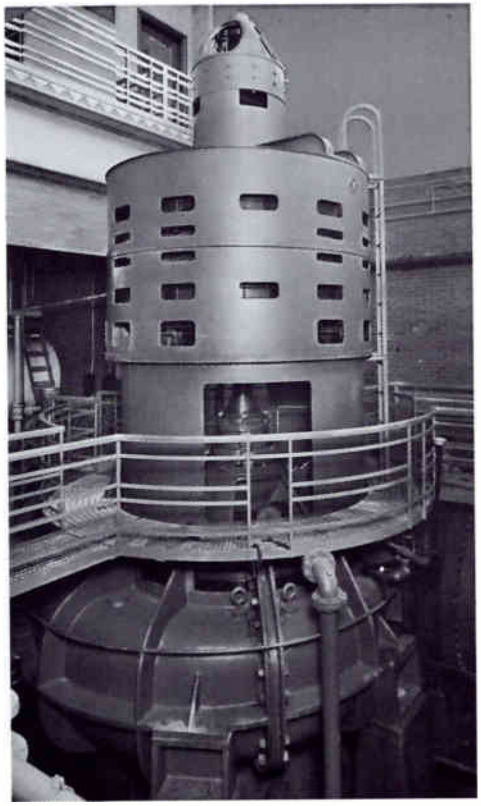

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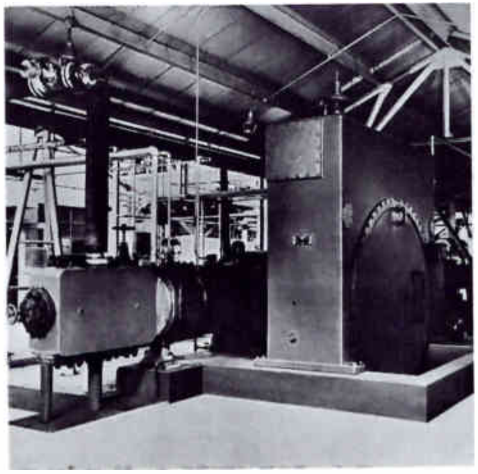
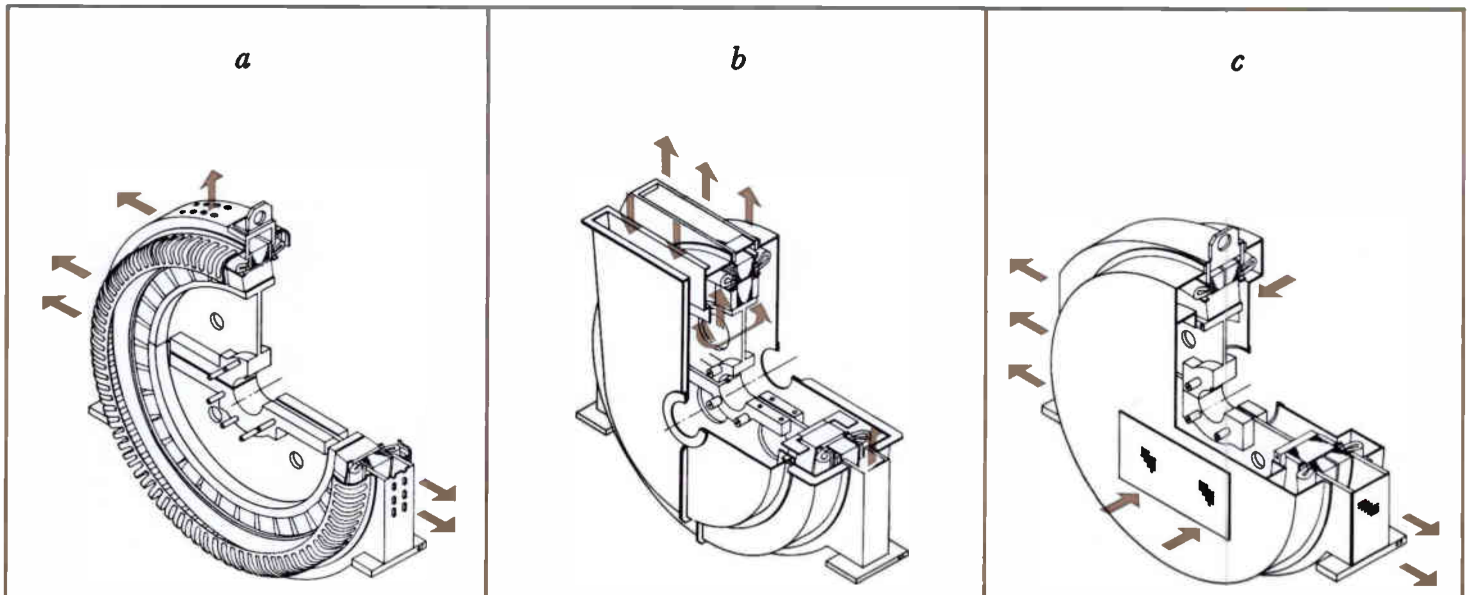


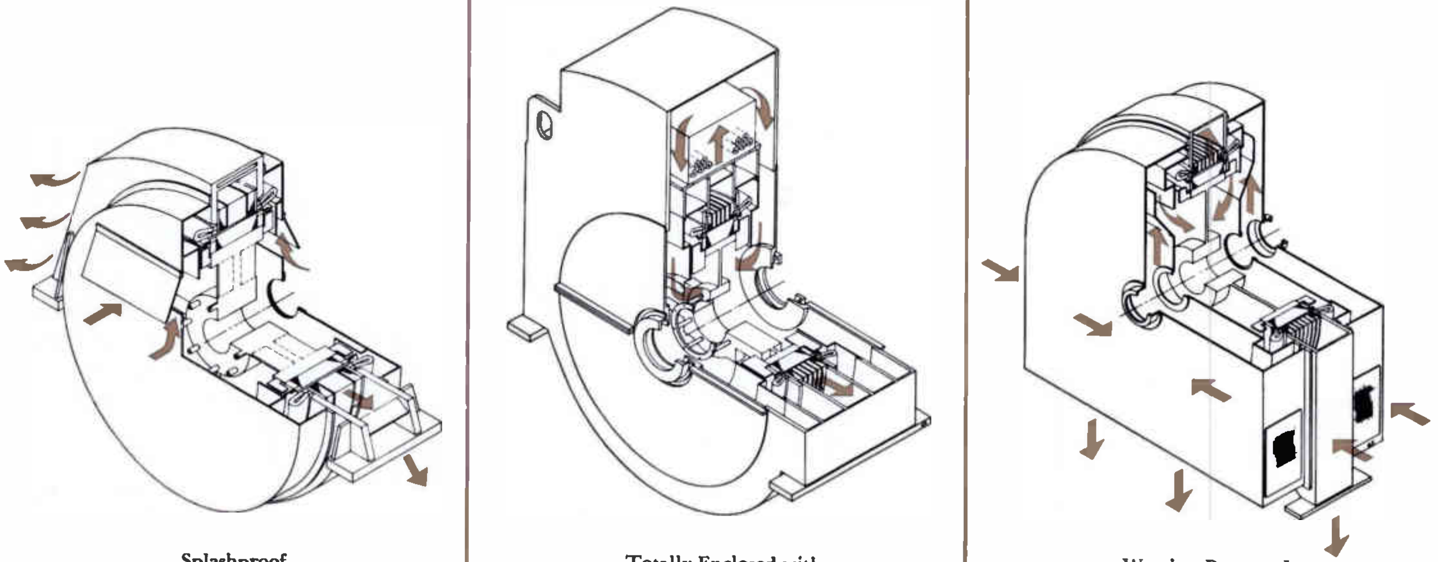
***Photo 1*—Compressor drive (15,000 hp, 900 r/min) with force-ventilated enclosure and purged collector rings for outdoor service in semihazardous atmosphere. *(2)* Jordan drive motor (250 hp, 514 r/min) with dripproof enclosure for paper mill atmosphere. *(3)* Two-speed vertical motor for water pumping service has two stators and rotors mounted in tandem using a common frame and shaft. *(4)* Engine type reciprocating compressor drive (1000 hp, 327 r/min) with inert gas filled, water cooled enclosure for hazardous atmosphere.**



Open

Totally Enclosed,
Force-Ventilated

Weather Protected,
Type I



Splashproof

Totally Enclosed with
Air-to-Water Heat Exchanger,
Inert Gas Filled

Weather Protected,
Type II

3—A variety of motor enclosures are available to satisfy application requirements. The most economical enclosure designs (*a*) can be applied in clean indoor areas. They range from the open enclosure for use in relatively dry locations to dripproof and splashproof designs. Totally enclosed units (*b*) should be used in dirty, hazardous, wet, or contaminated indoor areas. Weather-protected motor enclosures (*c*) are used for outdoor service in nonhazardous areas that are either clean (Type I) or dusty or sandy (Type II).

Excitation Methods

When several synchronous motors are installed in the same plant location, excitation for all motors is often supplied from a common dc source. A motor-field rheostat is required if field adjustment is necessary. Rheostats are usually designed so that the motor can be operated at its rated power factor down to 75 percent of load. Special rheostats must be used if a greater operating range is desired. There are also several individual motor-excitation methods that can be used.

Conventional Direct-Connected Exciters—Shunt-wound commutator-type dc exciters are suitable for most high-speed synchronous motors. At low speeds—514 r/min or less—the direct-connected exciter is relatively expensive because of its size.

Belted Exciters—High-speed dc generators driven by belt from the motor shaft can be provided for all synchronous motors, but other methods are usually more economic because of the cost of the pulley drive, belt, and maintenance.

Motor-Generator Exciters—Motor-generator sets are frequently used for exciting synchronous motors. For multiple motor installations, a single m-g set to supply excitation for all motors is usually the more economic approach.

Static Exciters—Silicon rectifiers are frequently mounted in the same cabinet with the motor control. In most cases, this method provides the least expensive field-current supply. However, power-factor regulation is difficult and inaccurate if only a tapped transformer is used for changing the field current. Also, if the same ac supply is used for both the motor and rectifier, voltage dips cause pull-out torque to decrease by the square of the voltage drop rather than in direct proportion to voltage drop.

Brushless Exciters—Brushless excitation with Westinghouse Pulse Syn control is available for all synchronous motor applications. This method is particularly suited to installations where brush maintenance or sparking problems would require that conventional brush-type motors be provided with special collector enclosures. Such installations include refineries and chemical-process plants.

Power Factor

Synchronous motors are rated at either unity power factor or some leading power factor—usually 0.8. Substantial power factor improvement can be obtained with leading-power-factor machines by allowing the motor to operate lightly loaded at rated field current (Fig. 2). Unity-power-factor motors may provide a small amount of leading kvar at reduced loads. (A machine of the usual proportions has about 30 percent reactive kVA at no load and zero reactive kVA at full load.) If maximum leading kvar is wanted at all reduced loads, field current should be set at rated value at all times.

If reactive kVA is not required, the excitation of either unity- or leading-power-factor machines can be adjusted to maintain unity power factor at all times. This results in minimum losses and highest operating economy. However, since pull-out torque of leading-power-factor motors is reduced below rated value, synchronous motors operated with reduced field excitation should also have automatic provision for increasing field excitation when the load returns to normal.

Hazardous Atmospheres

Hazardous atmospheres, defined by the National Board of Fire Underwriters, are denoted by groups and classes depending on material (explosive dust or gas) and ignition temperature of the particular material. For example, Division 1 areas have hazardous atmospheres at some time during normal operation of the process system or are *likely* to have them during maintenance or breakdown. Division 2 areas are not normally hazardous but may become hazardous if a malfunction such as a pipe rupture occurs.

Explosion-proof construction is generally impractical for synchronous motors. For Division 1 areas, a totally enclosed design with a ventilation system that insures that only nonexplosive air or inert gas is inside the machine enclosure (Fig. 3) *may* be acceptable to the local code-enforcing authority. For Division 2 areas, any sparking contacts can be enclosed in explosion-resisting, hermetically sealed or purged covers. Suitable enclosures can be recommended, but acceptance *must* be obtained from the local code-enforcing authority. In addition, the local authority may require either brushless excitation or separately enclosed and purged collector rings.

Dynamic Braking

For many motor drive applications where rotation should be stopped quickly, dynamic braking may be desirable. Dynamic braking consists of short-circuiting the armature through an external resistor while maintaining full field excitation. As the rotational energy of the machine is dissipated in the resistor, the speed of the rotor decreases. The rate of motor speed change is dependent upon the connected resistance.

Synchronous Motor Inching

Many applications for synchronous motors require that the driven equipment be stopped at a given angular position for setting up, loading, or unloading, or that the equipment be rotated at slow speeds. Jogging the motor from the normal power supply is destructive to the contactor or circuit-breaker parts and may overheat the motor windings. In many cases, it is also difficult for the operator to obtain the desired positioning accuracy.

Accurate inching is possible with a positioning control system that uses a low-potential dc power source, commutated by magnetic contactors. In effect, this method provides a low-frequency source of power, adjustable between 12 and 36 cycles per minute so that the motor rotates from 1/300 to 1/100 of normal speed.

Low frequency is obtained by first connecting two phases in parallel and then in series with the third phase across the dc supply. The phases are then reversed one at a time in the proper sequence. Six single-pole magnetic contactors are required for accomplishing this reversal. The coils of these contactors are energized by a motor-driven sequence timer. The dc power source may be an existing constant-voltage supply or a motor-generator or static dc set supplied for this purpose.

Automated Engineering Information Systems Can Provide Company-Wide Cost Improvement

H. H. Hansen

Computerizing routine engineering effort does more than free engineers for creative work. It can improve information flow into and out of the engineering department to the economic benefit of the whole organization.

Most engineering uses of computers have been restricted to performance of design calculations, while data-processing applications have generally been business oriented and have remained in the domain of the company's controller. Now, however, the emergence of engineers with data-processing experience has created the potential for *improving flow of engineering information* as well as improving the accuracy and speed of engineering calculations. Automation of the information flow to, within, and from an engineering department provides cost-improvement benefits that extend beyond the domain of engineering.

The AEIS Concept

The Automated Engineering Information System (AEIS) concept developed by Westinghouse Tele-Computer Systems Corporation is a systematic approach to building a flow of information containing high concentrations of engineering data. The goal of the concept is to make information flow as directly as possible from the originator to the user.

In most manufacturing companies today, a salesman who obtains an order forwards it to an order-entry or customer-service group that then notifies such other groups as engineering, manufacturing, and accounting of the order. Engineering may be called on to modify and improve an existing design, a manufacturing information group may prepare shop work instructions and routings, and accounting may set up the appropriate cost accounts. Shop personnel finally receive the manufacturing information and build the product.

The AEIS concept is to enable the salesmen to tell shop personnel directly when and what to build, and to do so in a manner that also insures that the product design is correct and all costs are assigned to proper accounts. Such an ideal situation is not attainable in every case; in others, it is approachable if not completely obtainable, especially when some of the present constraints are due to tradition based on earlier technology.

The key advantage to the engineering department is an increase in the amount of time available for creative engineering, accomplished by making a computer assist designers in a number of ways. First is the readily apparent time saving in having the computer help the engineer retrieve reference data. Second, if the information system is extended into the functional areas that supply input to engineering, such as marketing, the order-entry information can be processed and restructured into a format that is more useful to designers. Third, the information system can be extended into adjacent functional areas, such as manufacturing, that depend on engineering information. The computer can accept information in a form convenient to the designer, yet process the information to provide output usable by manufacturing.

The availability of directly usable output that can be rapidly produced provides additional benefits through the resulting ability to retain information in the computer until it is required. For example, many revisions can be made directly in the computer, reducing the number of changes that actually leave the engineering department, and schedules do not have to be made final so early as they otherwise would.

The economically justifiable level of automation of engineering information flow, like the level of manufacturing automation, depends directly on the degree of standardization. At times, however, the degree of standardization is not readily apparent.

The obvious standardization is that in which components are drawn from stock and assembled into products according to a set of logical rules. Those logical rules can be documented by use of decision tables. By learning a very small subset of COBOL (Common Business-Oriented Language) and the technique of applying decision tables to product designs, engineers can easily write involved part-selection programs for new designs or can modify existing product lines (Fig. 1).

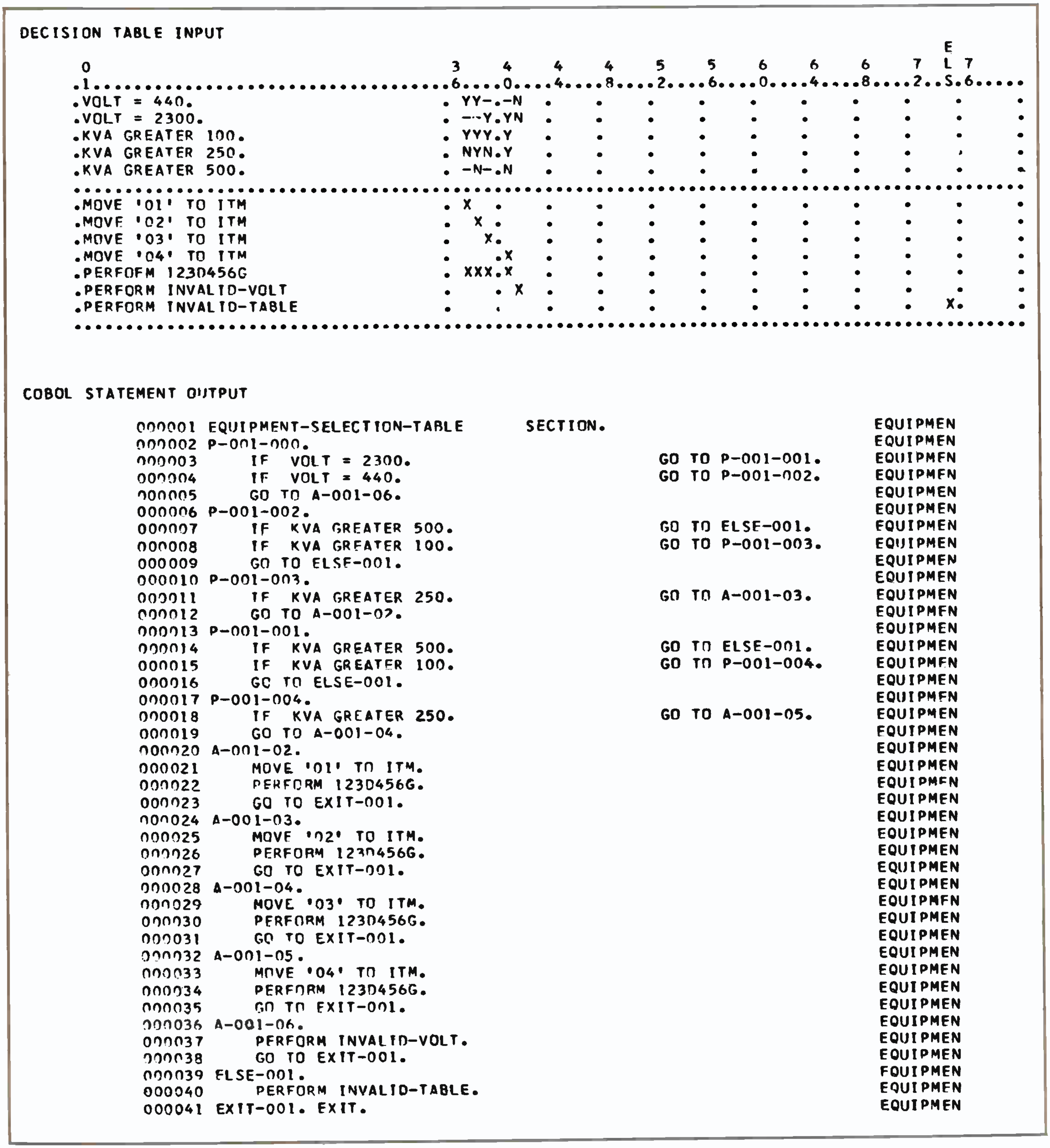
Frequently, standardization can also be applied to custom-made components that can be depicted by variable dimensions and that may or may not have features (such as cutouts or appendages) depending on certain logical rules. The recognition of such characteristics in a product is the key to significant engineering benefit.

Custom Products

Many product lines composed of custom designs are sufficiently stable to warrant the cataloging of basic designs and their possible options. One such product line is elevator cabs, which are constructed from steel panels that are similar in shape but vary in size and number depending on such architectural and engineering considerations as the dimensions of the building. Added to the basic cab shell are a number of accessories, some of which are optional and some required to meet particular building codes. By use of decision rules established during the product design, all basic parts and accessories

1—Use of decision tables enables a design engineer to quickly write the complex computer programs required for a wide range of design decisions, even though the engineer is not a proficient programmer. This simple example illustrates decision table use for selecting equipment on the basis of voltage and rating. The top part is the information developed by the engineer and keypunched on data processing cards. It lists all conditions on which decisions will be based, such as "VOLT=440," and then lists possible actions. Decisions are input to the right, with "Y" and "N" meaning yes and no on the condition rows and "X" meaning to perform the actions on the action rows. The computer generates the logic by reading down a column. In column 37, for example, voltage is 440 and kVA rating is greater than 100 and less than 250, so the computer selects item 1 from drawing 123D456G. The "ELS" column at the far right provides a path of action if none of the condition combinations is fulfilled. At the bottom of the illustration is the program code, in COBOL, automatically generated by the computer. It is now part of the program that enables the computer to make decisions for the design engineer, for any input information, on the basis of the rules he has established.

H. H. Hansen is Product Manager, Management Systems, Westinghouse Tele-Computer Systems Corporation, Pittsburgh, Pennsylvania.



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DECISION TABLE INPUT
                                                                    E
 0                           3   4   4   4   5   5   6   6   6   7  L 7
.1...........................6...0...4...8...2...6...0...4...8...2..S.6.....
.VOLT = 440.                . YY-.-N .   .   .   .   .   .   .   .  .    .
.VOLT = 2300.               . --Y.YN .   .   .   .   .   .   .   .  .    .
.KVA GREATER 100.           . YYY.Y  .   .   .   .   .   .   .   .  .    .
.KVA GREATER 250.           . NYN.Y  .   .   .   .   .   .   .   .  .    .
.KVA GREATER 500.           . -N-.N  .   .   .   .   .   .   .   .  .    .
............................................................................
.MOVE '01' TO ITM           . X  .   .   .   .   .   .   .   .   .  .    .
.MOVE '02' TO ITM           .  X .   .   .   .   .   .   .   .   .  .    .
.MOVE '03' TO ITM           .   X.   .   .   .   .   .   .   .   .  .    .
.MOVE '04' TO ITM           .    .X  .   .   .   .   .   .   .   .  .    .
.PERFOFM 123D456G           . XXX.X  .   .   .   .   .   .   .   .  .    .
.PERFORM INVALID-VOLT       .    . X .   .   .   .   .   .   .   .  .    .
.PERFORM INVALID-TABLE      .    .   .   .   .   .   .   .   .   .  X.   .
............................................................................
```

```
COBOL STATEMENT OUTPUT

000001 EQUIPMENT-SELECTION-TABLE     SECTION.                        EQUIPMEN
000002 P-001-000.                                                    EQUIPMEN
000003     IF  VOLT = 2300.                      GO TO P-001-001.    EQUIPMEN
000004     IF  VOLT = 440.                       GO TO P-001-002.    EQUIPMEN
000005     GO TO A-001-06.                                           EQUIPMEN
000006 P-001-002.                                                    EQUIPMEN
000007     IF  KVA GREATER 500.                  GO TO ELSE-001.     EQUIPMEN
000008     IF  KVA GREATER 100.                  GO TO P-001-003.    EQUIPMEN
000009     GO TO ELSE-001.                                           EQUIPMEN
000010 P-001-003.                                                    EQUIPMEN
000011     IF  KVA GREATER 250.                  GO TO A-001-03.     EQUIPMEN
000012     GO TO A-001-02.                                           EQUIPMEN
000013 P-001-001.                                                    EQUIPMEN
000014     IF  KVA GREATER 500.                  GO TO ELSE-001.     EQUIPMEN
000015     IF  KVA GREATER 100.                  GO TO P-001-004.    EQUIPMEN
000016     GO TO ELSE-001.                                           EQUIPMEN
000017 P-001-004.                                                    EQUIPMEN
000018     IF  KVA GREATER 250.                  GO TO A-001-05.     EQUIPMEN
000019     GO TO A-001-04.                                           EQUIPMEN
000020 A-001-02.                                                     EQUIPMEN
000021     MOVE '01' TO ITM.                                         EQUIPMEN
000022     PERFORM 123D456G.                                         EQUIPMEN
000023     GO TO EXIT-001.                                           EQUIPMEN
000024 A-001-03.                                                     EQUIPMEN
000025     MOVE '02' TO ITM.                                         EQUIPMEN
000026     PERFORM 123D456G.                                         EQUIPMEN
000027     GO TO EXIT-001.                                           EQUIPMEN
000028 A-001-04.                                                     EQUIPMEN
000029     MOVE '03' TO ITM.                                         EQUIPMEN
000030     PERFORM 123D456G.                                         EQUIPMEN
000031     GO TO EXIT-001.                                           EQUIPMEN
000032 A-001-05.                                                     EQUIPMEN
000033     MOVE '04' TO ITM.                                         EQUIPMEN
000034     PERFORM 123D456G.                                         EQUIPMEN
000035     GO TO EXIT-001.                                           EQUIPMEN
000036 A-001-06.                                                     EQUIPMEN
000037     PERFORM INVALID-VOLT.                                     EQUIPMEN
000038     GO TO EXIT-001.                                           EQUIPMEN
000039 ELSE-001.                                                     EQUIPMEN
000040     PERFORM INVALID-TABLE.                                    EQUIPMEN
000041 EXIT-001. EXIT.                                               EQUIPMEN
```

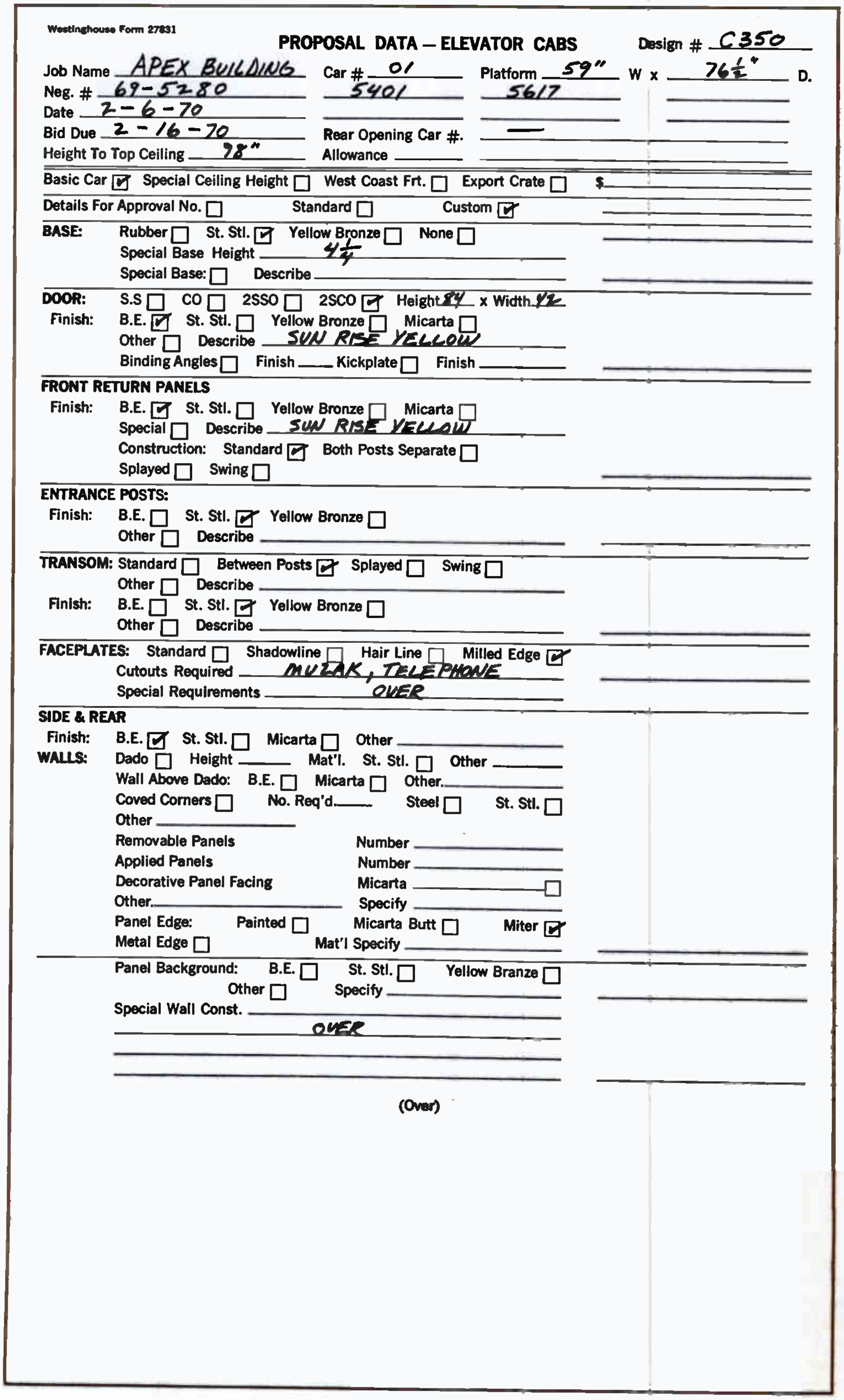
can be selected and sized directly from order input prepared by the marketing department.

Such a system is in use at the Westinghouse Elevator Division's components plant. Even though it is the first of its kind, it allows, a salesman to input an order for an elevator cab and the cab to be built and shipped without involving engineering, except for special designs.

To initiate the action, the salesman consults with the architect and completes a questionnaire that identifies basic cab dimensions and desired accessories (Fig. 2). The coded questionnaires are keypunched and processed as part of a computer run. (Engineers have prepared the part-selection programs through use of decision tables, allowing the actual cab orders to entirely bypass engineering.) Output includes a confirmation copy of the order to the salesman, a master parts-required list, a standard cost report broken down by manhours and materials, a summary of the weight of the cab for use by the control designers, a punched tape for use in a numerically controlled punch press, and instructions for the punch-press operator.

To the extent that decision-table logic can be applied to a *portion* of a product, that portion can be automated in a fashion similar to the elevator cab automation. Power transformer tanks are one example. The *size* of a tank depends on the transformer's rated kVA and voltage, but its *shape* is constant over a wide range of ratings in that depth, width, and height can be defined by A, B, and C. There are no restriction on A, B, and C; they can change from order to order (with transformer rating) in both magnitude and ratio.

For each order, design programs select tank parts and calculate the necessary dimensions. Tank dimensions are then processed against coded patterns in the



Westinghouse Form 27831

PROPOSAL DATA — ELEVATOR CABS Design # C350

Job Name APEX BUILDING Car # 01 Platform 59" W x 76½" D.
Neg. # 69-5280 5401 5617
Date 2-6-70
Bid Due 2-16-70 Rear Opening Car #. —
Height To Top Ceiling 78" Allowance

Basic Car ☑ Special Ceiling Height ☐ West Coast Frt. ☐ Export Crate ☐ $

Details For Approval No. ☐ Standard ☐ Custom ☑

BASE: Rubber ☐ St. Stl. ☑ Yellow Bronze ☐ None ☐
Special Base Height 4¼
Special Base: ☐ Describe

DOOR: S.S ☐ CO ☐ 2SSO ☐ 2SCO ☑ Height 84 x Width 42
Finish: B.E. ☑ St. Stl. ☐ Yellow Bronze ☐ Micarta ☐
Other ☐ Describe SUN RISE YELLOW
Binding Angles ☐ Finish ___ Kickplate ☐ Finish

FRONT RETURN PANELS
Finish: B.E. ☑ St. Stl. ☐ Yellow Bronze ☐ Micarta ☐
Special ☐ Describe SUN RISE YELLOW
Construction: Standard ☑ Both Posts Separate ☐
Splayed ☐ Swing ☐

ENTRANCE POSTS:
Finish: B.E. ☐ St. Stl. ☑ Yellow Bronze ☐
Other ☐ Describe

TRANSOM: Standard ☐ Between Posts ☑ Splayed ☐ Swing ☐
Other ☐ Describe
Finish: B.E. ☐ St. Stl. ☑ Yellow Bronze ☐
Other ☐ Describe

FACEPLATES: Standard ☐ Shadowline ☐ Hair Line ☐ Milled Edge ☑
Cutouts Required MUZAK, TELEPHONE
Special Requirements OVER

SIDE & REAR
Finish: B.E. ☑ St. Stl. ☐ Micarta ☐ Other
WALLS: Dado ☐ Height ___ Mat'l. St. Stl. ☐ Other
Wall Above Dado: B.E. ☐ Micarta ☐ Other.
Coved Corners ☐ No. Req'd.___ Steel ☐ St. Stl. ☐
Other
Removable Panels Number
Applied Panels Number
Decorative Panel Facing Micarta ☐
Other. Specify
Panel Edge: Painted ☐ Micarta Butt ☐ Miter ☑
Metal Edge ☐ Mat'l Specify

Panel Background: B.E. ☐ St. Stl. ☐ Yellow Branze ☐
Other ☐ Specify
Special Wall Const.
OVER

(Over)

2—This elevator-cab order form is typical of the simple input sheets that can be devised to enable personnel (salesmen in this example) to use a computer-programmed engineering design service without having to learn programming. The salesman obtains the necessary information from the building architect.

computer's files. (The coded patterns are prepared by draftsmen at the time the variable dimension drawings are made.) From the dimensions and patterns, the computer prepares punched paper tape and operator instructions for the numerically controlled punch press (Fig. 3).

Job-Shop Products

Even in a job shop, which is highly specialized, automation of the engineering information flow supplemented by design engineering input can provide substantial cost benefits. To the degree that the engineering information varies from job to job, it is input each time, but all information that repeats often enough to justify its storage cost is cataloged for computer retrieval. Having available the total product information to satisfy a specific order again enables the computer to output information in a directly usable format. In addition, the computer can coordinate input from several design sources and produce output that, without a computer, could be produced only through tedious manual collating.

Sometimes, automating the information flow from engineering into other areas (such as production or cost accounting) produces greater economies in those areas than in engineering. That turned out to be the case in Automated Cabling/Wiring, an information system for electrical and electronic data in naval shipyards that was developed for the Naval Ship Systems Command.

Automated Cabling/Wiring assists design engineers by using computers to perform such tasks as information retrieval by catalog lookup, design computations such as voltage drop analysis, and design decisions such as cable route selection and cable arrangement in penetration areas. (A penetration area is the part of a water-tight bulkhead designated for the passage of cables from one compartment to another.) The system accepts input from a number of design engineers, each concerned with a specific circuit—for example, the 60-Hz power system, the automatic telephone circuit, or the 5-inch-gun fire control circuit.

Designers are provided confirmation copies of their input, as well as information required for compartment arrangement such as equipment size and weight, mounting requirements, and cable entrance locations. When most of the circuits on a ship have been input, the computer can then be used to route cables, arrange cables in penetration areas, and calculate voltage drops in accordance with previously programmed procedures.

It is in the area of production, however, that Automated Cabling/Wiring provides the greatest benefits. Because all the information is available in a form that can be read by a computer, the computer can readily produce valuable outputs that previously were not economically justifiable. One example of this type of output is the Compartment Material Lists that enable workers to gather all material for each compartment into a staging area.

Another example is the Local Cableway Planning List that provides an electrician entering a compartment with complete information on all cables entering that compartment, such as where they came from and what he must do with them. Previously, this information could be gotten only by a search of the drawing for each electrical circuit. Still another example is the Wire Connection List that provides instructions for cable hookup (Fig. 4).

A benefit analysis conducted by the Philadelphia Naval Shipyard listed the following advantages:

1) Data need be input only once, saving man-hours and simplifying correction control;

2) Each output is custom tailored to a specific task;

3) Computer speed allows design and planning departments to accomplish their functions just before output is required by the production department;

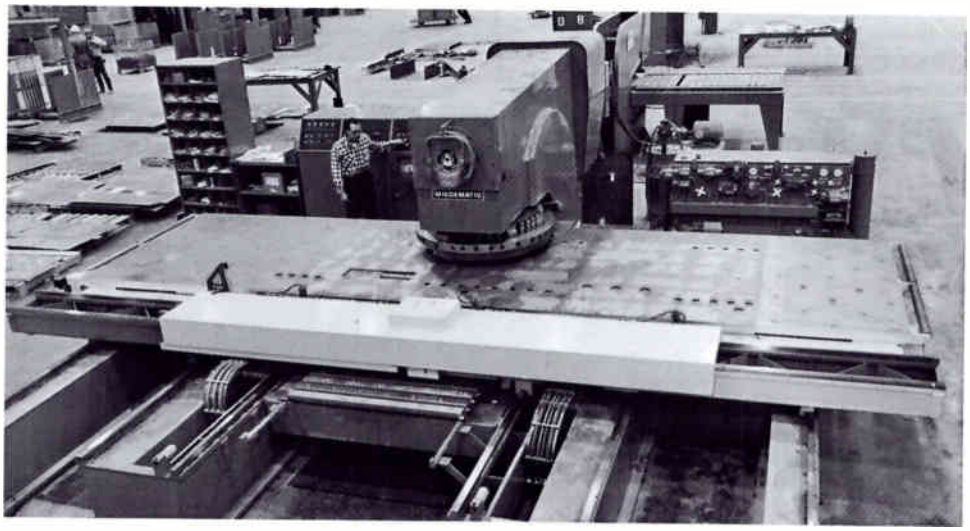
4) Much routine catalog searching is eliminated;

5) The system provides a vehicle for future addition of more analytical programs;

6) The number of drawings required probably is reduced; and

7) Input forms can be filled out by unskilled personnel from information supplied by the designer.

The results of the analysis indicated a saving, for a prototype ship the size of an Amphibious Assault Ship (LPH), of 8.5 percent in production and planning man-hours required in the electrical and



3—Steel plates for fabrication of power transformer tanks in a range of sizes are produced at the Westinghouse Power Transformer Division plant, South Boston, Virginia, by automated methods similar to those used for elevator cabs. Computer design programs select tank parts, calculate dimensions, and prepare punched tape and operator instructions for the numerically controlled punch press.

electronic area. This is a saving of $225,000 and 28 days in the construction schedule. The analysis further indicated that while there were no immediate hour and dollar savings in the design area, due to the newness of the technique and the initial lack of catalog data, improvement over the results of the first design effort is expected.

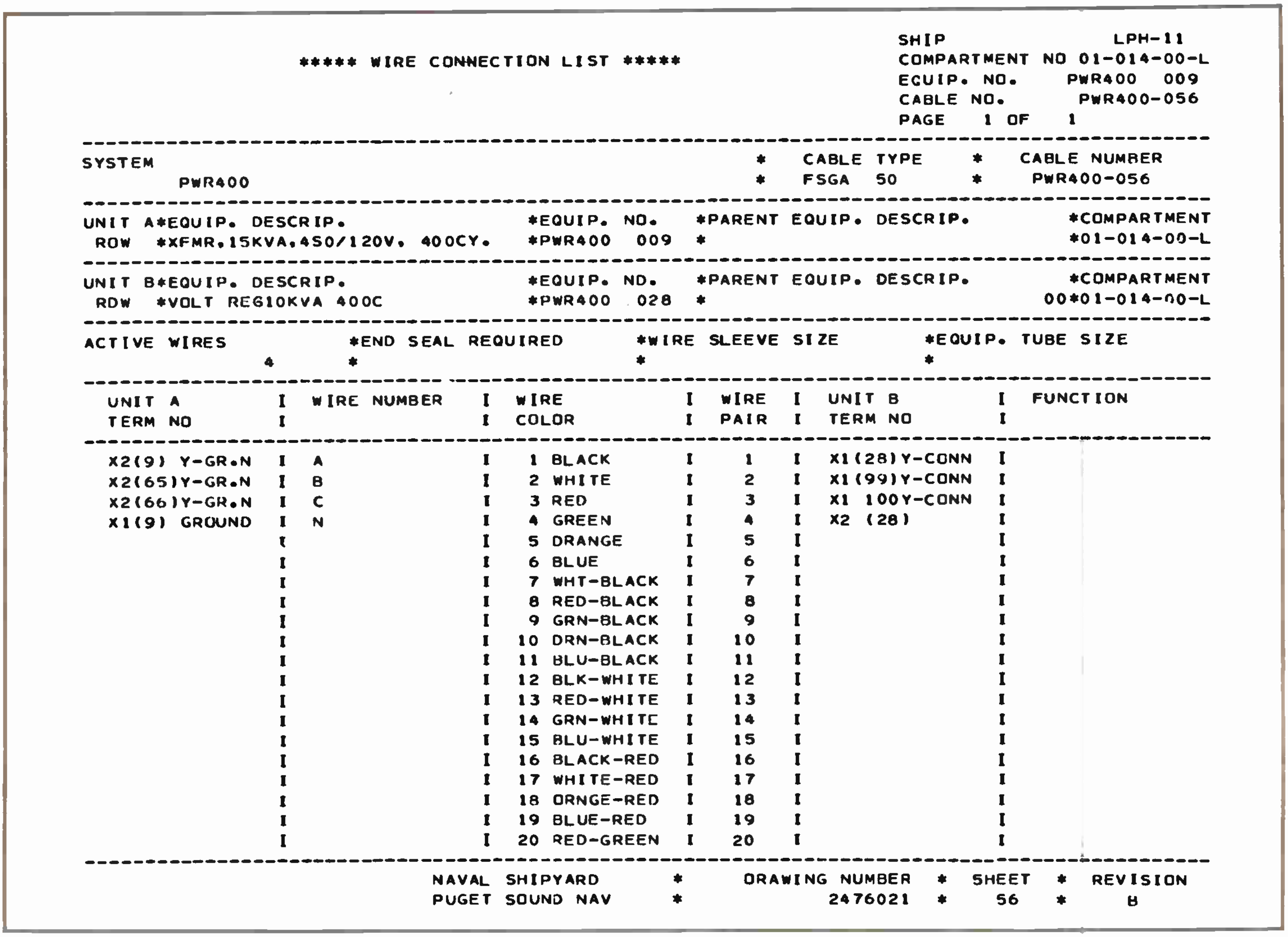
A job-shop system need not start on as large a scale as the Automated Cabling/Wiring system. Some have been concentrated principally on retrieval of previously prepared drawings on the basis of a number of descriptions such as key words, shop orders, and the usual drawing numbers. The important thing is that the potential for a broader system be considered when the files are created and that expansion capability be incorporated.

Other Areas

The potential for automating engineering information systems is a relatively recent development, and, while the examples discussed in this article provide significant cost improvements, they are pioneering efforts. Standardization probably will be extended into presently unstructured product designs, thereby broadening the base of products for which the automation of engineering information flow is economically justifiable.

Moreover, future extensions beyond the domain of engineering are expected to go beyond manufacturing into financial areas such as receivables, payables, and cash flow. The flow of engineering information may well provide the base for management systems of the future.

Westinghouse ENGINEER **March 1970**



4—Wire Connection List is one of the outputs of the Automated Cabling/Wiring information system that is oriented toward the production department of the shipyard. Electrical-shop mechanics use it aboard ship to connect cables to the correct equipment terminals.

```
                                                                    SHIP                LPH-11
                  ***** WIRE CONNECTION LIST *****                  COMPARTMENT NO 01-014-00-L
                                                                    ECUIP. NO.     PWR400   009
                                                                    CABLE NO.       PWR400-056
                                                                    PAGE    1 OF    1
-----------------------------------------------------------------------------------------------
SYSTEM                                                  *    CABLE TYPE    *    CABLE NUMBER
      PWR400                                            *    FSGA   50     *     PWR400-056
-----------------------------------------------------------------------------------------------
UNIT A*EQUIP. DESCRIP.                 *EQUIP. NO.   *PARENT EQUIP. DESCRIP.        *COMPARTMENT
 ROW  *XFMR.15KVA.450/120V. 400CY.     *PWR400  009  *                              *01-014-00-L
-----------------------------------------------------------------------------------------------
UNIT B*EQUIP. DESCRIP.                 *EQUIP. ND.   *PARENT EQUIP. DESCRIP.        *COMPARTMENT
 RDW  *VOLT REG10KVA 400C              *PWR400  028  *                            00*01-014-00-L
-----------------------------------------------------------------------------------------------
ACTIVE WIRES             *END SEAL REQUIRED      *WIRE SLEEVE SIZE        *EQUIP. TUBE SIZE
           4             *                       *                        *
-----------------------------------------------------------------------------------------------
  UNIT A        I  WIRE NUMBER   I  WIRE          I  WIRE  I  UNIT B         I   FUNCTION
  TERM NO       I                I  COLOR         I  PAIR  I  TERM NO        I
-----------------------------------------------------------------------------------------------
  X2(9) Y-GR.N  I  A             I   1 BLACK      I   1    I  X1(28)Y-CONN   I
  X2(65)Y-GR.N  I  B             I   2 WHITE      I   2    I  X1(99)Y-CONN   I
  X2(66)Y-GR.N  I  C             I   3 RED        I   3    I  X1 100Y-CONN   I
  X1(9) GROUND  I  N             I   4 GREEN      I   4    I  X2 (28)        I
                I                I   5 DRANGE     I   5    I                 I
                I                I   6 BLUE       I   6    I                 I
                I                I   7 WHT-BLACK  I   7    I                 I
                I                I   8 RED-BLACK  I   8    I                 I
                I                I   9 GRN-BLACK  I   9    I                 I
                I                I  10 DRN-BLACK  I  10    I                 I
                I                I  11 BLU-BLACK  I  11    I                 I
                I                I  12 BLK-WHITE  I  12    I                 I
                I                I  13 RED-WHITE  I  13    I                 I
                I                I  14 GRN-WHITE  I  14    I                 I
                I                I  15 BLU-WHITE  I  15    I                 I
                I                I  16 BLACK-RED  I  16    I                 I
                I                I  17 WHITE-RED  I  17    I                 I
                I                I  18 ORNGE-RED  I  18    I                 I
                I                I  19 BLUE-RED   I  19    I                 I
                I                I  20 RED-GREEN  I  20    I                 I
-----------------------------------------------------------------------------------------------
                              NAVAL SHIPYARD      *    DRAWING NUMBER  *  SHEET  *  REVISION
                              PUGET SOUND NAV     *           2476021  *   56    *     B
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Bay Area Transit System Will Have Automated Central Control

Thomas R. Gibson

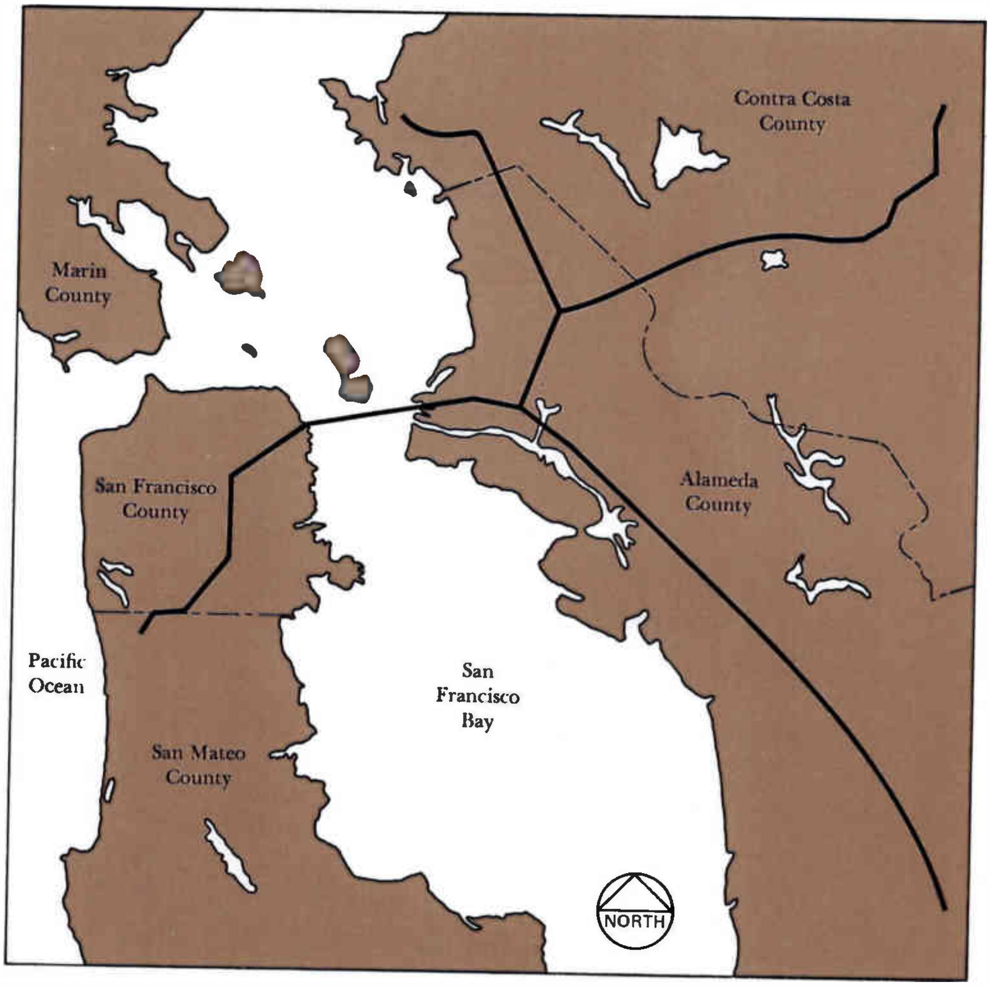
Trains on the new rapid-transit system will operate automatically at speeds up to 80 miles an hour for fast, safe, and efficient service.

The rapid-transit system of the Bay Area Rapid Transit District (BART), now being built in the San Francisco area, is the first completely new metropolitan rail transit installation in the nation in 60 years and the first in the world to be completely automated. It is a regional rapid transit network built as an integral part of the total transportation facilities of the San Francisco Bay Area, serving San Francisco, Alameda, and Contra Costa counties (Fig. 1).

The system will include 23 route miles of underground and underwater construction, 25 route miles of aerial construction, and 27 route miles at grade: a total of 75 miles, double track. Thirty-four passenger stations will be located at major points of passenger origin and destination.

A computerized control system will be used to maintain train schedules, or, if that is not possible, to maintain proper spacing between trains and thereby minimize passenger waiting. During peak rush hours, trains will be operated on as little as 90-second headways through the Oakland "Y" area (MacArthur to 12th Street). Trains will be operated at speeds approaching 80 mph along some parts of the track. The system includes a central control complex, located in the BART headquarters building at the Lake Merritt station near downtown Oakland, and secondary "local" control units at the passenger stations and train yards.

The local control units are used for control of the "vital" functions of the transit system (those functions associated with protective spacing of trains, overspeed prevention, and switch locking), while the central computer system is used for the "nonvital" functions such as system optimization. The vital functions of the local system cannot be overridden by the central computer, but some nonvital



1—The BART system will serve three counties in the San Francisco area. Its central control computer complex will be located in Oakland at one of the stations.

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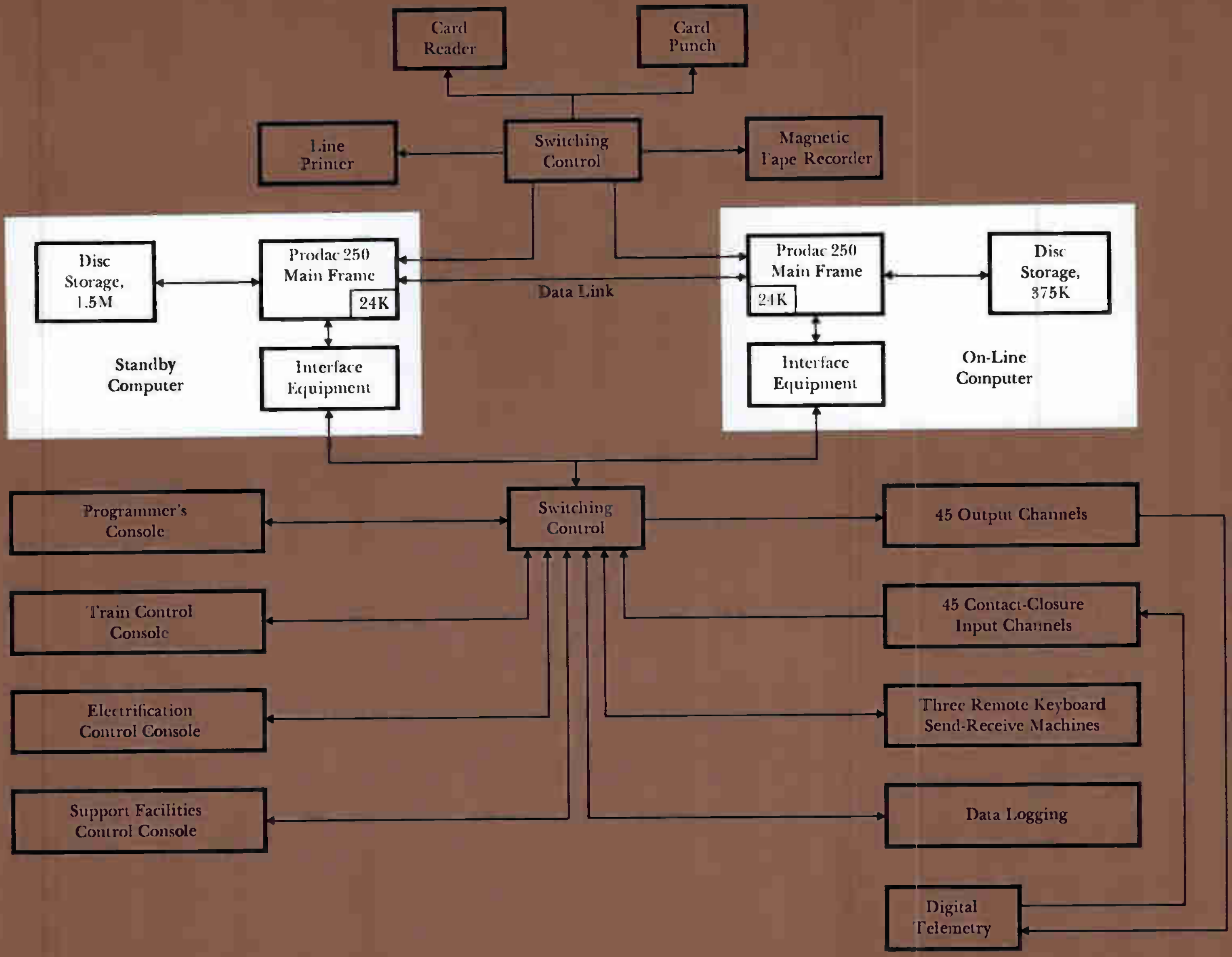


2—The central control complex includes two Prodac 250 industrial control computers. One is an on-line unit that supervises the scheduling and monitors the operation of the system; the other is a standby unit that will take over automatically if trouble develops in the on-line system. The standby unit also can simulate the BART system for experiments with system operation and for training operators without involving actual operations.

functions also performed by the local system (such as station dwell time) will normally be overridden by the central computer in the process of optimization.

Westinghouse is providing the central and local control systems, including communications equipment and installation, under a prime contract with BART. It is also providing the vehicle propulsion equipment for the cars under a subcontract to the car builder, Rohr Corporation. The first 10 cars are expected to start test runs this fall, and revenue service is scheduled for part of the East Bay leg by late 1971.

Central Control

The central control complex consists of two Westinghouse Prodac 250 computers and associated peripheral equipment (Fig. 2). One of the computers (the on-line unit) will supervise the scheduling and monitor the operation of the system, while the second computer (the standby unit) will provide complete emergency back-up for the on-line unit as well as simulation of the system for off-line experimentation and for operator training. The standby computer is constantly informed of system status.

Information about the status of the transit system, electrification status, and support facilities status, as well as train operation data, will be provided to the central computers by 45 independent digital telemetry channels. The telemetry equipment operates at 1200 bits per second, allowing scanning of each telemetry point on the system at least once every half second.

Guided by the operating schedules, the computer will check for correct train makeup and determine departure times from yards and stations. It will use various performance adjustments and other corrective strategies to maintain a high standard of service throughout the system. Some of the corrective strategies are: adjust station dwell time, revise dispatch schedule, distribute the intervals between trains, and control the sequence of trains through a single-track area when one track is out of service.

Other functions of the computer system are to log and display train performance on request, log and display the train schedules on request, log accumulated car miles and operating hours, control operation of fans, vents, electrification breakers, pumps, and so on from operator inputs, alarm and log malfunctions and log operator actions in response, and operate the central display boards that show system status.

The display board that shows train operations is associated with a train control console (Fig. 3). The board is normally not illuminated; however, the console operator (equivalent to a train dispatcher) can display any one or combination of the five lines (Southern Alameda, Downtown Oakland, San Francisco, Concord, Richmond) or any specific interlocking or combination of interlockings. An operator command directed to a specific interlocking illuminates the addressed section, as does an alarm condition coming in from the field. A white-illuminated track section indicates nonoccupancy, while red indicates occupancy. In general, the track zones represented are functional zones rather than geographic distances: that is, station zones, interlocking zones, interlocking approach zones, and turnback zones.

In addition to manual train control functions, the console operator controls the voice communications equipment for talking to the trains via radio or for making announcements at passenger stations.

Another console is used to control support facilities, which are mostly located in the underground portions of the system and consist of such things as ventilation dampers, fans, and water pumps. A display board in front of the console shows the status of the facilities (Fig. 4). Also shown on the board is the occupancy of each 1000-foot section of the trans-bay tube and such alarm functions as station trouble, fire, and communications failure. Emergency telephones also are answered at this console. The telephones are located frequently through the underground sections, in station agents' booths, and at yards.

A third console and display board serve the system electrification facilities. They correspond to the conventional power-controller or power-dispatcher po-

Glossary

This glossary defines terms used in this article and in the following one.

Control Location (*CL*). A location at which trains are in communication with the central control computer.

Convergence. A place where two lines merge into one.

Critical Point (*CP*). A control location at which it is especially desirable for trains to be on time; i.e., origins, destinations, some intermediate stations, and converging routes.

Dispatch Time. The time at which a train is to be put into revenue service from a terminal zone or a transfer track.

Divergence. A place where a line diverges into two lines.

Dwell Time. The period from the time a train stops at a station until it resumes moving.

Headway. The time separation between two trains traveling in the same direction on the same track.

Identification Point. A point where trains are identified as they arrive or pass.

Interlocking. An arrangement of apparatus controlling switches, signals, and train movements, so interconnected that functions must succeed each other in proper sequence. It permits train movements over controlled routes only if conditions are safe.

Line. A subsystem of the entire transit system.

Offset. The constant by which every train schedule has been displaced in time to stabilize the system.

Performance Index (*PI*). The measure of how close a train adheres to its theoretical schedule.

Performance Level (*PL*). Desired percentage of maximum allowable train speed.

Rapid Transit. Mass transit employing grade separation and private right of way.

Route. A specified succession of contiguous zones over which trains operate between two gates that are capable of stopping the trains.

Train Control. A system for automatically controlling train movement, enforcing train safety, and directing train operations.

Turn-Around Time. The time between a train's arrival in one direction and its departure in the opposite direction.

Turnback. An interlocked zone within which the prescribed direction of running can be reversed while the zone is occupied by a train.

sition in an electric-utility or electric-railroad facility.

The computer room is immediately behind the display boards. All manual controls to train-control, electrification, and support facilities are routed through the computer, where the keyboard inputs from the consoles are converted into the proper data words and passed to the data transmission system. Likewise, all incoming data from the data transmission system is routed through the computer, where it is analyzed and appropriate action taken (as changing a track section from white to red to indicate occupancy).

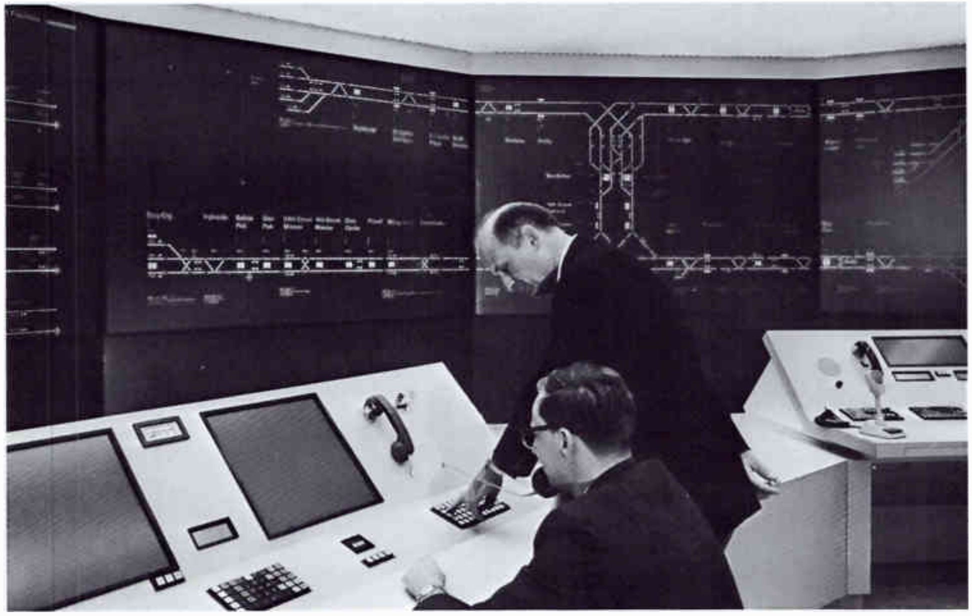
Much of the data processed through the computer is, of course, not associated with manual commands or display functions. For example, routing can be handled automatically on the basis of schedule information, automatic car identification data from trains departing yards is coupled to train identification numbers and used to maintain records of car miles and hours, and power consumption can be analyzed on the basis of data brought in from remote sensors.

The core memory in each of the computer main frames has a nominal capacity of 24,000 words. In addition, the on-line and standby units have word discs for bulk storage of nominal 375,000- and 1,500,000-word capacity respectively. Some additional work, such as train-control system simulation, is done solely in the standby unit, which is the reason for its larger disc.

The system simulation capability will be used to determine how the system would operate under a contemplated change, enabling BART officials to weigh alternative operating modes without tampering with actual train operation. It also will simulate system disruptions for operator training purposes.

A high degree of reliability has been built into the BART control system by inclusion of the back-up computer at central and the local control facilities at each station and yard. Moreover, battery-operated inverters supply power to all essential operating equipment to provide control and monitoring capabilities in event of power failure.

3—The central control complex includes this room with display panels and control consoles for system electrification, support facilities, and train control. The train control console shown here provides for manual control input, and it also enables the operator to display train operations at the console and on the display board in the background (which shows the entire track system, though not to scale). The panel in the upper left part of the console is for malfunction alarms. The cathode-ray-tube display unit in the center of the console has a keyboard used to request various data displays and to input minor program changes, such as a change in nominal dwell time at a passenger station. To the right of the console is a typewriter for printing a hard copy of any desired cathode-ray-tube display; to the left is another typewriter for logging alarms associated with train control.



4—Support facilities console and display board enable another operator to control those facilities and show their status. The panel at left on the console displays any malfunction alarms. The one to the right of it is the screen of a rear-projection slide projector. BART intends to reduce facilities drawings to slides and store the slides in the projector unit for easy access when they are needed.

System Modeling and Simulation Help Develop and Test the Logic for BART Train Control Strategies

Albert F. Harsch

Computer modeling and simulation of the Bay Area Rapid Transit (BART) network and its control system were powerful aids in developing and testing the system's control strategy logic. They made it possible to determine the effects of various corrective control adjustments long before the adjustments could actually be tried on the BART system, and even before the logic could be programmed on the control computer. Similar simulations can be used in other applications.

Among the major problems in design and construction of a new high-speed rapid transit system such as BART are the devising of a track and roadbed system for safe and relatively quiet operation, a fail-safe train protection system, a reliable automatic train operation system, and reliable digital telemetry. Then comes the operating problem of generating the daily train schedules that will minimize total cost while satisfying required service standards.

Train schedules are implemented in the BART system by automatic controls that include a central computer for efficient train operation. The main control problem is devising control strategies, which are the various operating decisions that will maintain normal service (or minimize delays) while satisfying the system's standards of passenger comfort and convenience.

To develop and test the control strategy logic for the BART system, the Westinghouse Information Systems Laboratory (now the Tele-Computer Systems Corporation) wrote a rapid-transit simulation program for a large digital computer (CDC 6600). The simulation is based on the BART system in that the computer is used only for monitoring what the system is doing and for controlling it to optimize passenger satisfaction and convenience. The independent block signal control system used to prevent trains from getting too close to each other and the redundant local controllers at passenger stations were not simulated because they are not part of the computer optimization and control.

The simulation proved to be a practically indispensable tool in analyzing the BART system and in formulating and testing the control strategy logic. Even for the so-called simple control adjustments of changing performance level and dwell time, pitfalls were encountered that otherwise would have shown up much later when changes would have been difficult or even impossible. Much valuable information was gained as to how the system will operate.

Digital simulation should be used to analyze and test even simple control adjustments for rapid-transit systems of any magnitude and complexity. Similar simulation techniques can be used in other applications, such as conveyor belt systems, assembly lines, pipelines, baggage handling, and possibly even a system of air traffic corridors.

BART Control Concepts

Trains will be in communication with the central control computer by data link only in the vicinity of passenger stations and interlockings, since those are the locations at which control strategies are applied (Fig. 1). Input/output devices communicate to the computer the following data: identification number of trains at identification points, which are located at ingress and egress points of a route; presence of a train (without identification) at a station or interlocking; train with its doors open; and departure of a train from a station. The computer communicates a corrective speed command to a train departing a station and also hold and release signals to override local programming devices, which otherwise cause trains to dwell for a predetermined interval.

The control strategy logic makes use of two schedules. One is the *theoretical* schedule calculated from the current system operating schedule (supplied by BART personnel) plus or minus any system offset. The other is the *modified* schedule, which starts out being the same as the theoretical schedule. However, whenever an event occurs (i.e., a train arriving at or departing from a control location), the actual event time is placed in the modified schedule for that train, and predicted times of future events replace the scheduled times in the modified schedule. Moreover, if the control strategy logic determines that a train must do such things as slow down, speed up, or run through a station, the appropriate event times are altered in the modified schedule so that the logic will take those actions.

Since the theoretical train schedules will be designed to optimize passenger flow, performance of the system is judged by measuring total error between the actual event times and the theoretical-schedule times. (BART will specify each train's dispatch time, route, and scheduled arrival times at critical points between origin and destination on each trip.) Corrective strategies endeavor to keep trains on time at critical points while allowing some latitude at other points. If that is not possible, the next objective is to try to keep the correct train sequence. If neither strategy is practical, then, although nothing more can be done at that critical point, the strategies try to remedy the situation by the time the train reaches the following critical point.

The measure of how close a *train* comes to its theoretical schedule is performance index (PI). For example, if a train is dispatched a few minutes late according to its theoretical schedule, since its target is the theoretical schedule it has a bad PI on dispatch and at all subsequent points until it gets back on schedule. Only if a new theoretical schedule is generated or the one in effect is modified (such as offsetting it) is it possible to avoid these bad PI values for a late-dispatched train.

System performance is measured by computing every *t* minutes:

$$\begin{aligned} \textit{Error} = {} & A \times (\textit{average PI of all trains in revenue service}) \\ & + B \times (\textit{deviation of all PI's about average PI}) \\ & + C \times (\textit{rate of change of average PI}), \end{aligned}$$

where *t* ranges from two minutes on peak to say five minutes off peak, *A*, *B*, and *C*

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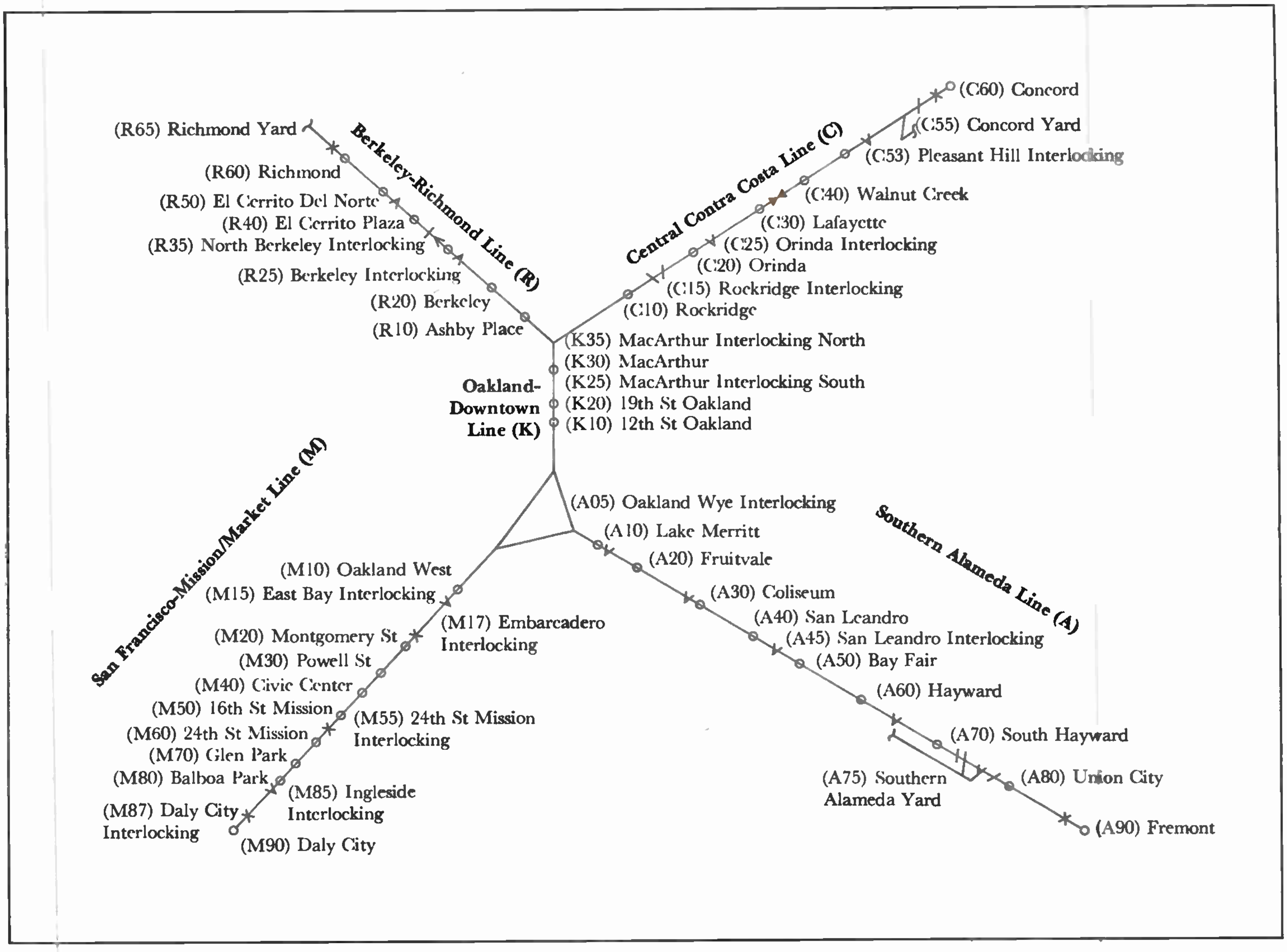
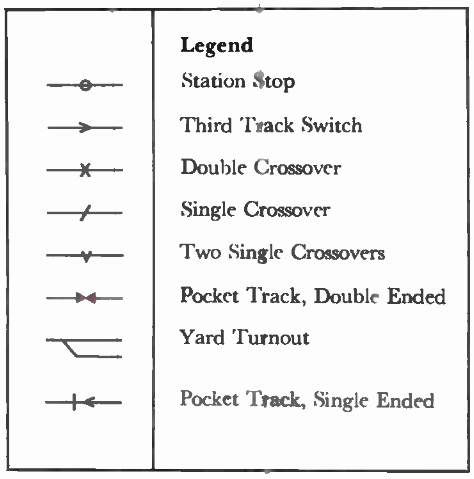


1—Bay Area Rapid Transit system has five lines under central automatic train control, operating through San Francisco County and the adjoining Alameda and Contra Costa Counties. Control locations (points where trains are in communication with the central control computer) are designated by a letter and two digits. The letter indicates the line, and the digits specify the location. Control adjustments can be made at those control locations whose last digit is a zero. (To simplify the figure, some control locations are omitted.)



are weighting factors that vary between peak and off-peak hours, and the rate of change is positive if the average PI has increased since it was last computed *t* minutes earlier. *Error* drops if the entire system schedules are offset, because the train PI's instantly improve when each train on the system finds itself closer to its new target.

It follows that there are basically two types of strategies the control computer can apply:

1) Strategies to reduce PI and maintain correct sequence for individual trains, such as delaying or speeding up trains relative to their schedule, distributing headways ahead of or behind a delayed train, revising sequence at interlockings, and running through stations without stopping.

2) Strategies to reduce error for the entire system, such as offsetting system theoretical schedules, offsetting theoretical schedules of trains in one section only, removing faulty trains from the system, and revising train destinations.

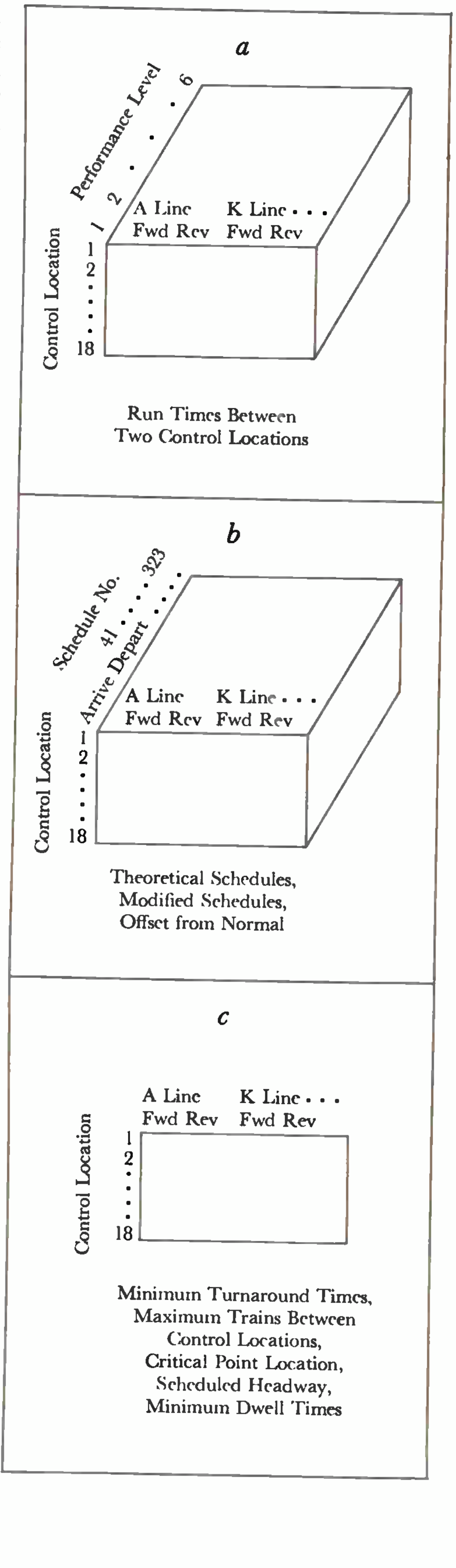
While system strategies are reviewed every *t* minutes, train strategies are selected every time a train arrives at or departs from a control location.

The control strategy logic has the task of determining which corrective strategy will result in the least unfavorable consequences. The least unfavorable consequences were defined to mean that a uniform gap (time between a train departing a station and the following train arriving at the station) is more important than the theoretical-schedule arrival and departure times. This means possibly slowing trains ahead of or behind a delayed train to make the gaps more uniform. To bring the system back to the theoretical schedule, all trains are dispatched from the turnback at the theoretical-schedule dispatch time if possible. That probably will not be possible during rush hours, but on medium-peak and off-peak hours it will enable the system to get back to the theoretical schedule.

The first part of the control strategy logic ("run train to schedule") essentially applies train strategies—trying to maintain the modified schedule and the proper sequence by reducing PI's through adjustment of performance level and station dwell time. In addition, it checks the dispatch time of a train coming into a turnback and revises it if necessary. Under normal operating conditions with small random variations, this part of the control strategy logic maintains the modified schedule.

The second part of the control strategy logic ("modify train schedules") essentially computes a performance index for each train in the system and, with it, changes the modified and theoretical schedules (if necessary) to apply system strategies that reduce *error*. Provided the schedules are realistic and the trains do not malfunction, this second part of the logic does not find it necessary to apply any further strategies. When something abnormal occurs, however (such as a car door sticking open in a station), it uses decision-table logic to apply more drastic train strategies.

The additional train strategies are applied by decision tables because the complex interrelationships between the operation of any one train on the transit system and the positions, performances, and abnormalities of the other trains make it difficult to draw conventional flow charts that take into account all possible conditions. The use of decision tables makes it possible to change the control logic without upsetting the main control program.



Run Times Between
Two Control Locations

Theoretical Schedules,
Modified Schedules,
Offset from Normal

Minimum Turnaround Times,
Maximum Trains Between
Control Locations,
Critical Point Location,
Scheduled Headway,
Minimum Dwell Times

2—Tables of this type were set up in computer memory to constitute a "model" of the BART system; that is, a representation of the system for developing and testing control strategies without committing the actual system for such development. (*a*) A three-dimensional table sets up run times for each of six performance levels for a train running between any two control locations on each of the five lines in either direction. (*b*) Theoretical and modified schedules also are three-dimensional, giving arrival and departure times for all trains in revenue service on any line in either direction. ("Schedule No." identifies the serial number of any train in revenue service.) The *Offset* table allows the program user to put in a time disturbance anywhere in the system for testing the more drastic corrective strategies. (*c*) These tables establish various system conditions at any control location for any line in either direction.

Table I. List of Critical Points

CP Number	CL Name	Performance Control*	Type**	Previous CP	Next CP
1	K35-R	1	0	2	3
2	K35-F	1	1	4	1
3	K05-R (A05-F)	1	2	5	2
4	A05-R	1	2	1	6
5	A75-R	1	0	6	4
6	A75-F	1	1	3	5

*1 = No, 0 = Yes.

**0 = start of a line, 1 = turnback, 2 = end of a line.

Table II. Schedule of Train Arrivals at Each Critical Point (at start of simulation—130700 hours)

Train ID	In Rev Service	Next Six Critical Point Numbers and Theoretical Schedule Times					
		1st	2nd	3rd	4th	5th	6th
41	Yes	6 132353	5 132500	4 134343	2 134853	1 135100	3 135400
169	Yes	3 131010	6 132853	5 133000	4 134843	2 135343	1 135800
323	No	1 131000	3 131510	6 133353	5 135200	4 135200	2 135700

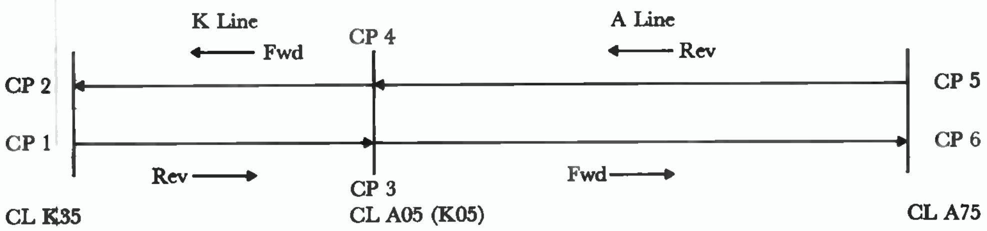
Table III. Latest Particulars of All Trains in Revenue Service

Train ID	Last CP		Next CP Predicted Time	Last PI	Last CL
	Number	Actual Time			
41	3	130510	132353	0	A60-F
169	1	130500	131010	0	K25-R

Table IV. Current Train Performance Indices During Last Four System Error Computations

Train ID	PI Values at Time*			
	T	T-t	T-2t	T-3t
41	0	0	0	0
169	0	0	0	0

*T is last time, t is interval between computations.



3—Simplified two-line system was used for the first of the simulation programs that "operated" the system model and permitted development and testing of control strategy logic. It consists of the double-track *A* and *K* lines shown in Fig. 1. Control locations (CL) are numbered the same as in Fig. 1, but only the ones that are critical points (CP) are included. *CP 3* (and *CP 4*, which is the same point except that it refers to trains going in the opposite direction) is designated as *CL A05* (*K05*) because, for the model, it was necessary to define a control location *K05* (and also *M05*) that is the same location as *A05* in Fig. 1. Tables I through IV describe train operations on the simplified system.

Trains run to the modified schedule, then, while train performance is based on the theoretical schedule. However, if a train is to be slowed or otherwise disturbed not due to its own fault, the theoretical schedule is changed along with the modified schedule in order not to give that train a bad performance index. A train is considered at fault for its delay if the reason is something that happens to it, such as a door being held open by a passenger or an obstruction on the track; it is considered not at fault if the delay results from something that did not happen to it, as when the train is slowed to reduce or extend the gap between it and a delayed train. The distinction prevents irrelevent performance figures from clouding the diagnostic information in each train's performance record.

System Model and Simulation

Modeling of the BART system for the purpose of determining the control strategies needed to achieve the desired service was not elaborate or mathematical. The central control computer obtains information about the system from only 59 control locations in the system (Fig. 1). Of these, performance adjustments can be applied at only 33 locations—those with a zero as the last digit of the code name. The central control computer has no control of the system other than at those discrete locations and no knowledge of what is going on between them. This is analogous to a series of batch processes where calculations and adjustments are made at the start of each process (i.e., leaving a station zone) to obtain the correct result at the end of that process (i.e., arriving at the next station zone).

To make matters simpler, a train is assumed to cover the distance from one of the control locations to another in only one of six nominal run times (the "performance level") and to dwell at stations only in increments of one second. Thus, the model of the BART system for the purpose of determining control strategies was essentially a tabular representation of the system at the control locations and the associated logic to set up and use those tables.

The simulation program used is an event-oriented simulation that runs faster than real time because events are allowed to happen as fast as possible. It is made up of four distinct parts:

1) Setting up the model. In essence, this part reads in the system data and sets up the tabular representation of the system at the control locations as shown in Fig. 2.

2) Initializing the model to establish a starting point for the simulation.

3) Sequence of events. This is the heart of the event-based simulation program, which features a new approach on how to specify what events occur. Instead of reading in a stack of cards containing each event in the order of occurrence, an offset-from-normal table is read into the computer. The logic is such that an event occurs as predicted (plus a random variation) unless there is an offset associated with that train at that control location, which makes the event occur earlier or later than normal.

4) Control strategy logic. This consists of two parts corresponding to "run train to schedule" and "modify train schedules" as described earlier. The latter was the main reason for the simulation. It is the experimental part employing decision-table logic that was tested to devise the proper operational strategies to minimize delays when performance level adjustments and dwell time changes alone could not maintain the schedule.

The first portion of the "modify train schedules" part of the control strategy logic sets up tables such as the simplified ones included here for illustrative purposes as Tables I through IV. (These tables go with the system shown in Fig. 3.)

Table I lists those control locations (CL's) that are to be considered critical points (CP's) during the simulation. Six critical points were chosen, but more could have been used. A train must enter or leave revenue service at a critical point. Table I also lists control location names (with "R" and "F" being the arbitrary reverse and forward directions of train movement), whether or not performance can be adjusted at the critical point, what kind of point it is, and the previous and next critical points.

The remaining tables show entries at the beginning of a test simulation run at 130700 hours (1:07 p.m.). Train 41 was traveling in the forward direction on the *A* line, train 169 was traveling in the reverse direction on the *K* line, and train 323 was waiting to enter revenue service at *CP 1*. Table II gives train arrival times at the next six critical points for trains in revenue service or going into revenue service. Table III gives latest particulars on all trains in revenue service, such as actual arrival time at last critical point, predicted arrival time at next critical point, and latest performance index. Table IV gives the last four performance indices of trains during the periodic system error computations.

The tables are updated whenever a train arrives at a control location, which

Table V. Sample Decision-Table Logic

Rules	*Conditions*						*Actions*[1]
	Where event occurred[2]	*Is train approaching CP at ≤ minimum tolerance?*	*Will first-come-first-served give correct sequence?*	*Will behind train be delayed?*	*Train performance index*[3]	*Can ahead trains be slowed?*	
1	0	Yes	Yes	Yes			2
2	0	Yes	Yes	No			0
3	0	Yes	No				3
4	0	No		Yes			2
5	0	No		No			0
6	1			Yes			2
7	1			No			0
8	2				0		0
9	2				1		0
10	2			Yes	2		2
11	2			No	2		0
12	2			Yes	3		2
13	2			No	3		0
14	2				4	Yes	1
15	2				4	No	4

[1] Action 0, continue with existing schedule; 1, revise schedules ahead of delayed train to reduce extended gap; 2, revise schedules behind delayed train to extend reduced gap; 3, recommend revised sequence at interlocking; 4, recommend station run-through.

[2] State 0, between a station and a merge; 1, between a station and a CP that is not a merge; 2, at least one station before a CP.

[3] State 0, <10 seconds late; 1, 10 to 30 seconds late; 2, 30 to 60 seconds late; 3, 60 to 120 seconds late; 4, >120 seconds late.

makes it possible for the program to take an overall view of the system. With the entire multiline system simulated, the tables played a very important role in sequencing, assigning trains to scheduled runs, and revising destinations.

Whenever an event occurs in the main simulation, full particulars of the type of event, the control location, and the number of seconds between the train's actual event time and the event time in the theoretical schedule are sent to the "modify train schedules" part of the program. From this information and the information stored in Tables I through IV, the programmed logic generates a keyword (identifying the conditions on the system).

The keyword matches a rule that links the actions and conditions in the decision table. That table may comprise several hundred rules; a simplified version is shown in Table V to illustrate the form used. It is simply a tabular list of logical relationships consisting of conditions, actions, and rules. Conditions are all the variables that influence any decision, actions are the things to be done once a decision has been made, and rules link the actions and conditions by showing the states of each variable that have to be satisfied for any decision. The action to be taken following a match between a keyword and a rule might vary from a simple confirmation that the latest schedule is satisfactory to some of the more involved strategies listed in the system specifications.

Table VI. Random Variations Used in Simulation Runs

	Magnitude of Delay (%)	Frequency of Occurrence (%)
Set 1	0	64
	5	8
	10	7
	15	6
	20	5
	25	4
	30	3
	35	2
	40	1
		100
Set 2	0	84
	2	4
	5	3
	7	3
	10	2
	12	2
	15	1
	17	1
	20	0
		100
Set 3	0	100
Set 4	50	100
Set 5	75	100

Using the Simulation Program

The first step was to set up the simple two-line system (Fig. 3), with only a few entries in the decision table. The disturbances included in the input data contained the most probable number of time delays of each magnitude (Table VI). On the initial runs, the maximum delays were limited to approximately half the average headway time.

Since the initial decision table had only a few entries, the program first tried the simple strategy of running to the modified schedule whenever there was no specific match in the decision table. Error was computed every two minutes, and, so long as it was not excessive, the strategy was satisfactory. A subroutine then converted the large number of unmatched keywords generated during the simulation into a smaller number of rules, which were added to the decision table. This procedure was repeated with a higher maximum delay limit until error became excessive. Additional simulations were then run so that another strategy would be applied to any event having an unmatched keyword.

The next set of rules introduced into the decision table were those to distribute headways, and they were effective in reducing the previously excessive error. As delays and other system abnormalities were increased, more advanced strategies were tried and the decision table was gradually built up to encompass all likely eventualities.

While the simulation runs were being made, the control strategy logic for running trains to schedule by using performance level adjustment and dwell time changes were tested under the various operating conditions. Changes had to be made because of certain pitfalls and limitations encountered with this part of the logic, such as in determining station dwell time for an arriving train and its planned performance level when it leaves the station.

One of the features of the simulation program is provision for a number of different random variations as disturbances to the system. That feature provided more realistic description of the real BART system than would a simulation that allowed trains to arrive at and depart from control locations as predicted by the control strategy logic.

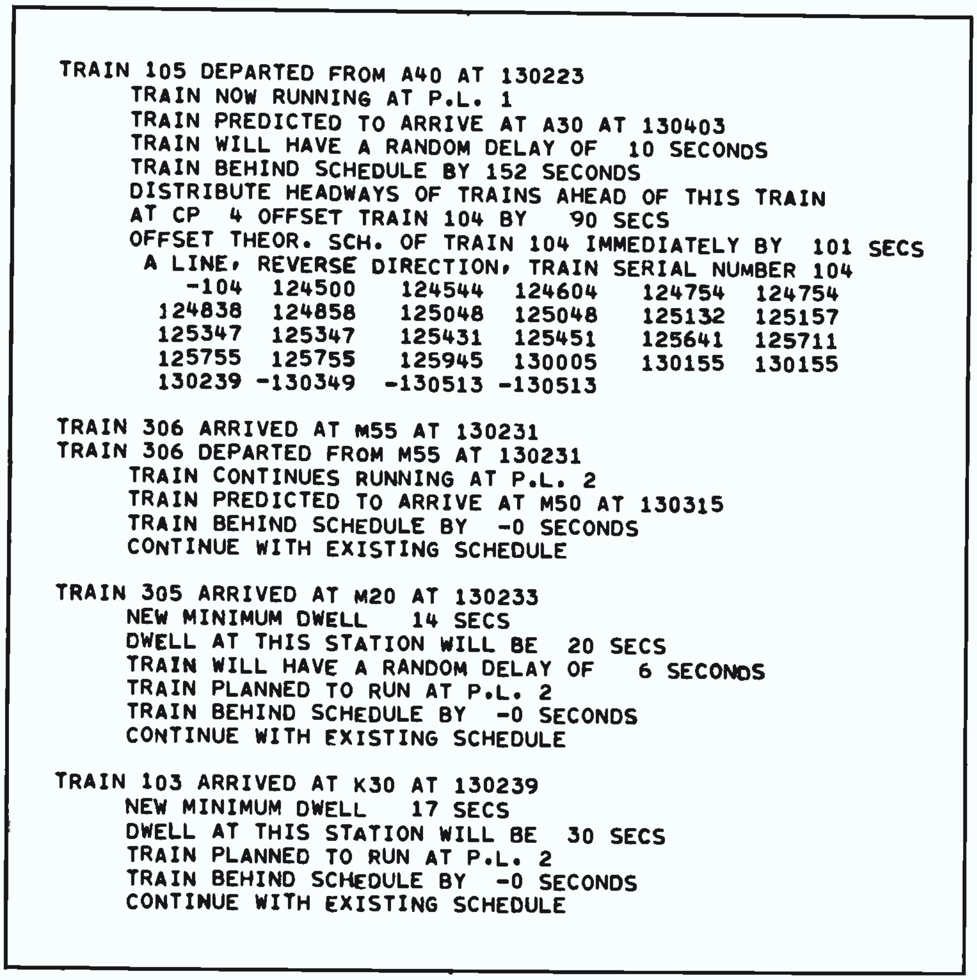
Essentially all of the simulation runs were made with the five sets of random variations shown in Table VI. With the Set 1 random variations, once a train was slowed down or delayed it never caught up. The reason is that the schedules used in the simulation were based on normal run times, which were minimum run times plus 10 percent, while Set 1 random variations give a 36-percent chance of a delay occuring and a weighted average delay of 22.5 percent. The combination, in effect, gives an average delay of approximately 8 percent for every event. With only a 10-percent margin in run times to catch up and increased minimum dwell times, the train never had a chance to get back to the theoretical schedule before it reached the turnback. If magnitude and frequency of random variations in the real-life BART system are on the order of Set 1 random variations, and if the schedules are based on the normal run times, a train that has an abnormal delay will never get to its destination on time.

In most of the simulation runs, Set 2 random variations were used (half the magnitude and half the frequency of Set 1 variations). Set 3 random variations were not used much except for some comparisons, because they did not appear to describe the real-life system.

Other disturbance types were put into the system to try to simulate abnormal delays. Such disturbances consisted of choosing 30-second or 150-second delays for certain trains departing from certain stations. This allowed us to determine what the best rule in the decision table would be if abnormal conditions occur. Other disturbances such as the Set 4 and Set 5 random variations in Table VI were used to determine the effect of offsetting the entire system in time.

Most of the simulation runs were made with 5-minute and 2½-minute headways on the simplified two-line system, and at 5-minute headways with a more complex three-line system. These runs gave us all the necessary interactions between trains in revenue service. Runs were carried out for 25-minute periods of simulated time, with trains dispatched from turnbacks at approximately 5-minute intervals.

An example of printout from a simulation run for the three-line system is shown in Fig. 4. It shows that train 105 departed at performance level 1 from station A40 152 seconds behind schedule, and it gives a predicted arrival time at the next station. It informs the simulation user that random variations will cause the train to arrive 10 seconds later than predicted. (That information is not available to the control strategy logic until the simulation actually causes the train to arrive late; it is printed out only to help the user see what is going on.)



```
TRAIN 105 DEPARTED FROM A40 AT 130223
     TRAIN NOW RUNNING AT P.L. 1
     TRAIN PREDICTED TO ARRIVE AT A30 AT 130403
     TRAIN WILL HAVE A RANDOM DELAY OF  10 SECONDS
     TRAIN BEHIND SCHEDULE BY 152 SECONDS
     DISTRIBUTE HEADWAYS OF TRAINS AHEAD OF THIS TRAIN
     AT CP  4 OFFSET TRAIN 104 BY   90 SECS
     OFFSET THEOR. SCH. OF TRAIN 104 IMMEDIATELY BY  101 SECS
      A LINE, REVERSE DIRECTION, TRAIN SERIAL NUMBER 104
         -104  124500   124544  124604   124754  124754
       124838  124858   125048  125048   125132  125157
       125347  125347   125431  125451   125641  125711
       125755  125755   125945  130005   130155  130155
       130239 -130349  -130513 -130513

TRAIN 306 ARRIVED AT M55 AT 130231
TRAIN 306 DEPARTED FROM M55 AT 130231
     TRAIN CONTINUES RUNNING AT P.L. 2
     TRAIN PREDICTED TO ARRIVE AT M50 AT 130315
     TRAIN BEHIND SCHEDULE BY  -0 SECONDS
     CONTINUE WITH EXISTING SCHEDULE

TRAIN 305 ARRIVED AT M20 AT 130233
     NEW MINIMUM DWELL    14 SECS
     DWELL AT THIS STATION WILL BE  20 SECS
     TRAIN WILL HAVE A RANDOM DELAY OF   6 SECONDS
     TRAIN PLANNED TO RUN AT P.L. 2
     TRAIN BEHIND SCHEDULE BY  -0 SECONDS
     CONTINUE WITH EXISTING SCHEDULE

TRAIN 103 ARRIVED AT K30 AT 130239
     NEW MINIMUM DWELL    17 SECS
     DWELL AT THIS STATION WILL BE  30 SECS
     TRAIN PLANNED TO RUN AT P.L. 2
     TRAIN BEHIND SCHEDULE BY  -0 SECONDS
     CONTINUE WITH EXISTING SCHEDULE
```

4—This sample of printout from simulation of a three-line system shows what the trains were doing and what strategies were applied. Such information provided the basis for optimizing the BART train control.

The printout also shows that, at the time of departure of train 105, the control strategy logic determined that the train ahead (104) must be slowed to help pick up the increased passenger load due to a longer time than normal between trains at succeeding stations. The new schedule for train 104 is printed out.

The next event is train 306 going through control location M55 (an interlocking). Printed out is the performance level the train is running under, predicted arrival time at the next station, amount of time it is behind schedule, and what strategies were applied at this time ("continue with existing schedule"). Similarly, trains 305 and 103 arriving at stations are the next two events.

Among the things determined from these simulation runs was a minimum dwell time calculation formulated and tested because the early simulation runs showed a need for it. A method of selecting a planned performance level on station arrival and of adjusting dwell time up or down from scheduled dwell was formulated and tested because of instances where simpler methods gave inconsistent or incorrect train behavior.

The rules and method for changing headways were formulated and tested. Also, the rules and method for offsetting the entire system in time—positive when performance index is bad, and negative (or back to normal) in steps when it gets good again—were formulated and tested. Last but not least, conditions, rules, and actions for the decision table were determined from many simulation runs under various operating conditions.

Much insight was gained as to how the system will operate. The control strategy logic developed and tested with the simulation approach is being implemented with a high degree of confidence.

Technology in Progress

The diver is injecting formaldehyde into a "crown of thorns" starfish to kill it as part of an effort to control a rapidly expanding population of the creatures. The starfish eat the living outer layer of coral, causing widespread destruction of reefs.

Starfish Invasion of Pacific Reefs Confirmed by Surveys

Surveys have confirmed earlier indications that large numbers of "crown of thorns" starfish are invading and destroying coral reefs in several Pacific Ocean areas at an alarming rate. A report on the surveys states that the plague probably relates somehow to man's interference with his environment, recommends an immediate effort to bring the starfish under control, and calls for research to find specific causes for the starfish population explosion and to develop methods for reestablishing natural population controls and restoring devastated coral reefs.

The report was submitted by the Westinghouse Ocean Research Laboratory to the U.S. Department of the Interior, which had provided the Laboratory with the major funding to survey 16 islands in the U.S. Trust Territory of the Pacific. It presents the results of the project, carried out to determine the extent and severity of the starfish population explosion. The report also includes the results of a companion survey of islands in the Hawaiian and Marshall chains conducted by the University of Hawaii with funds from the National Science Foundation. Additional financial assistance to the projects was given by the Office of Naval Research, the Smithsonian Institution, and the University of Guam.

Severe infestations were found on the reefs around Guam, Saipan, Ponape, Rota, Truk, Tinian, Ant, and Kuop and abnormally large numbers around several other islands. Known scientifically as *Acanthaster planci*, the starfish has as many as 21 short arms covered with poisonous spines that have earned it the common name "crown of thorns." It normally is rare, but infested reefs are crawling with them.

A starfish herd can strip living coral polyps from an island reef at a rate of as much as half a mile a month. Since reefs are built up and maintained by material deposited by the polyps (simple forms of sea life), reef growth is arrested when the polyps are eaten, and erosion may begin. Reef fish tend to disappear with the polyps. Thus, the seafood supply, tourism possibilities, and wave protection provided by reefs, all important to islanders, are threatened as the reefs decay.

Until a better way can be found through research into starfish and coral reef biology, the report recommends killing starfish adults one by one by injecting formaldehyde. They cannot be killed simply by cutting them up, because pieces can regenerate new starfish.

The epidemic seems to be related somehow to the activities of men, since infestations usually occur near human settlements, but the cause is not clear. The report suggests two likely possibilities. First, blasting and dredging reefs may have touched off the population explosions by clearing wide areas of coral polyps, thus giving large numbers of young starfish a foothold. (Most of the very young starfish are normally eaten by coral polyps before they grow big enough to turn the tables.) The second suggestion is that shell collectors may have taken too many of the large conches called tritons. As one of the few natural predators of adult starfish, tritons normally help to keep them in check.

Weather-Sensitive Utility Loads Are Forecast Accurately

One of the principles of forecasting electric utility power loading is that if components of the total load on a system are growing at different rates, the most accurate total load forecast can be achieved by forecasting the components separately and then combining them to obtain the aggregate. Moreover, the component load forecasts are often useful themselves.

Among such loads are those that are sensitive to weather conditions. They have been predominantly air-conditioning and other forms of cooling in recent years. Because they have been growing much faster than the total load, they are becoming increasingly important in utility planning.

One of the most accurate methods introduced to date for modeling the effects of weather on power system loading has been developed by Advanced Systems Technology, Westinghouse Power Systems Planning. The method involves development of a unique model for each geographical area, utility system, or subsystem of interest. Individual models are necessary because weather influences vary with the topography, meteorology, and load makeup of the area.

The first step in generating the model is processing and reducing historical load and weather data for the area. The weather data is obtained from the U.S. Weather Bureau, normally on magnetic tape; it contains hourly measurements from one or more local weather stations of at least a dozen variables such as temperature, humidity, wind, precipitation, and cloud conditions.

The general form of the weather model is nonlinear, being a quadratic equation with exponential decay applied to certain terms. The nonlinear form allows a much more accurate model to be generated than could be obtained with a linear form; exponential decay is included to account for residual effects of previous weather.

A correlation analysis is performed between the weather variables and the historical load, and between the variables themselves. If two or more variables correlate very closely with each other, the benefit of retaining more than one of them is minimal. Therefore, variables that contribute little to the model mathematically are eliminated.

Even after discarding such variables, there are vast possibilities as to how the remaining ones might enter a general quadratic-exponential form. Selection of the most significant variables is aided by the use of a Westinghouse model that simulates buildings and their heat flow.

Once the basic form of the equation (model) and the significant variables have been selected, nonlinear multiple-regression analysis is performed to determine the proper coefficients for best accuracy. This process also extracts the basic (non-weather-sensitive) load.

Very generally, the model takes the following form:

$$DPL = B + CDF \cdot WV,$$

where DPL is daily peak load; B is basic load (which grows with time); CDF is cooling demand factor, a constant proportional to the amount of weather-sensitive equipment installed at any time (generally growing with time); and WV is the nonlinear combination of weather variables.

Once the model has been developed for a system or area, it can be used for making both long-range and short-range load forecasts. Statistical input is used for the long-range predictions of levels of annual or seasonal load peaks; more accurate short-range peak load predictions are made by using weather forecasts as input data.

Tunnel Lighting Helps Driver's Eyes Adapt to Transitions

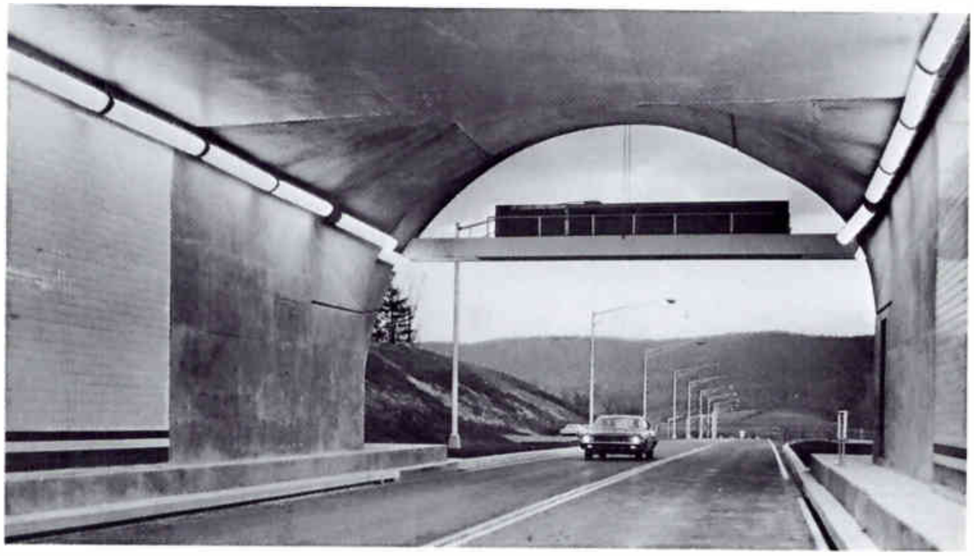
A variable lighting system used to illuminate the three new tunnels recently opened on the Pennsylvania Turnpike provides easy eye adaptation and thus eliminates the blind spots often encountered when entering or leaving a tunnel. The system is divided into four sections. In the daytime, the section closest to the entrance is brightly lit so that the eye readily adapts to the transition from bright sun to relatively darker tunnel; there is no shadowed area just inside the entrance, where other cars would be virtually invisible. The light levels then taper off in the succeeding sections.

At night, one light level is used throughout the tunnel; it is the lowest level of day lighting used. The change is made automatically at evening, or manually if clouds darken the day.

The lighting system was designed for the Pennsylvania Turnpike Commission by Michael Baker, Jr. Inc., of Rochester, Pennsylvania, in conjunction with the Westinghouse Lighting Division.

The newly designed PTC-96 fluorescent tunnel luminaire, which made the system possible, has two variations: one has a single ballast and the other two ballasts. The latter can operate combinations of fluorescent lamps independently, and the lampholder assembly in both types is designed to accept various numbers and arrangements of 1, 2, or 3 lamps. Thus, the lamps can be used in the combinations that give the desired light levels. In the Tuscarora Tunnel, for example, the four zones of light intensity in the daytime average 100, 75, 52, and 37 footcandles.

Entrance to Tuscarora Tunnel on the Pennsylvania Turnpike shows the bright illumination at the entrance that makes eye adaptation easy. Luminaires are mounted end to end to prevent the flickering effect sometimes encountered when luminaires are spaced.



TV Camera Tubes Study Universe in Ultraviolet Light

Four of the world's most-traveled television camera tubes have seen things that may well change man's ideas about the size, age, and evolving nature of the universe. The tubes were launched into earth orbit aboard the Orbiting Astronomical Observatory (OAO-II) in December 1968 by the National Aeronautics and Space Administration. Called Uvicons, they are the key element in four special telescopes that map the skies by means of ultraviolet light, which cannot penetrate the atmosphere for earthbound telescopes to see.

NASA has called OAO-II's first-year performance "exceptional." The satellite collected data on the brightness of more than 17,000 stars in each of three spectral ranges in the far ultraviolet. To do so, it took some 6000 pictures of about 2300 sky areas. (Before OAO-II, 15 years of effort with some 40 flights of sounding rockets produced roughly three hours of ultraviolet viewing of about 150 stars.)

The Uvicon tubes are an ultraviolet-sensitive version of a family of low-light-level television camera tubes known as SEC (secondary electron conduction) image tubes. They and other SEC tubes are the result of a continuing research and development program at the Westinghouse Research Laboratories and the Westinghouse Electronic Tube Division, and they were built by the latter division.

At the time of launch, the four Uvicon camera tubes could observe stars at least 100 times fainter than those easily visible to the naked eye. One was damaged during an early orbit and has not been in service since March 1969. The others, however, were still sensitive enough to provide useful scientific data even after a year of operation and exposure to the high radiation levels of space.

NASA scientists report that the observations of OAO-II have raised a number of interesting astronomical possibilities. For example, the universe may be several times larger than has been thought, since unexpectedly bright ultraviolet from the far galaxies suggests the existence of extremely bright objects much farther away than has been assumed. Theories of star aging may need updating: the hottest stars are hotter and some cooler ones are cooler than expected from present ideas of stellar energy production and aging. Theories of star creation may be advanced, because thin dust nebulae, where stars are believed to form, are stronger in ultraviolet than those infant stars should be.

Other important discoveries include a new analysis of the more-than-expected amount of hydrogen in the earth's atmosphere, lack of ultraviolet radiation from suspected but unobserved matter in the universe, and a density of luminous matter in the universe too low to support the theory of a steady-state universe.

The sky-mapping experiment, called Project Celescope, is being conducted for NASA by the Smithsonian Astrophysical Observatory. A second experiment aboard OAO-II is directed by the University of Wisconsin; it makes detailed ultraviolet observations of individual celestial objects. EMR-Telemetry, a division of Weston Instruments, Inc., designed and built the four telescopes that house the Uvicon tubes and the digital television system that transmits their pictures to earth.

Products for Industry

Permanent lifting magnet uses flux-transfer principle in combination with a rechargeable nickel-cadmium control-coil battery to provide lifting power dependably and inexpensively. Rated conservatively at 2000 pounds, the Type FTL permanent lifting magnet is made of ceramic material. Flux transfer allows the magnet to be turned off, in effect, by directing the magnetic lines of force through a keeper plate. When the magnet is put in contact with a load, a toggle switch is thrown to the "lift" position; it activates the control coil momentarily, opposing magnetic flux through the keeper plate and forcing it to transfer to a path through the load. Before the load is lifted, the keeper plate disengages from the poles, and all the flux then flows through the load. The load can be released only after it has been lowered so the keeper plate is again in contact with the poles; the switch is then thrown to the "release" position to reverse the effect of the control coil. *Westinghouse Repair Division, 543 N. Lang Avenue, Pittsburgh, Pennsylvania 15208.*

Type JF Autostarter, Class 10-600, is an extension of the line of manual reduced-voltage ac motor starters to 300 hp. Used with squirrel-cage induction motors, it provides the least expensive means of keeping inrush current within limits set by the local utility distribution system or plant power system while still giving maximum starting torque. It has double air-break silver alloy contacts for long life and a sequence mechanism that ensures trouble-free motor starting. The standard unit comes in a NEMA-1 floor-mounted enclosure 28 inches wide by 64 inches high by 21 inches deep. Weight is 800 pounds. Voltage rating can be 440 or 550 volts at 60 hertz. *Westinghouse General Control Division, 4454 Genesee St., P.O. Box 225, Buffalo, New York 14240.*

High-power thyristor (silicon controlled rectifier) has peak forward blocking voltage of up to 2000 volts, typical turn-on time of seven microseconds, and turn-off time of 150 microseconds. The 286-Y30 thyristor handles an average current of 300 amperes while withstanding surge currents up to 6000 amperes. Control requires an average of only three watts for the gate. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697.*

Environmental data recorder operates unattended to monitor and record weather data and air pollution levels. The heart of the system is one or more Pulse-O-Matic slow-speed magnetic tape recorders, each of which can record as many as three channels of data simultaneously, while a fourth channel records time. At the end of the recording period, which can be as long as a month, the tape is removed and run through a translator for conversion to a form that can be analyzed by a digital computer. *Westinghouse Meter Division, P.O. Box 9533, Raleigh, North Carolina 27603.*

About the Authors

Dr. Walter H. Esselman has devoted most of his career to the development of atomic power. He is presently Executive Assistant to the Vice President, Nuclear Energy Systems.

Dr. Esselman received his BS degree in Electrical Engineering in 1938 from Newark College of Engineering. He joined the Westinghouse Elevator Division but continued his education, receiving his MS degree from Stevens Institute of Technology and his PhD from Brooklyn Polytechnic Institute. At the elevator division, he helped develop the control concepts for automatic elevators and, during World War II, worked on development of antiaircraft fire control systems.

In 1950, Dr. Esselman joined the Bettis Atomic Power Laboratory as a senior engineer in the control section. He soon was appointed supervising engineer of the section that was developing the control systems for the atomic submarine *Nautilus*. He later became Section Manager and then Manager of the power plant systems subdivision, and in 1953 he was named Technical Assistant to the Manager of the Naval Reactors Facility, where he supervised the test program for the *Nautilus* prototype reactor. He returned to the Bettis Laboratory in 1955 to establish the advanced development and planning activity there.

Dr. Esselman joined the Astronuclear Laboratory when it was formed in 1959 and since then has been associated with design of nuclear powered rockets. With the award of the NERVA contract in 1961, he became Manager, Engineering and Development. In 1964, he was made Deputy Manager of the project for Westinghouse, and, in 1968, Manager. He was appointed Executive Assistant to the General Manager last year and assumed his present position early this year.

Melvin R. Keller is Technical Advisor to the NERVA Project Manager at the Westinghouse Astronuclear Laboratory, responsible for advising on long-range planning and objectives in nuclear rocket propulsion. The position also involves assessing the national space programs and goals and recommending appropriate actions to Astronuclear Management.

Keller graduated from the University of Colorado in 1949 with a BS in Aerospace Engineering. He worked for Davison Chemical Corporation as an estimator and then, in 1950, joined the U.S. Air Force as a project engineer in the Propulsion Laboratory Rocket Unit. He did graduate work at North Carolina State University under Air Force sponsorship, getting his MS in Nuclear Engineering in 1953. (Keller has since done graduate work in mathematics at Stanford University and in nuclear rocket propulsion at UCLA.)

His next assignment was as Chief, Engineering Unit, Civilian Institutions Division, Headquarters, Air Force Institute of Technology, Wright-Patterson Air Force Base, and in 1956 he moved to the Physics Department as an Assistant Professor. He joined the Physics Department at the Air Force Academy in 1958, advancing to the rank of Associate Professor.

In 1962, Keller returned to Wright-Patterson Air Force Base as Chief, Internal Flow Group, Aerospace Research Laboratories. He was made Director of the Energetics Research Laboratory there in 1966. He retired from the Air Force in 1968 with the rank of Lieutenant Colonel and assumed his present position with Westinghouse the same year.

Keller received the Air Force R&D Award in 1964, and he holds the Air Force Commendation Medal with oak leaf cluster.

B. C. Estep and **B. S. Strait** team up to discuss the principles of selecting large ac motors.

Estep earned a BBA degree from Westminster College in 1953 and a BS in Mathematics at the University of Pittsburgh in 1965. Since joining Westinghouse in 1956, he has worked in the Motor Sales Department, Large Rotating Apparatus Division. He is presently responsible for motor applications in the chemical, petroleum, cement, and compressor industries and for development of computer programs to provide pricing, performance, and descriptive information for motor negotiations.

Strait attended the University of Norwich and Marietta College. Before joining Westinghouse in 1965, he was an application and sales engineer for manufacturers of motors and controls. He is now a sales engineer in the Motor Sales Department, Large Rotating Apparatus Division, with responsibility for the mining and pumping industries and for special drive applications.

H. H. Hansen's main interest is in combining engineering and business areas by use of computers. He is involved in various aspects of manufacturing information, order entry, engineering information flow, and information storage and retrieval.

Hansen graduated from Illinois Institute of Technology with a BSEE degree in 1952 and then joined the U.S. Navy Bureau of Ships to work on magnetic mine-sweeping equipment. From 1954 to 1957 he was on active duty in the Navy in mine warfare operations, training, and equipment development. Hansen joined Westinghouse in 1958 in the former Marine Systems Engineering group, where his first assignments were in systems design of power supplies for high-energy sonars and radars. He also was responsible for a study of electrical equipment for deep-diving submarines, participated in a Merchant Marine Province Study, and served as technical advisor to marketing personnel serving the Navy.

Hansen joined the Analytical Department in 1965 and then became part of the Westinghouse Information Systems Laboratory when it was formed in 1967. He was project leader for WIRES, a manufacturing information system for electrical shops at Naval shipyards. He was appointed Consultant for Automated Engineering Information Systems in 1968 and Product Manager, Management Systems, last year. He retains that position in the newly formed Westinghouse Tele-Computer Systems Corporation. Along the way, he has earned his MSEE and MBA degrees at the University of Pittsburgh.

T. R. Gibson earned his BEE degree at the University of Minnesota in 1949. He worked in communications and signaling with several railroads before joining the Westinghouse Transportation Division in 1967. As Central Control Project Manager for the Bay Area Rapid Transit (BART) project at the Transportation Division, Gibson has contributed to development of the BART control system discussed in his article. He is a member of IEEE and a registered professional engineer in the Commonwealth of Pennsylvania.

Albert F. Harsch graduated with a BSEE degree from Carnegie Institute of Technology (now Carnegie-Mellon University) in 1957 and received his MSEE degree there in 1969. His main work has been in application of high-speed digital computers to solution of engineering problems in such areas as control systems analysis and design, batch and continuous process control, regression analysis, curve fitting, and data reduction and analysis.

Harsch joined Westinghouse on the graduate student training program in 1957 and then entered the Army, serving in Japan as officer in charge of radio and photographic intelligence for a Signal Corps technical intelligence team. He rejoined the Westinghouse student training program in 1959 and was assigned to the Analytical Department. There he was responsible for developing a cold-rolling-mill simulation program and for developing and refining methods of controlling hot-rolling mills. He also contributed to the development of other digital computer control systems, including a dynamic control for a basic oxygen furnace.

Harsch joined the Westinghouse Information Systems Laboratory when it was formed in 1967. As Consultant, Computer Control Systems, he was responsible for specification, development, and implementation of information systems involving on-line process control computers, a responsibility that included development of the BART control strategy logic and dispatching logic. He was made Manager, Software Systems, in 1969, a position he retained when he became part of the new Westinghouse Tele-Computer Systems Corporation this year.

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Divers survey coral reef for starfish invasion. (Information on page 62.)