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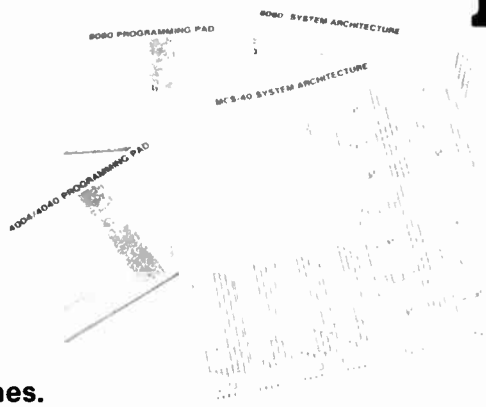

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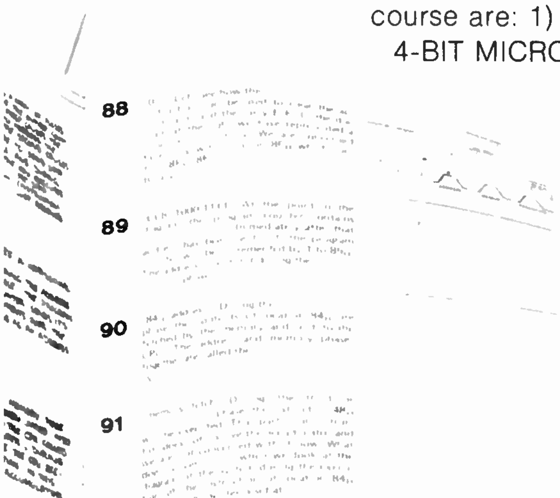

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the cover

Background to the 707 and 727 silhouettes is an air traffic controller's radar display at Kennedy International Airport's common IFR room (article, p. 26).

spectrum

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The promise of air safety

Although air traffic has been increasing for years, installation of collision avoidance systems is only now being mandated

In 1974, according to the U.S. National Transportation Safety Board (NTSB), 467 deaths were attributable to commercial aviation accidents in the United States. This number more than doubled the fatality toll of 1973 and was the greatest for any year since 1960. Further, 1974 marked world aviation's worst disaster—the DC-10 Turkish Airlines crash near Paris, France, that claimed 346 lives.

Statistics like these, representing an exception to what had been, since 1959, a steadily improving safety record in commercial jet travel, have caused widespread concern. This concern is further heightened by an increase in air traffic and the advent of jumbo jets.

According to the Federal Aviation Administration, air passenger enplanements have been increasing at a rate of 8–9 percent per year and general-aviation aircraft are being produced at over 10 000 per year—a figure considerably higher than that of decommissioned planes. Thus, based on this forecast, future air traffic should grow by as much as 6 percent per year—or a doubling of air activity every 12 years.

Compounding the dangers of increased air traffic, the Boeing 747, the DC-10, and the L-1011 jumbo jets would all occasion catastrophic loss of life if involved in major accidents. In an address before the Radio Technical Commission for Aeronautics, Representative Barry M. Goldwater, Jr. (R-Calif.), a chief proponent of air safety, reflected the thinking of many concerned about large-capacity jets: "Even one midair collision is one too many, and the thought of a fully loaded 747 going down . . . horrifies me."

The confluence of the two trends just mentioned means the presence of an ever-increasing number of passengers in already crowded skies. In the words of David R. Israel, FAA Deputy Associate Administrator for Engineering and Development: "This doubling of traffic is, frankly, a rather frightening prospect, for we can be certain that over the same general time period there will *not* be a doubling of major hub airports or the runways on these airports (in fact, little physical growth is expected with which to accommodate the increased demand), there will *not* be a doubling in the range of altitudes which aircraft desire to use, there will *not* be a doubling of major city pairs between which the bulk of this traffic will travel, and the radio spectrum available for air traffic control use will *not* double."

Even now, some pilots refer to their destinations as "scareports," and anyone who has ridden in a cockpit during a landing approach in minimum visibility weather knows the frightening experience described. And adding to the complication of increased traffic is the fact that controllers must attain efficient take-off and landing rates in order to make flying a competitive and practical means of transportation—disgruntled customers are hardly what the airlines want!

In the face of what may be a deteriorating situation, the questions arise: what systems are currently in use to protect the passenger and what is being done to supplement or replace them to continue the outstanding safety record achieved until now.

Marce Eleccion Associate Editor

Today's hazards: solving them now

In 1974, 75 percent of all air fatalities occurred during landing approaches. One of the most notorious incidents occurred on December 1 near Washington, D.C. The weather was stormy. A TWA Boeing 727 was making its approach into Dulles International Airport. In the cockpit, someone was saying, "You know, according to this dumb sheet, it says thirty-four hundred to Round Hill is our minimum altitude. . . Hang in there, boy. . . . We're getting seasick." Seconds later, the plane had slammed into a Virginia mountaintop killing all 92 people aboard.

This accident should never have occurred. And neither, according to Glenn Jones of Sundstrand Corp., should 36 of the 42 crashes attributed to "controlled flight into terrain" in the U.S. over the past five years. As long ago as 1969, Sundstrand had flight-tested its first ground proximity warning system (GPWS)—today's version warns pilots who stray too close to ground: "Whoop! Whoop! Pull Up!" The price for this system, which might have prevented the

One man's opinion!

A *Spectrum*-conducted interview earlier this year with the then executive director of the Air Traffic Control Association, John K. King, in Washington, D.C., provided some scathing insight into some of the present problems confronting air safety in the U.S. A veteran of 31 years with the FAA (going back to the days when it was still called the Civil Aeronautics Administration), Mr. King accumulated 18 years of airport traffic control tower and air route traffic control center experience before becoming a controller instructor at the FAA academy, finally attaining the position of chief, Southwest Region Training Branch, before retiring in 1973. Excerpts from the *Spectrum*-King interview follow:

Spectrum: **In 1969–1970, there was a lot of publicity given to the work overload of the air traffic controllers—particularly in the New York area—and a job action was threatened. How has that situation resolved itself?**

King: Well, there will always be periods of work overload, because there is no way you can ever staff for the busiest conditions that you can have. . . . Part of the overload situation was the building of traffic,

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spectral lines

. . . by any other name?

Your friends and neighbors may think of you as an engineer, you may have practiced engineering for several or even dozens of years, and you may hold one or more degrees in engineering. Yet legislation in effect or under consideration in some states of the U.S. could make the use of several engineering titles, including, specifically, that of "electrical engineer" illegal except for those persons registered as such by a state board.

Texas already has such a statute on the books. It specifically prohibits the use of the title engineer, in any form or abbreviation, by a nonregistered engineer. Thus such a title cannot be used by a person not properly registered to advertise services in the "Yellow Pages," nor can it be used on a business card, or even on a certificate publicly displayed.

Another such piece of legislation is California Assembly Bill 2166, introduced in April of this year. Some who have carefully studied this proposed legislation believe that its passage would put IEEE and its members in violation of the law in California, except for those who are, or elect to become, registered in that state. There is some indication in the proposed California legislation as it is presently written that "employees engaged in the branch of electrical engineering" would be permitted to work as "employees in the communication industry" provided they refrain from calling themselves engineers. Yet a pair of Philadelphia lawyers might well disagree on the meaning and/or the intent of that particular provision.

In the cases of both Texas and California, the restrictions on the use of the title engineer are part of a general licensure statute. The objective of such statutes is to prevent the practice of engineering by charlatans or those otherwise unqualified, or as many state statutes specify "to safeguard life, health, property, and public welfare." Yet the specific restrictions on the use of the title "engineer" add a dimension that is not present in most existing licensure statutes. Moreover, these restrictions suggest possibly ludicrous and capricious applications that might go well beyond the basic intent of the laws themselves. True or not, a story now making the rounds is that an applicant for registration in one state listed as one of his credentials his certification by a national engineering society, and was promptly fined for prematurely calling himself an engineer. (If one accepts this story as more than apocryphal, it is easy to imagine other, equally absurd scenarios. Consider the case of the M.I.T. professor, a registered professional engineer in the Commonwealth of Massachusetts, but not registered in, say, Texas. Addressing an august gathering of his peers in Dallas, he cannot be introduced as an engineer, perhaps not even as a professor of engineering. At least he can be identified as affiliated with the Massachusetts Institute of Technology —maybe even with its school of electrical engineering.)

One may be tempted to wonder whether the sponsors of title-protecting legislation are not simply equating state registration with professionalism. In a *Spectrum* article,[1] Professor Hansford Farris suggested several steps to professionalism that could be taken by engineering educators, professional societies, employers, and engineers themselves; in no case do these recommendations relate directly to state registration, although they recognize that there would be a registration procedure for those individuals whose work is in the public domain.

The rationale for registration is understandable where engineers practicing in direct contact with the public are concerned, yet the benefit to the public in the case of the employed engineer is not as clear. It is for this reason that many states have a provision to exempt those engineers employed by industrial manufacturers from mandatory registration. In a relatively few cases, this provision is explicitly stated; in most cases, it is implicit or at the discretion of the state authorities. (In a recent addition to the Montana laws, however, certain engineers or engineering managers employed by private industry are required to become registered if they are in responsible charge of the design of products that are used by the public. On the other hand, an attempt by Ohio to eliminate the "industrial exemption" met with stiff opposition from manufacturers.)

Proponents of registration for all engineers (including those in private industry) view the "capture" of the title engineer by the state boards as fair and proper leverage to help expedite their objectives.

On the other hand, a large percentage of engineers, most of whom are employed in private industry, see registration as simply irrelevant and costly. In New Jersey, for example, the application fee for initial registration is $40, with an annual renewal fee of $5.

Corporate managers are inclined to view compulsory registration as preemptive of their "right" to assign titles and jobs without regard to education or certification. Those engineers and managers who take a reasoned stance seem to believe that registration for all engineers, without exception, may be inevitable, but that any mechanism to bring it about cannot be arbitrary. Such a mechanism must, they believe, provide an evolutionary way to accomplish this, and, above all, should not jeopardize the job of any practicing, unregistered engineer who is doing his job competently. In this light, they view "Texas-style" statutes as threatening, and the reclamation of eminent, practicing engineers' titles as unfair and unwarranted.

Donald Christiansen, Editor

REFERENCE

1. Farris, H. W., "Engineers or 'ingenors'?," *IEEE Spectrum*, vol. 10, pp. 74–79, Mar. 1973.

Washington, D.C., crash, was $10 000. Since the disaster, the FAA has mandated the installation of GPWS on all U.S. commercial jet air carriers by December 1, 1975. Unwilling to deal with single sources, the airlines—through the Airlines Electronic Engineering Committee (AEEC) of Aeronautical Radio, Inc. (ARINC)—went to Collins Radio, Bendix, and Litton, urging them to offer competitive systems. This resulted in a reduction in price to less than $6000.

But if GPWS—installed on every U.S. commercial plane—will, in combination with existing technology, solve most of the ground-approach hazards, the problem remains: what of mid-air collisions? While these accounted for less than 4 percent of U.S. air fatalities in 1974, their incidence and consequences could become ever greater in skies crowded with jumbo jets.

At present, the air traffic control (ATC) system under FAA responsibility consists of a network of navigation, surveillance, communication, and control facilities collectively called the National Airspace System (NAS). The primary function of this system is to guarantee safe separation between aircraft while in flight; all separation assurance measurements are made on the ground, with controller-to-pilot clearances hopefully maintaining the safe separation.

To participate in this NAS system, all aircraft must carry basic avionics equipment and are required to file a flight plan with an air traffic control facility. If "cleared," the pilot must then navigate his flight plan route with the help of navigational equipment and monitored by ground-based primary and secondary radars. The purpose of the secondary surveillance radar (SSR) is to interrogate all aircraft carrying ATCRBS (air traffic control radar beacon system) beacon transponders, each of which has the capability of transmitting any of 4096 discrete identity codes (called Mode A); as of last January 1, all aircraft operating in a Group 1 terminal control area (TCA)—which includes the major airports—must also carry encoding altimeters to transmit altitude readings (Mode C) via the same ATCRBS transponder.

From the "first-generation" ATC system—a totally manual system based on time separations—developed during the 1930s, "second generation" evolved through the use of primary radar (to detect aircraft "skin" reflections), ATCRBS, and computerized printing of flight progress strips. With the introduction of the semiautomated enroute system now being deployed (NAS Stage A) and the terminal area system called ARTS III (automated radar terminal system), "third generation" was born. ARTS-III automatically decodes all identity- and altitude-encoded beacon data received from SSR-interrogated aircraft and displays them, with primary radar reflections, on the air-traffic controller's console (Cover and Fig. 2).

But present ATC technology may be insufficient, and increasing pressure by the Air Line Pilots Association (ALPA), the airlines, some segments of general

(Continued on p. 31)

but part of it also was just poor management foresight. . . . I think the situation is much better today, and I don't believe that too many facilities are understaffed for the amount of traffic that they have today. There *are* some exceptions, however.

On the other hand, both the FAA and the controllers' union have used the matter of work overload as a scare tactic for Congress—and for a good long while. In other words, the easiest thing in the world to get out of Congress is money for controllers. So you must always have a shortage of controllers if you want to get money out of Congress. [Smile.]

***Spectrum:* And I suppose you have to overstate your case in order to get some action?**

King: Correct. And that has been done. The FAA, as you well know, puts out staffing standards for air traffic control facilities. I think an impartial investigation will show that those staffing charts overstate the number of people needed for individual facilities.

***Spectrum:* Do you feel there is a lag or foot dragging on the part of FAA in implementing and upgrading air safety standards?**

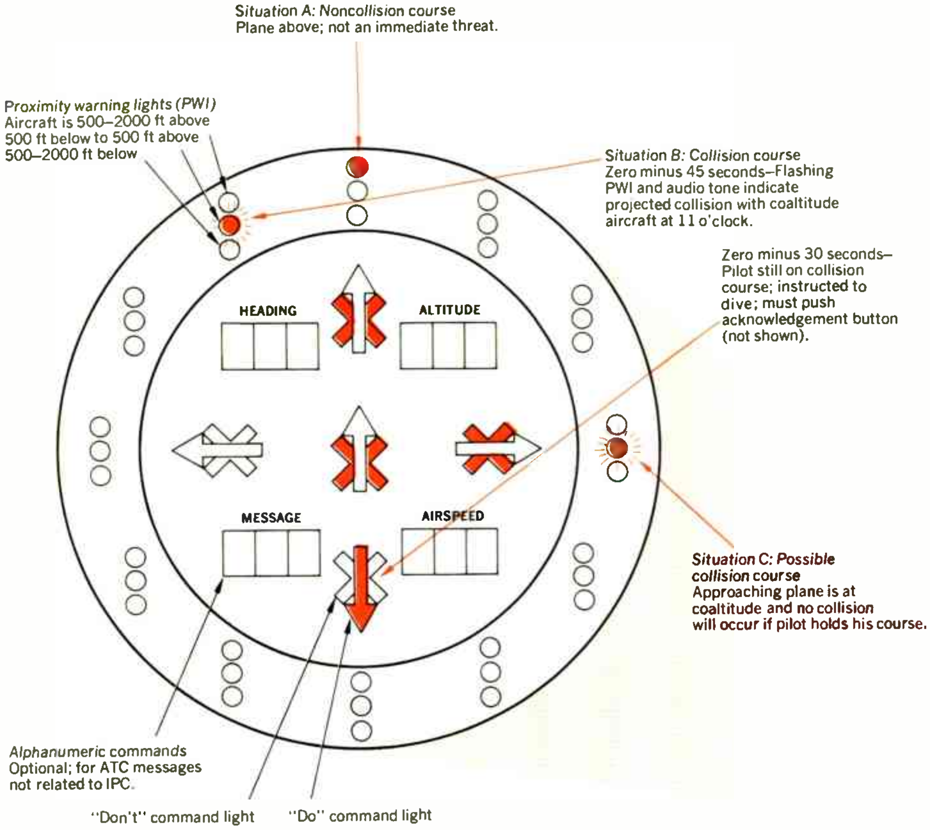
King: I think we in aviation all sense that there is a lag. Now, the country has been on a kick for the last several years of cutting back Government expenditures. And while the emphasis has been on controllers—because we can scare Congress with "My God, if there is no air traffic control system, we will fall apart"—we will *also* fall apart if we don't have enough electronics technicians, and the system will *also* fall apart in the safety area if we don't have enough flight standards inspectors; a shortage that became so acute that the FAA, by necessity, had to delegate quite a lot of its inspection policies over to industry, the airlines, the pilots, and the ground schools—all of whom are inspecting themselves.

***Spectrum:* Do you think it would be advantageous if the FAA were divorced from the Department of Transportation and set up as a separate entity?**

King: I think it would not only be advantageous, but it is the only way we can have a decent aviation program in this country. The DOT has been nothing but a roadblock and a hinderance. I just looked at the DOT yearbook that was put out to glorify Mr. Brinegar as he left office. In it, it was shown that 50 percent of DOT personnel are in the FAA; but when it quoted his remarks of what he had done in office, he mentioned aviation only 14 percent of the time. The book also shows the lopsided budget (all 9 percent of it) going to the FAA. I realize that a lot of money is needed for building highways and that sort of thing. Nevertheless, the emphasis at DOT has been very definitely and clearly on railroads, highways, and urban mass transportation. Aviation has had a back seat all the way!

***Spectrum:* What is the attitude of the controller toward systems that are being conceived right now, some of which may reduce their work load?**

King: I'm afraid that the average controller isn't that much interested in the technology of ATC. He has resisted every advance in the system—the VOR and ILS, radar, and computerized control equipment. But I personally believe that the sooner we can get to a more completely automated, computerized system of controlling airplanes, one which takes the control from both the pilots and the controllers and puts it into a computer, the better off things will be. Now that won't reduce too many pilot jobs, but it certainly will reduce some controller jobs, and there's the rub! As one who is interested in safety from the point of view of the whole system, however, I would like any development that will make the ATC system work efficiently and safely.

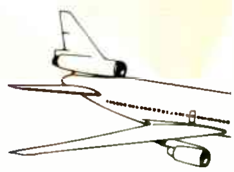


M.I.T. Intermittent Positive Control

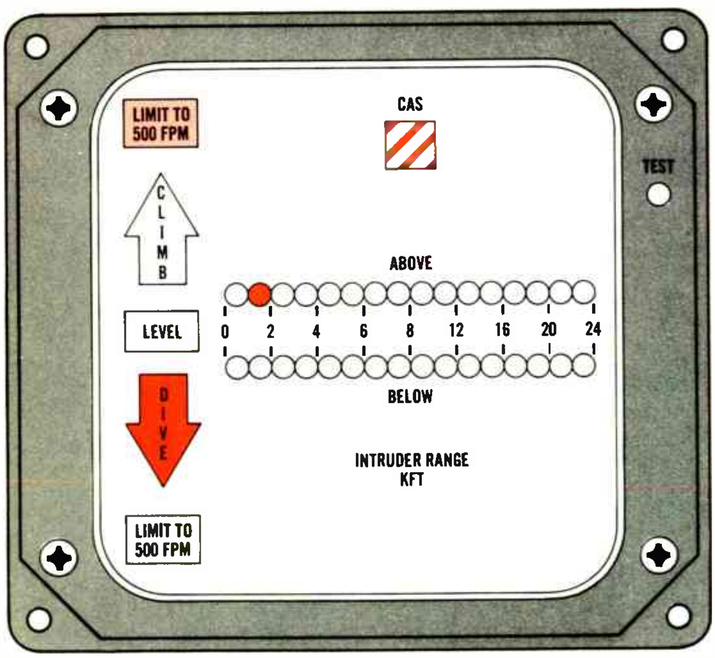
- Ground-based discrete-addressed beacon transponder system; $1000 (GA), $6775 (C)
- Additional equipment: ground stations ($200k–$500k each); Synchro-DABS ($2k (GA), $10k (C))
- Availability: mid-1980s

Glowing light

Flashing light (with audio warning)



AVOIDS-2



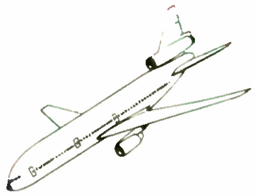
Honeywell AVOIDS

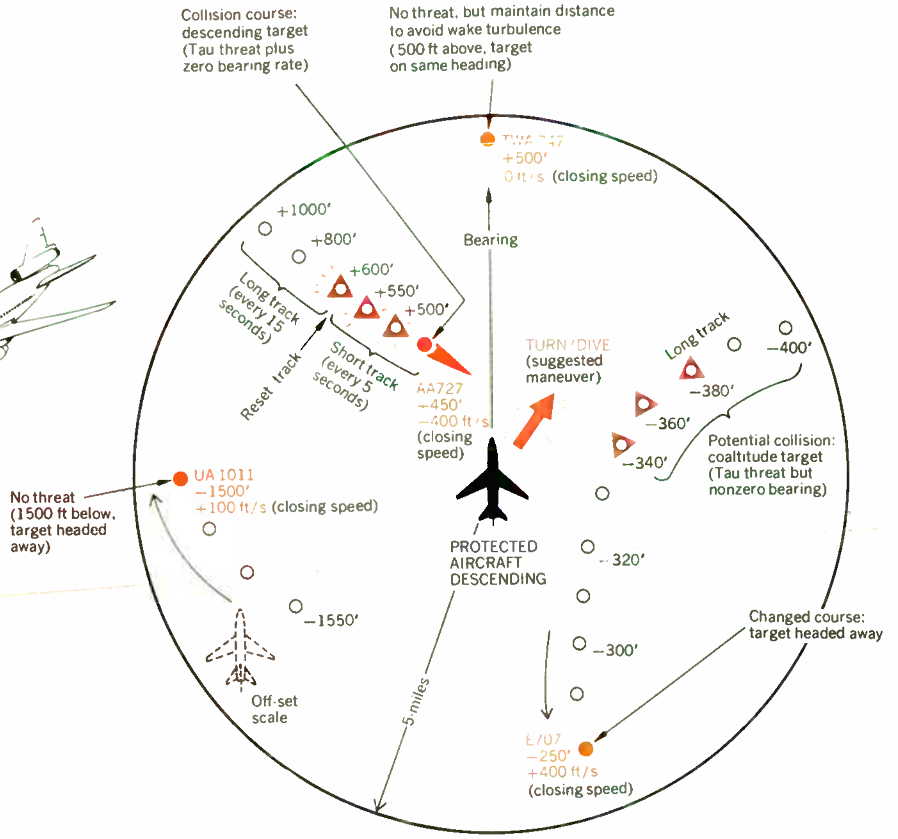
- Airborne transponder system; $564 (GA), $16 629 (C)
- Additional equipment: none
- Optional: YG1081 PWI for bearing indication
- Availability: today

[1] Collision-avoidance systems (CAS) now under consideration by the FAA include one ground-based and four airborne concepts. All prices that are shown were taken from a recent FAA-sponsored ARINC Research Corp. study based upon an actual parts count and technology projection; since commercial (C) aviation will probably be required to carry dual black boxes as well as dual pilot warning indicators and antennas, the prices reflect acquisition of these multiple units, with general-aviation (GA) pricing reflecting purchase of less sophisticated single units.

It should be remembered that all of the CAS technologies described here require a remitter or transponder on board all detected aircraft, with safeguarded planes carrying the basic CAS unit itself to detect such aircraft. The practical differences in these CAS lie in how much the present and costly ATCRBS network is affected, however. Since the McDonnell Douglas CAS is a two-way communications system, it functions independently of the ATCRBS network (aside from using the altitude encoder output that normally serves the ATCRBS transponder), as do the RCA and Honeywell CAS systems, which provide two-way beacon ranging between two cooperative aircraft—as such, these three systems necessitate a specialized remitter to be purchased by all detected aircraft. In the Litchford system, however, no additional remitter beyond that required by the present ATCRBS Mode-C network is necessary, with collision avoidance obtained via one-way ranging from an ATCRBS ground station to all detected aircraft to the safeguarded aircraft, or two-way ranging outside of ground station range by means of active interrogation from the safeguarded aircraft to the all detected aircraft. In M.I.T.'s IPC, the entire ATCRBS network will have to be expanded to include DABS—with Synchro-DABS (an air-to-air interrogator-transponder system that is to DABS what the Litchford system is to ATCRBS) giving the Intermittent Positive Con-

RCA SECANT
- Airborne transponder system; $1149 (GA), $19 508 (C)
- Additional equipment: none
- Optional: modular additions for bearing and miss distance display and future-threat evaluation
- Availability: today





Typical CAS deployment
Scale (variable): 5-mile radius
Altitude band (variable): 1000-ft up/3000-ft down

Litchford Semiactive BCAS
- Airborne ATCRBS transponder system; as yet unpriced, but expected to be cost-competitive with other CAS
- Additional equipment: none
- Availability: within a year

trol (IPC, see below) pilot a CAS capability in areas not covered by ground-based DABS stations.

M.I.T. Intermittent Positive Control

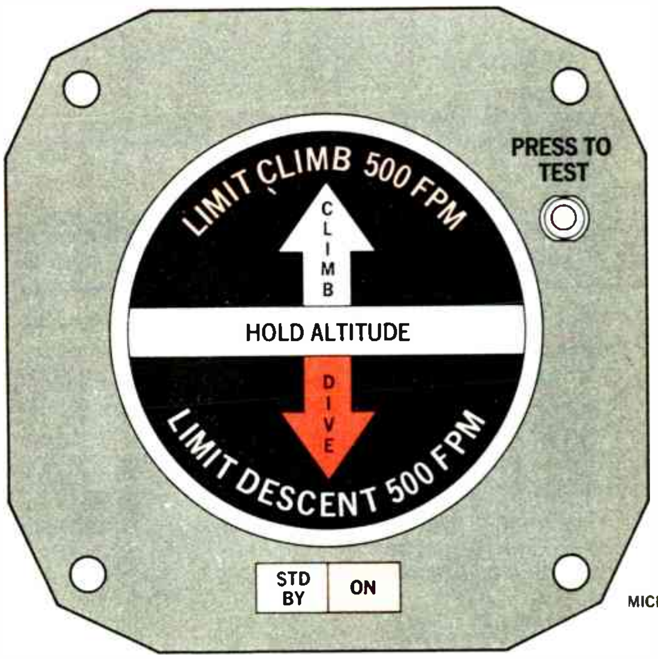
In order to receive IPC service, an aircraft must carry both a DABS transponder and an IPC display similar to the one shown here, in addition to the encoding altimeter already required by many airports. The cost to air carriers is expected to be $5700 for the transponder, $1075 for the display, and $5300 for the encoding altimeter; for general aviation, these costs will be reduced to $750 (transponder), $250 (display), and $1400 (altimeter). The Synchro-DABS avionics equipment (being built by Bendix Corp.) required for additional airspace coverage via air-to-air interrogation is estimated at $10 000 for each airliner and $2000 for general-aviation aircraft. Added to this are a $40 million DABS/IPC development cost, and a preliminary estimate of $190 million for 300 DABS/IPC ground sites.

In this FAA-developed totally automatic ground-based CAS system, the airborne transponder receives digital messages from the ground and presents them on the display. A pilot may receive any of four IPC warnings: an ordinary proximity warning indicator (PWI), which warns of a nearby aircraft in a noncollision course with the pilot's own course; a flashing proximity warning indicator, which tells a pilot of the existence of another plane in a potential collision course; a "don't" command instructing the pilot not to maneuver in a specific direction; and a "do" command, which gives the pilot positive maneuvers. In addition, IPC informs the air traffic controller of all conflict situations.

Honeywell AVOIDS

Honeywell's entry into the airborne CAS market takes the form of two "avionic observation-of-intruder danger

(Continued on p. 30)



MICRO-CAS

McDonnell Douglas EROS-II
- Airborne time-frequency system except for ground-based time stations; $990 (GA), $17 992 (C)
  —airborne time clock not included in price
- Additional equipment: ground stations ($750k each)
- Optional: airborne stationkeeping and ground-station flight-following equipment
- Availability: today

systems" (AVOIDS). Based on Tau calculations (range divided by relative range-rate between any two aircraft) to determine threat status, AVOIDS-1—intended for airliners and other high-performance jet aircraft—and AVOIDS-2—a somewhat simplified version primarily for low-speed VFR (visual flight rules) aircraft—are essentially 1.6-GHz pulse beacon ranging systems that serve both interrogation and response functions.

Since calculation of time-to-collision (Tau) is based only upon range and range-rate, with relative bearing angle between the two aircraft unknown, the AVOIDS CAS can only indicate that a definite threat exists at a specific altitude and is closing in at a certain rate. As a result, a pilot can only be warned to "dive," "climb," or remain "level" (see illustration) since he does not really know at what angle the threat is coming from. To deal with this problem, Honeywell does offer a PWI with bearing indication—the YG1081—that can be incorporated into AVOIDS.

McDonnell Douglas EROS-II.

The only airborne CAS that requires a ground station (although it can function without one)—necessary for the precise air/ground clock synchronization upon which the system is based—EROS (eliminate range zero system) was designed to Air Transport Association specifications (ANTC-117) for airliners and high-performance aircraft, with less sophisticated MICRO-CAS and MINI-CAS systems envisioned for general-aviation aircraft. Test-evaluated as long ago as 1973, EROS-II is admittedly costly ($17 992, with thousands of dollars more for the time-clock) because of its time resynchronization technology, which requires time-ordered reporting of all participants every three seconds at an accuracy of better than 100 ns.

Because of its ground-station capability (McDonnell Douglas claims that 20 are needed for adequate coverage over the U.S.), EROS provides ground controller flight-following capability. And because radar is not used, there is an absence of ground clutter and weather returns on the ATC screen.

In the EROS time-frequency system, all planes must carry a cooperative unit precisely synchronized in time with all ground stations and all other airborne units. With time divided into discrete slots, each airborne and ground unit is assigned an empty time slot in which to transmit up to 150 bits of data—including identification, altitude, avionics systems status, and liftoff/landing times—at 5-MHz switching increments through the 1.600–1.615-GHz band. During all other slots, transmissions from other users are received.

It is interesting that, although MICRO- and MINI-CAS originally evaluated threat maneuvers based solely on range and altitude measurements, at this writing the FAA informed the author that MINI-CAS will—like EROS-II—measure range-rate as well; MICRO-CAS, however, is no longer being considered.

With the addition of special station-keeping equipment, EROS-II can be modified to include bearing information, in which case a pilot is able to monitor the range, altitude, and bearing angle of predetermined aircraft by means of an additional digital cockpit display.

RCA SECANT

Flight tested by the Naval Air Development Center in December 1973, RCA's SECANT (separation and control of aircraft using *nonsynchronous* techniques) is actually a family of airborne CAS that actively interrogates cooperative aircraft within range (15.2 nmi) to evaluate a collision threat based on altitude, range, and range-rate; while aircraft identity (via ATCRBs encoding) is also exchanged, other data such as heading, airspeed, and course changes could also be included. In addition, SECANT has the capability of advising ground control centers of potential encounters, thus enabling such ATC centers to participate in a more coordinated disengagement.

Of the SECANT modular systems, VECAS ($19 508), vertical escape CAS, which includes a remitter and a PWI (see illustration) display, is intended for high-performance aircraft such as airliners, and VECAS-GA ($1149)—a less sophisticated version—is for general-aviation use; planes carrying remitters only will not be protected from each other. Although both VECAS and VECAS-GA meet the threat logic requirements of ATA specifications (ANTC-117), RCA has developed a second group of SECANT systems that go beyond these requirements by adding modular circuit functions for pilot display of bearing measurement, miss-distance calculation, and future threat evaluation of nonthreatening aircraft.

Once a SECANT system is installed in an aircraft, a pilot has the option of adjusting his PWI to accommodate a threat range of from 0.2 to 4.0 nmi. After a target is detected, a tracker is activated and the range from each reply to an interrogation (1000 pulses/s) is measured for threat evaluation. If a threat exists, the pilot is instructed by his PWI to remain level, climb, or dive. In VECAS-GA, a simpler, less-costly cockpit display is employed.

Litchford Semiactive BCAS

The latest entry into the airborne-CAS race, the Litchford system—developed for the Air Force Electronics Systems Division (for $250k) as SSR-CAS/PWI in late 1973—was demonstrated to the FAA on March 19 of this year. In its newly evolved form, it is the most favored contender among the airborne-CAS systems, according to FAA's David Israel. The reasons are:

- Rather than having to install a new cooperative transponder or remitter in all aircraft, as in other CAS systems, Litchford Electronics' Semiactive BCAS (beacon CAS) would use the ATCRBS Mode C transponders now mandated in all aircraft operating from Class 1 terminal control areas (TCAs), or over 100 000 planes.
- By triangulating on the ATCRBS responses from other planes to the hundreds of rotating ground-based secondary-radar (SSR) stations already in existence throughout the country, BCAS can not only determine range, range-rate, and altitude (from Mode-C transponders), but bearing angle as well; this in turn gives the pilot omnidirectional escape maneuverability rather than the restricted vertical escape paths offered by the other basic CAS systems.
- Since Semiactive BCAS—through airborne microprocessing techniques—obtains virtually the same information received by the ground controller, by localizing this data to the plane being protected, a pilot would have an "omniscient" display of his environment (see illustration) on both an expandable and displaceable scale similar to the console in front of the ground controller (see cover and Fig. 2). Hence pilot confidence, even under zero visibility, would be considerably enhanced.

With the BCAS display, not only are all targets of interest within the threat area under constant scrutiny, but immediate threats may be "tracked" in real time to assess convergence or divergence with the protected plane. In addition, altitudes (translated as feet above or below the pilot's aircraft) as well as the "state" (e.g., climbing, descending, or maintaining) of the target can be displayed, along with any other useful information (e.g., identification).

In low-traffic density areas where there is no SSR radar, a protected aircraft will then automatically interrogate surrounding aircraft directly, processing the ATCRBS signal returns in the normal manner except for a translation of interrogator reference position.

Note: At this writing, *Spectrum* was informed by David Israel that the FAA is considering only a modified version of the Litchford system—one that offers the same vertical-escape maneuvers the other airborne-CAS displays offer. George B. Litchford of Litchford Electronics has told this writer that the capability of measuring bearing angle is inherently still there, however, and could be used in any future configuration that needed an omniscient display.

Perhaps the overriding factor in deciding to use any one of the proposed airborne CAS systems in the U.S. will be its acceptance not only nationally, but by the international and military community as well. Since ATCRBS or SSR—at over $2 billion, the largest single investment in air traffic control—has already been accepted by both the military (DOD has just spent $800 million to adopt a modernized Mode-C transponder system) and as many as 50 nations (through ICAO agreements), it seems reasonable to assume that a CAS utilizing this investment—thus contributing to minimal overall CAS system cost—would attract the greatest attention.

(*Continued from p. 27*)
aviation (private aircraft pilots), and Congress has been brought to bear on the FAA to mandate a collision-avoidance system (CAS) that would do for mid-air collisions what GPWS is expected to do for ground-approach hazards. Caught in the middle of a growing controversy and accused of foot-dragging by members of Congress, the FAA will soon be making a decision—however reluctantly—on what steps to take to decrease the probability of mid-air collisions. Right now, it looks almost certain that a CAS will be chosen for mandatory use on board U.S. commercial aircraft.* The only problem is what type of CAS will be mandated—a complex question at best (see Fig. 1).

As a result of delays in flight tests, an anticipated FAA report comparing test results of competing CAS systems and recommending a national program will probably be released in October, FAA's David Israel told *Spectrum*.

The outcome of such a decision will not only affect the future course of the nation's air safety, but provide economic benefits to a major segment of the electronics industry as well. Not only will such technologies as microprocessing and solid-state sensing enable CAS systems to become practical airborne realities, but pricing is expected to be much lower than for original prototype systems.†

The controversy

What is presently being argued by those concerned with air safety is not whether there is a need for a mandatory CAS—practically all agree that there is—but rather what type to choose—airborne or ground-based—and how soon. Proponents of airborne CAS (one contained in and controlled from the aircraft)—which include members of Congress, the airlines, and many private and commercial pilots—feel not only that an airborne system has better coverage, but that final control of a plane should be in the hands of the pilot.

On the other hand, the FAA—with 50 000 persons on its staff, almost half of whom are air traffic controllers—is concerned, among other things, with dividing responsibility between airborne and ground-based systems, and has historically favored ground-based CAS.

Despite FAA's preference for ground-based systems, there has been considerable pressure to have the FAA make airborne CAS equipment mandatory on all aircraft. In Congress, several bills have been introduced by such air safety proponents as Senator Frank E. Moss (D-Utah) and Rep. Barry Goldwater, Jr., with the most definitive proposed legislation requiring airliners to be equipped with an airborne CAS by mid-1976, and all other aircraft by mid-1978.

Congress's Aviation Advisory Commission (AAC) has cited preliminary studies showing that placing certain traffic control functions in the cockpit—including collision avoidance—may be *more cost effective* than an upgraded ground-controlled system.

Although differing in phraseology, several Congressional Committees have expressed similar sentiments. The House Committee on Government Operations, cautioning against blanket acceptance of the ground-based approach, felt that, even with improved equipment and procedures, such a system was inadequate to meet collision needs. Furthermore, it recommended that FAA consider airborne CAS and less-costly (at the time) PWI (proximity warning indicators; see box, p. 32) as inherent elements of the ATC system and not merely as backup devices.

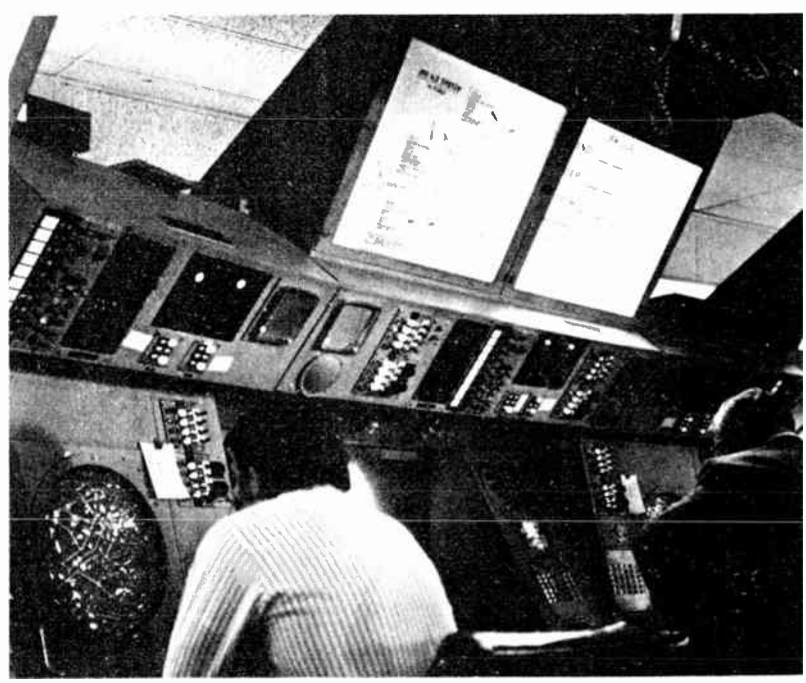
Other pressures to install airborne solutions have come from various professional aviation groups, including the Air Line Pilots Association, the Air Transport Association, and the Aircraft Owners and Pilots Association, and the CAS manufacturers.

Air vs. ground control

As seen in Fig. 1, in order for any airborne or ground-based CAS to work, the detected aircraft *must* carry compatible airborne equipment. In the case of airborne CAS, the FAA estimates it will take about five years to equip the entire U.S. air fleet. In April, when asked which airborne system being tested stood the greatest chance of being accepted, Mr. Israel told *Spectrum*:

"At this time, it looks as if I would initially recommend a system much like the one proposed by Litchford, since it would seem to provide for a large incre-

[2] At the hub of Kennedy International Airport's air traffic control center is the Common IFR Room, where a myriad of ground controllers gaze steadfastly at their respective ARTS-III terminal displays providing continual tracking (along with such alpha-numeric tags as plane identification, Mode-C altitude, ground speed, and destination airport) of all aircraft in a particular sector of airspace (see cover). By 1976, this equipment will have an additional MSAW capability to warn controllers of aircraft intrusions below prescribed FAA-authorized minimum safe altitudes.



* Some CAS systems were described in Gordon D. Friedlander's definitive three-part series on air traffic control that appeared in *Spectrum* in June, July, and August of 1970 ("At the crossroads of air-traffic control"). CAS, incidentally, with even wider-ranging capability than GPWS, has been studied for almost two decades, with one system (McDonnell Douglas's EROS-I) operational since 1965.

† There have been only a handful of new sensor developments in the past 100 years (see R. K. Jurgen's "Instrumentation" article in *Spectrum*'s April issue, pp. 52–55). Luckily for the avionics industry, the solid-state pressure transducer—slated to replace the present aneroid barometric system for altitude recording—has been one.

ment of safety with minimum additional airborne equipment."

The principal ground-based technique now being studied by the FAA to augment the present ATC system is called intermittent positive control (IPC), which operates with the FAA's future discrete-address beacon system (DABS), a fully computerized interrogation system conceived by DOT's Air Traffic Control Advisory Committee (ATCAC), designed by the Massachusetts Institute of Technology's Lincoln Laboratory, and presently being tested at the FAA National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, N.J.

Based upon automatically generated and transmitted avoidance commands from ground computers to pilots within the existing airspace coverage, IPC could be expanded to cover additional airspace through either additional ground sites or a supplemental airborne system known as Synchro-DABS. The U.S. Comptroller General has estimated that a DABS-IPC ground network of sensors and equipment would not be fully operational until about 1988.

Despite the pressures for an airborne CAS, FAA officials at Congressional Committee hearings have voiced the position that the primary means of separating air traffic and avoiding in-flight collisions is the air traffic control system, a stance based on a 1969 ATCAC report favoring a ground-controlled CAS over any purely airborne system.

That FAA is indeed committed to ground-based air traffic control as the primary collision-avoidance system is unquestioned. In outlining the nine features of the nation's future upgraded third-generation ATC system (UG3RD), Mr. Israel listed IPC and DABS first and second (see Recommended Reading box).

When this writer asked Mr. Israel just how the airborne CAS system chosen at the end of the year would fit in with any future ground-based IPC CAS, his answer was that such an airborne system would only serve as an interim solution until the IPC system was fully installed, perhaps within a decade.

If the opinions of persons like Captain William B. Cotton, chairman, Air Line Pilots Association (ALPA) Air Traffic Control Committee, are any indication, however, IPC may have some trying times ahead of it: "Airborne CAS will work worldwide; IPC will only be operational in the U.S., at best."

Perhaps the greatest single difference between airborne and ground-derived systems—aside from cost and placement of system control—lies in the degree of

PWI—the cheapest way out?

Although there is at present no legislation mandating proximity warning indicators (PWI, also called pilot warning instruments) or even a national standard, it appears that—because most midair collisions have occurred near airports, during daylight, in clear weather, at low altitudes, and with slow closure speeds—PWI is the most likely and the most inexpensive candidate for immediate acceptance. Although this may have been true a year or more ago, development of the higher-capability CAS systems of today has deflated their cost to less than PWIs, one of the reasons the FAA has stopped testing PWIs. In the FAA's estimation, on a cost-benefit basis, the PWI is no longer viable.

Successfully used by the U.S. Army in dense operating areas, PWI has also been recommended by a 1973 FAA study on low-cost systems. As a result of this study, four companies were given a half million dollars in contracts to develop an experimental PWI by July 1974. So far, flight testing of these PWI systems has been suspended until test data can be obtained on airborne CAS systems. The four companies receiving FAA contracts appear with asterisks in Table I.

I. Available PWI systems (see Comptroller General's Report to the Congress)

Company/ System	Cost	Comments
Bendix*	$1400	As with most other PWIs, both planes must have PWI equipment for detection; however, since the system listens to another plane's ATCRBS responses, any plane with this PWI can detect any plane with an ATCRBS transponder.
CYGNED	2000	One of the few noncooperative systems, this PWI can detect other planes, even those without special equipment, within 3/4 of a mile and 1000 ft above or below the PWI-equipped aircraft.
Honeywell YG-1054	3500 (military), 900 (civilian)	Originally designed for low-performance helicopters, this unit warns a pilot whenever an equipped aircraft is within a preselected range and relative altitude.
YG-1081	—	Designed for high-performance aircraft, this unit and the YG-1054 can operate together, except that it issues an alarm only when an intruder is a definite threat.
Kollsman*	3000	Primarily an infrared strobe system, this unit uses optical sensors aboard protected aircraft to detect the near-IR radiation of xenon strobe lights emitted from other aircraft.
Lockheed*	3000	A cooperative radio system, Lockheed's PWI uses a receiver aboard the protected plane to detect radio beacon transmissions from intruding aircraft. The cooperative beacon costs $750.
Rock Avionics	1495	As with Kollsman, this unit detects IR from planes carrying anticollision strobe lights by means of optical sensors; detection range is 1½ miles or ½ mile in high-density areas.
Vega Precision*	4300	In this system, the PWI must interrogate intruding aircraft equipped with $400 remitters for 200-degree forward and 1000-ft above-and-below protection.

Simulating disaster: the best way to go?

Those readers familiar with the great contribution simulators have had in training pilots for both commercial and military flying will no doubt be surprised to learn that simulators for training air traffic controllers for today's radar environment are rarely, if ever, used. By the time an air traffic controller has grown from his original GS-7 Civil Service rating to a top-echelon GS-13 or GS-14, most of his radar control experience will have been obtained from real-time job training at one of the country's many airports.

Not that the capability for building a modern air traffic control simulator is lacking, mind you. In recent years, a whole new industry based on the digital computer and the realism derived from such methods as six-axis tables or platforms and film/video landscape displays has emerged in the simulation field—a far cry from the nonillusory stable platforms of *Links* trainers of three and four decades ago. Moreover, the world's best air traffic simulator is being used at FAA's NAFEC center in New Jersey, not for training purposes, but for R&D only.

The fact of the matter is that air traffic control simulators do not require such realistic and expensive techniques as six- or even four-axis platforms and wide-angle panoramic viewing, since all that a controller needs simulated are the two-dimensional, multisituational displays of the air sector under his control—quite a different problem from the motor/visual inputs demanded in pilot training.

The use of ATC simulators has already proven itself in ATC evaluation programs at Hurn, England; Amsterdam, the Netherlands; Rome, Italy; and Copenhagen, Denmark, where Ferranti simulators have the capability of displaying 100 targets of ten types in an 800-square-mile area. This ATC simulator can be used not only for training but for evaluating route changes and validating experienced controllers.

According to John K. King, past Executive Director of the Air Traffic Control Association, if the FAA had bought ATC simulators a dozen or more years ago—when King was a member of an FAA project group that suggested it—the problem of cost would not be the inflation-ridden problem it is today. As a result, "practically all air-traffic control experience is derived from actual training in the field, necessitating the use of an experienced controller as an instructor," claims King. Even worse, Mr. King maintains that "most controllers do not receive training on the most sophisticated ATC equipment until relatively late in their training, when they are actually working at an advanced air traffic control tower or center, participating in decision-making under unimaginable high-pressure conditions, practicing with real airplanes carrying real people and interfering with the control responsibilities of an experienced controller."

If the air-traffic controllers are operating in such high-tension environments, one can well imagine what the pilots themselves are going through. Part of the problem is the fact that pilots may not get enough practice in responding to emergency situations. Cited as a primary cause of aircraft accidents, *pilot error* has been recognized as a significant factor in well over 50 percent of all aircraft disasters.

Not all agree with this analysis, however. In the eyes of Captain W. B. Cotton of ALPA, "Response training to simulated emergencies does nothing to reduce this type of error. It can only be reduced through increased situational awareness and use of better judgement."

In determining what factors contribute most to human failure, various studies over the past few years have produced some amazing results. For one, it has been demonstrated that past accidents are not predictive of future accidents as far as the individual pilot is concerned.

How have pilots been practicing emergency flight procedures? For most pilots (except perhaps airline pilots), the chance comes only during an actual crisis in the air or whenever they can spend time in a simulator specifically designed for the aircraft being flown. Unfortunately, an air crisis can be calamitous, and the scarcity of aircraft simulators does not lend itself to continual pilot practice. One alternative, practiced by the military until several crashes dissuaded its further use, was to place a NATOPS (The Naval Air Training and Operating Procedures Standardization Program) flight evaluator in the cockpit alongside the pilot. During the flight, the NATOPS man would suddenly fiddle with some critical control, hopefully eliciting the correct emergency response from the pilot.

One of the most cost-effective ways this writer has seen to give pilots constant and convenient training in responding to flight emergencies was demonstrated by Grumman Aerospace Corporation in Bethpage, N.Y. What engineers at Grumman—a major supplier of Navy aircraft—have done is to build a portable (30–40-lb, 29- by 22- by 8-inch) emergency procedures trainer—called SCEPTR—that costs $15–$20 000 per unit (for a 25-unit order) and can be carried in a suitcase (see illustration).

Marketed over a year ago and soon to incorporate programmable ROMs (read-only memories) that will be erasable, SCEPTR can presently test a variety of simulated aircraft emergencies that are programmed on magnetic cards, each of which must be inserted into the unit separately. After insertion of the plastic card, the unit can be operated in a "training," "testing," or "timed" sequential mode, depending upon the application.

Those in other fields demanding similar *procedural decisions* to be made with or without disastrous alternatives for failure can expect to see more systems like SCEPTR used in lieu of actually dedicating real and costly main systems for instructional use.

coverage. In this respect, an excerpt from a recent U.S. Comptroller General's report to the Congress on aircraft mid-air collisions is revealing:

"Implementing any system will be costly to the user and the Government. Only an airborne solution can provide complete airspace coverage; however, FAA has not determined whether such coverage is warranted or what the cost-effective level of coverage would be. Ground-based control providing a collision-avoidance function will require large investments to upgrade present air traffic control capabilities. Since the present air traffic control system services only part of the airspace and less than 30 percent of flight operations within that airspace, total costs for facilities, equipment, and land . . . will depend partly on the extent of expansion necessary for effective collision avoidance. Whichever approach is chosen, new equipment will be needed in the aircraft."

Hence, the projected cost of either of the alternative CAS approaches to both the FAA and users of the airspace is expected to be very high, indeed, perhaps in excess of $1 billion. And with inflation and budgetary cutbacks dominating the economy, the system offering the best cost-effectiveness is going to be hard for the Government to resist, if it decides that a substantial new investment is required at all!

Indeed, Mr. Israel's most recent statement to the author last month made his position quite clear: "The FAA can be expected to recommend improvements to the existing system and then question whether *any* major new investment is required, either on the ground or in the air."

Planning future air safety

How then does the FAA plan to upgrade its air safety program over the next decade and a half? In an interview with Martin Pozesky, Deputy Chief of FAA's Communications Division, and others at FAA's Buzzard Point installation in Washington, D.C., *Spectrum* found that the agency is tackling the problem in a number of ways.

• To keep planes from running into the ground in both fair and foul weather, both airborne GPWS and ground-based MSAW (minimum safe altitude warning) have been scheduled for implementation, GPWS by December 1 and MSAW by August 1976. To get MSAW—an additional computer capability that will complement the present ARTS-III ground control system—into operation at 61 major terminals by this deadline, a $2.4 million contract was awarded to Sperry Rand's Univac Division in April for the necessary hardware and software, which will automatically trigger a visual/audio signal for a controller's attention whenever an aircraft penetrates the minimum safe altitude over terminal airspace.

Although GPWS is scheduled to go operational on December 1, more than 30 of the world's approximately 200 scheduled and nonscheduled airlines have already adopted the system, some as long ago as 1970. In the U.S., Pan American Airlines ordered GPWS for its 140 planes after two serious accidents last year.

• In providing air safety measures against air-to-air collisions, both airborne and ground-based collision avoidance, as well as proximity warning indicators (see box, p. 32) are being studied by the FAA. Whereas CAS is an all-weather system that detects threatening aircraft, automatically evaluates the degree of threat, and provides evasive maneuvers to the pilot, a PWI only alerts the pilot to nearby aircraft, after which the pilot must then visually locate the intruder and execute an evasive maneuver.

Describing the features of FAA's latest-version air traffic control system (UG3RD), Mr. Israel listed the following:

1. *Intermittent positive control (IPC).* IPC will offer ground-based surveillance of all aircraft—both controlled and noncontrolled—transmitting collision-avoidance instructions to pilots equipped with location, altitude, and identity transponders as well as cockpit displays. 1978 is the date that IPC might begin to be implemented, with full operational status by the mid-1980s, a major reason for early acceptance of an already-developed airborne CAS. Any CAS—either airborne or IPC—would have to receive acceptance by the International Civil Aviation Organization to be fully effective. In any case, foreign aircraft operating over the U.S. would have to carry compatible CAS according to Federal air regulations.

2. *Discrete Address Beacon System (DABS).* In order for IPC CAS to work, it will need an improved surveillance capability as well as a ground-to-air data link for rapid transmission of control messages—the DABS system. Fully compatible with the existing Mode C ATCRBS system, DABS does not have the problem of garbled replies from two planes within the same slant range that ATCRBS has, mainly because of DABS's selective interrogation system. A general-aviation version of the DABS transponder will cost a few hundred dollars more than present models (which provide Modes A and C at a cost of from $600 to $2500); DABS sites are expected to run from $200 000 to $500 000 each. If 200 sites are required (95 percent of U.S. air-carrier aircraft operate out of 200 airports), the total cost could reach $100 million.

3. *Area navigation.* To reduce the extra mileage that aircraft must now travel between certain terminals and to increase the capacity of present air routes, RNAV or "area navigation" will give aircraft an avionics capability of following predetermined altitude and time schedules, enabling more routes to be handled, controller vectoring and pilot workloads to be reduced, and airline operating costs to be lowered.

4. *Microwave landing system (MLS).* Following a decision made in behalf of DOT, DOD, NASA, and the FAA, the Bendix Corp. and Texas Instruments were chosen in February to develop an advanced MLS by 1976 for both U.S. and possibly international use. Based on a time-reference scanning beam technique, which was chosen over an ITT/Hazeltine doppler method, the two MLS prototypes are expected to cost $30 million above the $25 million already spent on R&D. To cost $100 000 each, approximately 1500 MLS units will be used throughout the U.S. to increase airport flight capacity via multiple flight paths and closely spaced parallel approaches.

5. *Automation.* Added to the present NAS Stage A and ARTS III systems, higher levels of automation should help to relieve controller workloads.

6. *Airport surface traffic control.* Commensurate with the increase in air traffic, there is a growing need for better control of airport surface traffic. Schemes for improved handling of such traffic include

Postmortem for Flight 66

At approximately 4:06 p.m. on June 24, Eastern Air Lines flight no. 66 (a Boeing 727 nonstop from New Orleans with 124 passengers and crew aboard) was making its final approach at New York's JFK Airport onto runway 22 during the height of a violent line squall, complete with thunder, lightning, heavy rain, and strong crosswinds. Runway 22 is equipped with an instrument landing system (ILS) to provide a precision approach procedure during instrument flight rules (IFR) conditions. ILS runways, therefore, furnish electronic instrument guidance to the pilot so that a plane with compatible on-board electronic equipment can "lock-on" to the system for a virtually "hands-off" landing glide-path until the final seconds before touchdown, during which time the on-board computer and instrumentation can attain the exact alignment and angle of descent for the final approach for landing.

The flight-control system, with its on-board computer, has several in-flight and landing capabilities, among which are:

1. Navigation (NAV). Inertial, doppler, loran, and compound navigation outputs can be processed by the flight computer to furnish commands to the autopilot and "flight director."
2. VOR/LOC. This mode provides the automatic intercept and tracking of VOR (omnirange) radials and localizer courses selected on the flight director's course indicator.
3. Approach (APPR). Glide-slope arm, capture, and gain programming are combined with localizer capture in the approach mode. Submode switching from glide-slope capture is automatic.
4. IAS hold. The "indicated air speed" at the moment of mode engagement will be maintained by the autopilot and commanded by the flight-director's "V-bar" pitch movements.
5. VS hold. Precisely timed descents can be flown by means of the vertical-speed hold mode. The autopilot will hold and the flight director will command the vertical speed indicated at the moment of mode engagement.

What went wrong? Why did EAL #66 suddenly plummet into the ground, short of the runway apron, and disintegrate? One theory is that it was nothing more than excess turbulence ("wind shear") accompanied by a strong downdraft that drove the aircraft toward the earth. Several eyewitnesses to the tragedy reported that they saw lightning strike the tail surface of the air carrier, seconds before projected touchdown, while it was apparently on its correct glide-path. Others observed the plane making an approach through the rain squall that was "too low." In any event, there seems little disagreement that the aircraft became unstable during descent, losing further altitude rapidly, and severing six of the high-intensity lighting towers that mark the approach to the runway.

Photo by: *The New York Times.*

Even if the lightning strike can be proven to have occurred, there is some disagreement among experts as to the conclusions that can be drawn. Most claim that, because of an elaborate system of arresters and protective devices, lightning striking a plane will "run around" the fuselage and/or wing surfaces without producing *any* structural damage while the plane is airborne; other authorities claim that a direct hit by lightning can blast a hole through a wing, or the cabin, sufficient to jam the controls. Further, at least one of two major disasters, involving air carriers, occurred as the direct result. (The proven instance was the crash of a Pan Am jet flying in a thunderstorm over Elkton, Md., several years ago. The bolt struck the vent line of a wing fuel tank, thereby igniting the fuel vapors. The subsequent flash exploded the fuel tank and destroyed the plane. However, since that time, protective baffles and other safeguards have been installed to preclude a repetition of such an event. The second—and still conjectural—incident involved a TWA Super-Constellation, flying out of Rome during a violent electrical storm, in the late 1950s. For want of a better explanation for that crash, the blame was placed on lightning.)

However, virtually *all* of the experts seem to agree that, whether or not actual major structural damage can occur, the on-board computer and associated electronic equipment could be completely knocked out by a lightning bolt. However, even if this were to happen, it is likely that a built-in "failsafe" feature would lock-out the computer and prevent it from going "haywire" and driving a plane into the ground. Nevertheless the next question may very well be: Were the computer and electronic circuits put out of effective action *before* the pilot could possibly override the system and resume manual control? The National Transportation Safety Board, which is investigating the accident for DOT, may soon have an answer to this perturbing question.

As of this writing, the death toll in the disaster stands at 112, with 10 of the 12 survivors on the critical list. The central—and paramount—question is whether, considering the systems, both automatic and manual, discussed in this article, the tragedy could have been avoided. Also, one might wonder if the only solution to this type of disaster—now and in the foreseeable future—lies in the human segment of the control process. In the case of Flight 66, this, perhaps, may have been accomplished by FAA's air traffic controllers temporarily halting landing operations—at least on runway 22—in view of the prevailing severe weather conditions on that terrible afternoon.—*G. F.*

Using color as a third dimension

It may be that the engineering community has been providing solutions for present-day problems years ahead of their time. In a press release dated May 18, 1964, that was subsequently picked up by *The New York Times* on May 30, 1964, David M. Goodman—then a senior research scientist at N.Y.U.'s College of Engineering—released details of a patent describing an all-weather landing and collision-avoidance system for commercial aviation. What is so remarkable about Mr. Goodman's data processing and display format is that it is now more applicable than ever for solving air safety problems.

Based upon another Goodman invention—a single-gun shadow-maskless high-resolution beam-indexing color CRT—the landing system includes a cockpit display that warns a pilot of collisions with either other aircraft or the ground by means of color ranging of radar targets. In its air-to-air and ground-avoidance detection modes, all targets are presented line-of-sight to the pilot, with color providing range information. Those planes or ground obstacles closest to the protected aircraft are displayed in red, followed by green, blue, and white for subsequently more distant aircraft. Interpretation of the display by the pilot is therefore instantaneous.

In its landing mode, the Goodman CAS system simulates the runway configuration by sensing runway markers similar to those used in the British RAE visual landing system, where markers seen from below the prescribed glide path appear as red and those seen from above as white. In tests conducted at FAA's NAFEC installation in 1960, pilots indicated a strong preference for just such a *visual* glide path indicator; the Goodman system gives pilots the same capability, only in zero-visibility weather as well!

Today's applicability of the Goodman concept would take the form of a third-dimensional addition to such two-dimensional CAS pilot warning displays as that used by the Litchford BCAS (see Fig. 1). Along with an alphanumeric tag of all relative altitudes, the CRT could just as well display all targets in color-coded parameters indicating varying levels of danger (e.g., closing altitude, closing ranges, closing bearing rates). In such a manner, the pilot would be able to distinguish which aircraft present the most immediate threat, thereby helping to choose the most appropriate escape maneuver.

new ground surveillance radars to supplement existing radar equipment, magnetic loops implanted in runways and taxiways, autonomous controls at intersections, and ATCRBS and DABS trilateration schemes for clutter-free surface pictures.

7. *Wake-vortex avoidance systems.* A problem that has marked the advent of large-body jets, wake vortices trailing such aircraft can endanger planes as far behind as four to five miles. If given the location of wake vortices as they occur, controllers would be able to tailor aircraft spacing on approaches to prevent inefficiently wide separations.

8. *Flight service stations (FSS).* Under an FAA network of 283 flight service stations, general-aviation pilots are now able to get telephone weather briefings and file flight plans. The system, however, is unable to keep up with present flight-service demands. When automated, FSS will maintain a central processing facility, 30–50 manned full-time stations, and some 3500 unmanned self-service stations accessible through remote input-output terminals.

9. *Aeronautical satellites for transoceanic flights.*

Recommended reading

The following literature will give the reader an excellent description of the development of the Federal airways system, air traffic control, and air safety:

- Jackson, W. E., ed., *The Federal Airways System.* IEEE Catalog No. 70M-27-AES, 1970, 458 pp.
- Israel, D. R., "Air traffic control: upgrading the third generation," *M.I.T. Technology Rev.*, vol. 77, pp. 14–25, Jan. 1975.
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With the launching of two Aerosat voice and data-link satellites over the Atlantic in 1978, a joint U.S./Canada/European program will have been started for complete oceanic airspace surveillance and communications (now conducted in HF only and approaching saturation in many parts of the world) in that area. If this effort is successful, worldwide oceanic coverage by geostationary satellites would not be unrealistic.

So far, there have been two challenges to the development of UG3RD. The first—a "fourth-generation" system called AATMS (advanced air-traffic management system) resulting from an independent Department of Transportation study—attempted to answer the question of what a system would look like if one started to design it from scratch. Based on satellite deployment for surveillance, navigation, and communications, AATMS—although extremely effective, accurate, and able to handle large volumes of traffic—was grounded as being highly susceptible to failure, vulnerable to jamming, and highly expensive.

The second obstacle to UG3RD came in the form of the already-cited Congressional AAC report questioning the use of centralized, ground-based traffic management in favor of "distributed management"—in other words, a return to the cockpit of some air traffic control functions.

In Mr. Israel's words: "The conclusion of this major technology assessment effort was that systems using satellites or more distributed systems involving greater avionics capabilities do not seem to hold major promise over the next 20 years. The UG3RD and extensions to it can handle air traffic control requirements to the end of the century; in the meantime, experiments on satellite-based control and increased avionics capabilities will continue." ◆

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The R&D 'bootleggers': inventing against odds

The persistence of individual researchers triumphed over skepticism and disinterest as illustrated in two revealing case histories

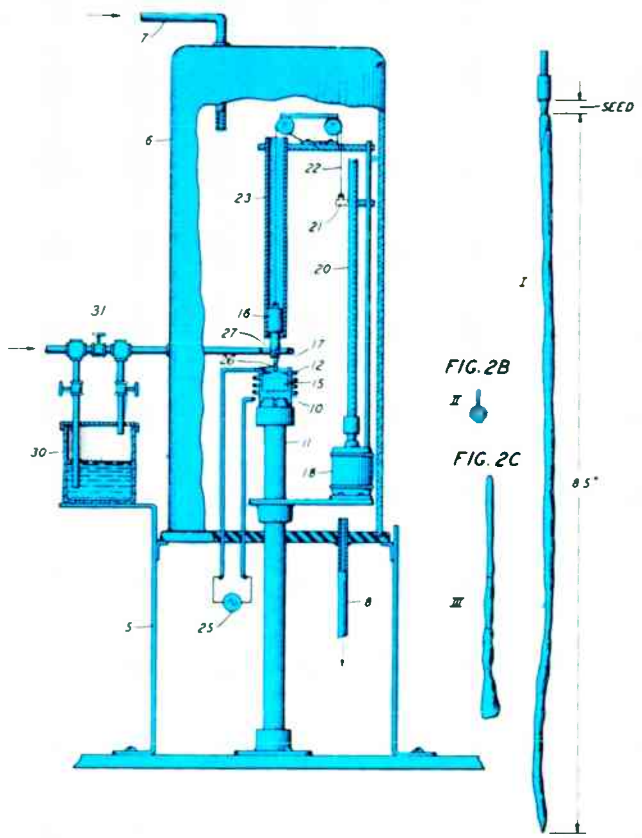
> . . . science seldom proceeds in the straightforward logical manner imagined by outsiders. Instead, its steps forward (and sometimes backward) are often very human events in which personalities and cultural traditions play major roles.
>
> —James D. Watson, *The Double Helix*

James Watson's observation is as appropriate to electronics as it is to the esoteric reaches of biology and physics. Yet, in biology and physics—and indeed in all science and engineering—this truth is often forgotten, lost amidst the dispassionate, "factual" syntax of the published papers on which posterity must rely for its understanding of technical progress. Despite the considerable merit in this style of reporting, there is also the serious weakness that it helps create an essentially mythical picture of an enterprise in which human drives and emotions play but a minor role.

Michael F. Wolff Contributing Editor

As a small step toward rectifying this imbalance, this article will describe just two of a great many inventions in electronics that owe their occurrence more to the inspiration, faith, and persistence of individuals than to the careful planning or prescient goal-setting of top management. These inventions are the methods developed at Bell Labs between 1948 and 1950 for growing single-crystal germanium and silicon for transistors, and the random access disk memory built at IBM during the mid-1950s. The former was chiefly due to the dogged persistence of one man, Gordon K. Teal, who in the words of William Shockley "bootlegged on a shoestring basis a program of preparing a crystal grower without an official authorization." The disk memory was the product of an inspired team working under inventor Reynold B. John-

Single-crystal germanium



Gordon K. Teal "bootlegged on a shoestring" a system for growing single-crystal germanium for transistors. Part of the July 13, 1954, U.S. patent, issued to Teal and J. B. Little, is shown.

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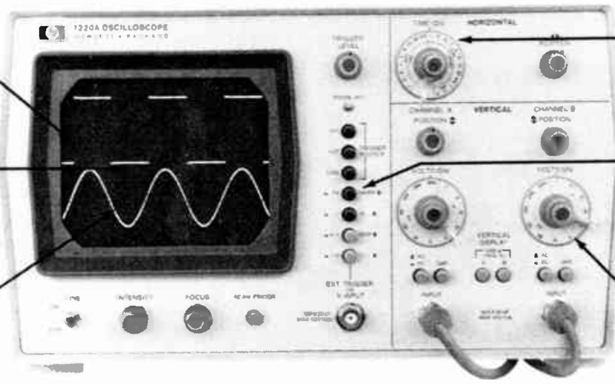

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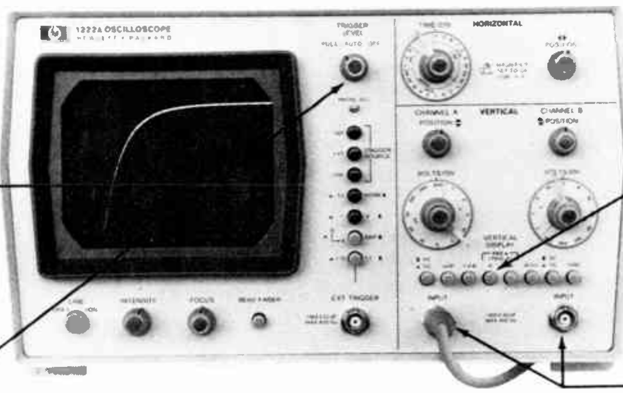

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son in a new laboratory that was created in the hope that something just that important would emerge.

A love affair with germanium

Gordon Teal's story goes back to the 1920s when he was a student at Brown of Charles Kraus, a former president of the American Chemical Society and one of the world's few experts on germanium. Teal wrote his master's and doctoral theses on germanium, forming in the process a deep sentimental attachment to "this strange and exotic element" that was to remain with him always. Teal recalls that, in those days, germanium was only a scientific curiosity and that its apparent uselessness both fascinated and challenged him. "A research man is endlessly searching to find a use for something that has no use," he observes.

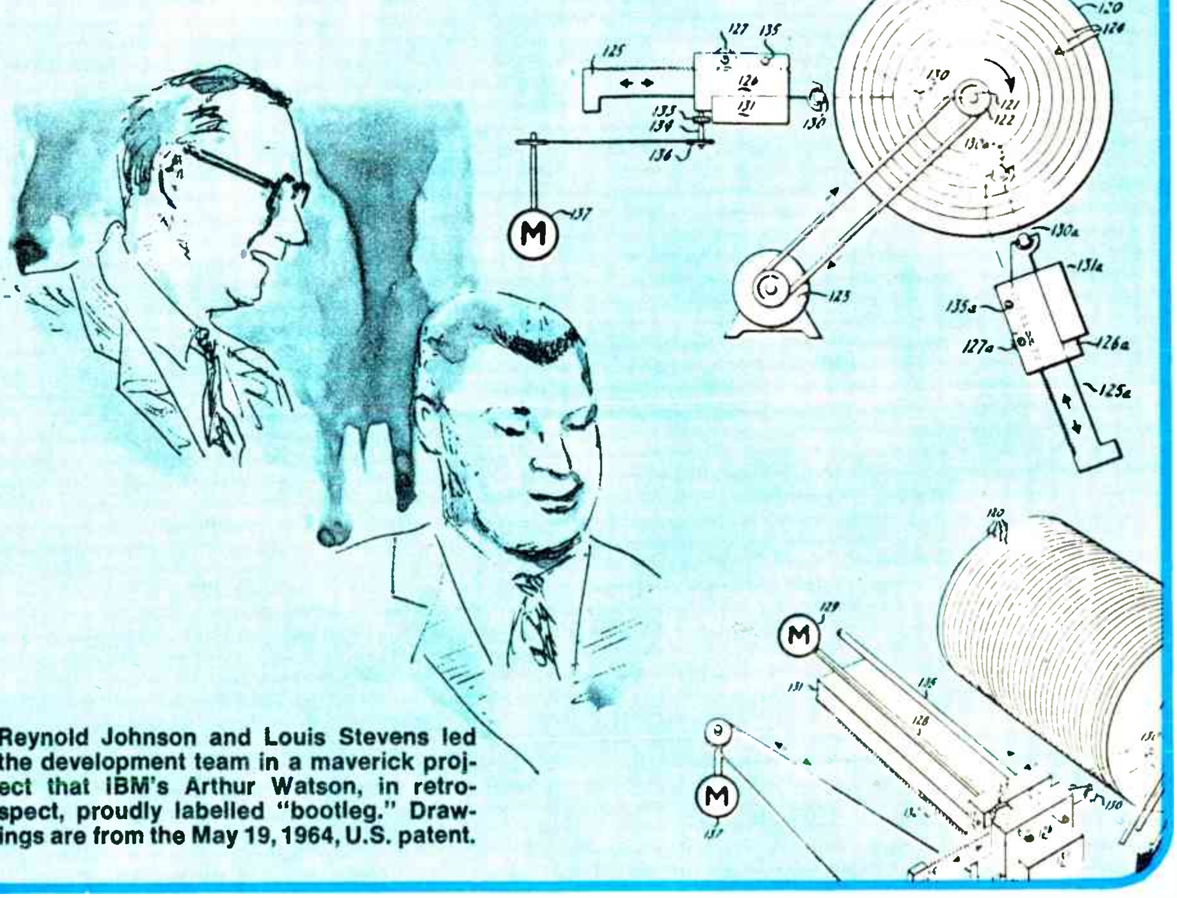
In 1930, Teal joined the staff of Bell Labs and for the next twelve years was involved with research on television tubes and materials. During this time, says Teal, he made several attempts to initiate germanium studies but was unable to arouse much interest among other researchers at the Labs.

In February 1942, the television work was discontinued and Teal had a chance to fabricate some germanium microwave rectifiers, believing they might be better for radar applications than the silicon rectifiers then being studied. But once again he was unable to interest others in giving much support to this line of research. A meeting was set at which Teal could show his results to Mervin J. Kelly the by-now legendary research director who pushed his people to seek a replacement for the vacuum tube. The outcome of the meeting, claims Teal, was that he would be permitted to continue his research but would have to do so on his own. "I felt that if they really thought it was important they would give me help. The result was that I became discouraged and began to doubt my intuition about its importance. I decided to look for other projects that would be more interesting to people at the Labs."

Thirty-five years afterward, it is probably impossible to determine just how much disinterest there actually was in Teal's experiments, and why. Kelly is dead; other principals have been retired for a number of years and are frank to admit having little memory of those incidents. Teal is remembered by one of his bosses, physical chemistry head Girard Kohman, as "a very careful worker, a perfectionist in whom I always had a great deal of confidence." A colleague remembers him as "a kind of lone wolf" whose sensibilities ruffled some feathers over the years.

Teal himself seems to attribute his difficulties in getting support largely to the fact that he was one man working in the physical chemistry subgroup of the chemistry department while most of the diode work was going on in another subgroup—metallurgy. But the importance of this episode lies not so much in what actually transpired as in how it was perceived by Teal and the effect it had on him. This effect was to discourage him so greatly that he switched to "more interesting" projects. But in so doing, he learned a lesson that was to prove of great importance

Random access disk memory



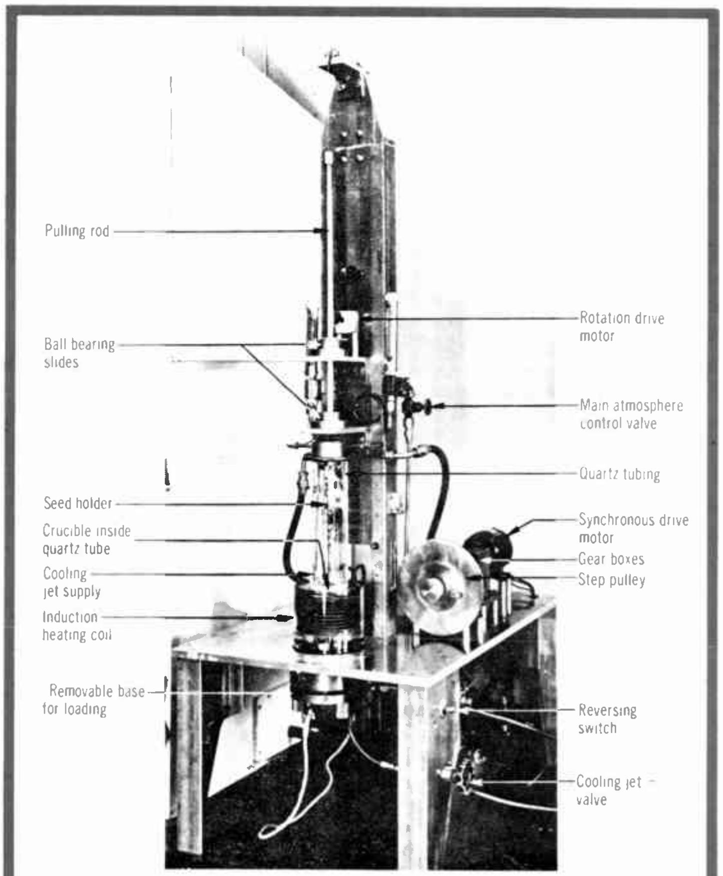
Reynold Johnson and Louis Stevens led the development team in a maverick project that IBM's Arthur Watson, in retrospect, proudly labelled "bootleg." Drawings are from the May 19, 1964, U.S. patent.

to his career as well as to the ultimate development of the transistor.

Teal learns a lesson

Teal worked on a variety of projects during the next year or so, including new types of resistors and pyrolytic deposition of alloy films of germanium and silicon. He requested and was given responsibility for coordinating assistance to Bell Labs' radar attenuator and termination research. Then, in the winter of 1943, he had an accident. While cleaning a waveguide with nitric acid, he breathed an excessive amount of nitric oxide and was laid up for several months with pneumonia. When he returned to work, he learned that the Massachusetts Institute of Technology's Radiation Lab, then deep into defense work, had given the metallurgy group a contract to study germanium!

"Over the next year or so, as germanium proved itself to be a marvelous rectifier (though not at microwave frequencies as I had originally thought), I came to the realization that I had made a great mistake in allowing myself to be so discouraged as to drop the project. Having had such a deep intuition that this was the most important job I could have worked on, I should have pursued it on my own regardless of what others might have thought. So I promised myself I would never make such a mistake again, that if I ever had another idea I considered a world-beater, I'd work on it even if nobody gave me any help. I'd work on it until I was kicked off."



One version of the apparatus Gordon Teal and John Little devised for pulling single crystals of germanium at Bell Laboratories nearly thirty years ago.

Teal's second chance came with the invention of the point-contact transistor in December 1947. At that time, he was in charge of the chemistry work on a silicon carbide varistor for a new telephone handset. This varistor was a critical component—it was to be extremely reliable and perform well while costing only one tenth what previous varistors had cost. Thus, Teal's assignment was considered an important one to Bell Labs, and Teal believes his superiors felt they were doing him a favor by giving him the responsibility. Nevertheless, the strange and exotic germanium was still his first love. Early in 1948 when he learned (unofficially) of the transistor project, he realized it was his chance and began writing memos proposing various germanium research projects.

Trying again

Teal recalls the rationale for his pushing: "From my varistor work, I had learned a great deal about what was required of a component that went into the telephone system. As I began to learn about the possibilities for the transistor from the discussions going on around the Labs, I became more and more convinced that this was no ordinary device, but one that would be as important as the vacuum tube and that would proliferate in as many forms. My work over the years with vacuum tube materials and design had convinced me that it would be tremendously important to be able to make transistors out of a material whose properties were completely known and controllable, without such defects as grain boundaries, lattice defects, chance impurities, and undesired variations in donor-acceptor concentration. I believed that freeing the solid-state medium, through which the electrons would flow, from such defects would be as important to the successful development of the transistor as the achievement of ultra-high vacuum had been for the tube.

"In August 1948, I proposed that I work on developing single-crystal germanium. I had been familiar with single crystals since my days at Brown and indeed one of my first jobs at Bell had been to grow single crystals from solutions of mercuric iodide. A number of times since then, I had thought it would be awfully interesting to pull a single crystal of germanium, but I had never had an adequate reason for doing so. Now I had. Moreover, pulling crystals out of a melt had a very great political advantage in that the metallurgists couldn't say that I was using their metallurgical method, which was to solidify the material in a crucible. In other words, once I got started they couldn't stop me by claiming I was duplicating their methods.

"One afternoon toward the end of September, around quitting time, I encountered John Little and we got to talking about our work. He began telling me how he needed a germanium rod thin enough to be cut by a very small wheel in order to minimize waste. I saw that here was an opportunity to make a rod for somebody who had a real job to do. So as we were getting on the bus for Summit, New Jersey, I said, 'Sure I can make you a rod by pulling one out of the melt, and incidentally, it will be a single crystal too.' As soon as we got on the bus we started sketching. All we needed was something that would pull the rod out and would withstand the heat. This meant a graphite crucible in which to melt the germanium, and some method of pulling the thing up smoothly. We concluded between us that a clock motor would do the job. John happened to have a bell jar about thirty inches high that was part of a large high-frequency heater he used for fabricating experimental parts. This would suffice for growing the crystals in a hydrogen atmosphere. By the end of the three-mile ride we had sketched the equipment, and two days later we had built a crude machine in John's lab in New York City that could pull germanium rods containing large single crystals."

Little, who calls the many months when he worked with Teal "an exciting time, a lot of fun," remembers that he had been drafted by the late Jack Morton (then heading transistor development under Kelly) to work at getting better transistor structures; at the time he met Teal in the hallway he was interested in making thin filaments of germanium for a particular point-contact transistor configuration. "I was not having much success and so was intrigued with Gordon's ideas. We haywired something together at West Street and pulled some very uninspiring crystals at first. It was obvious we were getting some single crystals, but not my filaments!"

Crystal-pulling after hours

The crystal-puller does not seem to have made much of an impact initially. Still primarily responsible for the varistor, Teal spent the next few months working nights with Little to improve their equipment. In December, he proposed a single-crystal program on germanium and silicon to Morton who then supported him to the extent of paying for the necessary equipment. Throughout the winter Teal's efforts were carried out principally at night and on weekends. Moreover, he remembers being permitted to use his equipment only after promising to roll it into the closet when he was finished each night so it wouldn't be in the way of the metallurgists during the day.

"This meant that around 3:00 o'clock in the morning, I had to disconnect all of the hydrogen and nitrogen lines and the electric plug for the high-frequency heaters. Then I had to take the pulling mechanism apart and roll my equipment, which was about 6 to 7 feet high, and about 2 feet square, into the closet along with the gas, electric, and cooling water lines which were about 30 feet long. Of course, the whole process was reversed every afternoon around 4:30 when the technicians started getting ready to go home and I was able to begin work. The whole arrangement was pretty unsatisfactory and I remember my wife saying she was sick and tired of my spending most of my days and nights at Bell Labs, because she had three small kids to take care of."

Teal, who was not to get his own laboratory until December of 1949, felt greatly put upon throughout this period. He believes there were some people who did not recognize the importance of single crystals until 1950-1951 when he and Morgan Sparks succeeded in making the first junction transistors. As he has written previously, "Even after John Little and I had furnished germanium single crystals to numerous scientific and development projects in Bell Labs and had aroused considerable interest in them, the acclaim was by no means universal or effusive. There were talented scientists who rated the availability of single crystals as of rather small consequence. One materials expert stated unequivocally that mass-produced transistors would never use single crystal material—the costs of the single crystals would be much too great in comparison with ingots and, besides, ingots were very good material."

William Shockley has stated on more than one occasion that Teal was unsuccessful in selling a single-crystal program to him or to the chemistry department. "My position at the time was that we could do adequate scientific research by cutting specimens from the relatively large crystals that appeared naturally in the polycrystalline ingots resulting from solidified melts."

Again, after so many years it is difficult to pinpoint precisely what was happening in this regard. Little, who speaks admiringly of Teal as a "real dedicated guy, a hard worker," recalls that the metallurgy department was pursuing alternate methods "which weren't working as well as our own," but admits he did not feel the situation as acutely as Teal "since, as a member of a device group, I had been cutting across organizational boundaries for a long time." Kohman claims not to remember any real opposition to Teal's work although he does remember the head of the metallurgy department trying to persuade him that the single-crystal work was a metallurgy project and Teal ought to be called off. "But I always had a great deal of confidence in Gordon and wanted to see him succeed. So I refused to stop him. Besides he couldn't have been stopped anyway. He was determined to produce a single crystal."

The research manager's dilemma

In addition to the skepticism on technical grounds which he encountered, Teal feels the plain exigencies of managing a large and highly competitive laboratory raised obstacles for him. He reflects, philosophically, that "running a big department in a big organization is a pretty complex thing. Looking back, I can imagine my bosses wondering why they should have Teal fooling around with germanium when there was a whole metallurgy department that had accomplished so much with microwave diodes during the War. Furthermore, the view that single crystal material would be superior to polycrystalline material was still just an idea and not a proven fact.

"It's not that management had anything against me personally—as a matter of fact I'm sure they had my best interests at heart. It's just that they believed in people being assigned certain jobs and they didn't want everybody trying to work on everything. As a research manager myself, I've had the same feelings at times. On the other hand, I've tried to remember that you cannot predict where an idea of major importance is going to pop up. It might very well be in some department that has no assigned responsibility for it."

A time of anguish

Regardless of the extent to which his work was or was not encouraged, Teal recalls this period as one of considerable personal anguish. "Life can be made difficult for you in many little ways if you are not fully authorized to work on a project. It's easy for people in other departments not to back you when they know your own department is not behind you. Under these conditions, anybody who wants to can drop you off the tailgate."

Shockley has recalled how Teal feared his obstinacy might even cause him to lose his job. Teal explains: "I knew that if I neglected the varistor job I would really be in Dutch with my bosses. When your bosses say, 'This is your job,' you know damned well that if you don't work on it you are failing them in a responsibility of major importance. I felt it would be disastrous for me to ignore the varistor project. I felt so oppressed and disapproved of for continuing to work on germanium single crystals that I realized I might just get myself fired. But I was determined that I wasn't going to give up the best idea I ever had in my life."

Teal's determination paid off. It wasn't too long before the single crystals he and Little were producing were shown to be very different from polycrystalline germanium. Their high degree of perfection and purity resulted in minority carrier lifetimes 100 to 300 times greater and mobilities 3 to 4 times higher. "By the fall of 1949 everybody wanted to grow single crystals," says Teal. That winter he finally got his own laboratory, and, in March 1950, he and Little made the first public report of their work at an American Physical Society meeting. Meanwhile, he and Morgan Sparks had begun the single crystal work that was to culminate in the fabrication of the junction transistor within the year. The days of bootlegging were over. The importance of single-crystal technology had been established, and the science of the solid state greatly enlarged.

Now retired from Texas Instruments, where he founded and ran the central research laboratory for many years after leaving Bell in 1952, Teal draws a lesson from his experiences that he never fails to pass along in addresses to young researchers: "When you have a very good idea, believe in yourself and in your idea, and don't let anybody talk you out of it. If you can't get any help, then do it yourself. This is the most important thing I have learned in my career."

A maverick project at IBM

An attitude quite similar to that expressed by Gordon Teal seems to have infused the IBM disk memory project, which is frequently referred to as a crusade by those who were close to it. But there were notable differences as well. Whereas Teal felt himself to be largely alone, the struggle at IBM was a team effort from the start. This gave an obvious psychological boost to the IBM researchers. Despite the fact that a number of people in the company's existing product groups apparently considered the scheme to build a random access disk memory to be a boondoggle, the team's leader, Reynold (Rey) Johnson, recalls that "such skepticism could not combat the enthusiasm of the team."

Further, whereas Teal worked within the confines of a laboratory already in existence and regarded as a leader in industrial research and innovation, the disk memory emerged from a brand-new laboratory that had been expressly set up as a corporate maverick, outside of the existing organizational structure and with the hope that something just that important would result.

And, finally, there is a distinction probably more curious than significant: Teal saw himself as forced to carry out what is commonly termed bootlegged research and even worried about losing his job. A similar story has been widely told about the disk memory, but today those closest to the project vigorously deny that it was bootlegged. The story apparently has its roots in an address to an accountant's congress in 1962 by the late Arthur K. Watson, who headed IBM World Trade. Watson said: "The disk memory unit, the heart of today's random access computer, is not the logical outcome of a decision made by IBM management. It was developed in one of our laboratories as a bootleg project—over the stern warning from management that the project had to be dropped because of budget difficulties. A handful of men ignored the warning. They broke the rules. They risked their jobs to work on a project they believed in."

Former Watson staffers remember him saying words to this effect on more than one occasion as a way of emphasizing his distaste for organizational rigidity. Nevertheless, as far as both Rey Johnson and his assistant Louis Stevens are concerned, no one ever directed them to stop their work, and if their jobs were ever in jeopardy they apparently knew nothing about it. However, both men agree that the project was a maverick for IBM. They also agree that it would probably not have succeeded if it hadn't been planned as a maverick.

W. Wallace McDowell, now retired as an IBM vice president and then director of engineering, explains that this was one of the reasons a new laboratory was established in 1952 in San Jose, California, and Rey Johnson was brought from Endicott, N.Y., to run it. "In those days there was mainly product development work going on at IBM and we wanted things that were not being developed as part of that process. We wanted there to be more freedom—we wanted less directed research. Any R&D is a gamble, but Rey Johnson had a reputation as a far-out thinker and many of us felt that someone like him would make something happen that would pay real dividends. It paid off."

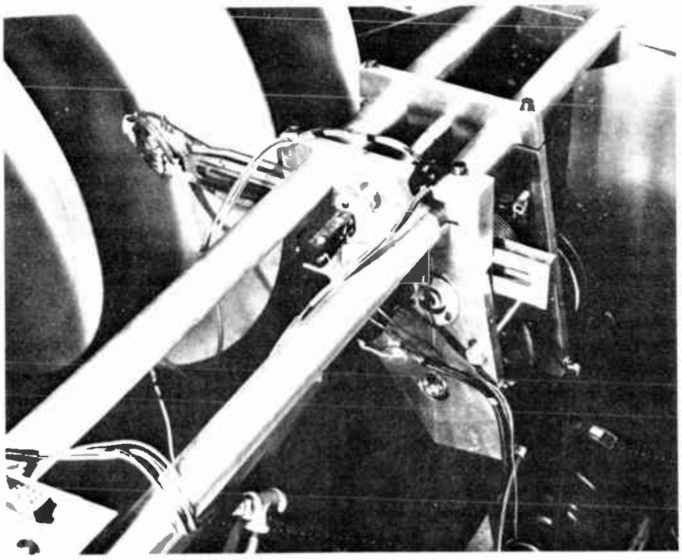
A lifetime of invention

Johnson, who today runs a small laboratory in Palo Alto, Ca., with his wife devoted to the design of such educational "tools and toys" as a small children's microphonograph, is considered one of IBM's great inventors. On the eve of his retirement in 1971, the company's *Think* magazine referred to his 37 years with IBM as ones of "brillant innovation, packed with inventions that have changed the worlds of both education and data processing." The first of these was the electric test scoring machine, which grew out of work Johnson had done as a young high school science teacher in Ironwood, Mich.

Between 1932 and 1934, Johnson tried to sell IBM on his machine, but received rejections of his ideas on three separate occasions. Finally, he sent a model to Benjamin Wood, of Columbia University, who was then establishing what was eventually to be the University's Thomas Watson Computational Laboratory. Wood was also interested in using machines to score tests and he considered Johnson's approach sound. "Nevertheless," recalls Johnson, "the patent department concluded the machine wouldn't work and IBM's executive committee turned me down with the suggestion that I return when it was complete. But Wood was confident it was a good machine. He called Tom Watson, Sr., in Maine, where he was on vacation, and told him he was missing a bet. Within the next couple of days I was hired—in spite of the executive committee."

By 1937, Johnson had turned the test scoring machine into a marketable product. In the years that followed, he developed the method for sensing pencil marks on tabulating cards, took charge of time clock development (then of great commercial importance to IBM), headed development of a new keypunch, and led several wartime projects. It was this record that, by 1952, had led Wallace McDowell to conclude that Johnson was the kind of prolific inventor he wanted to head the San Jose research laboratory.

Johnson brought only three people from the East. One of these was Lou Stevens, a husky Texan who had gotten his master's degree in electrical engineering at the University of California at Berkeley and had gone to Poughkeepsie to work under Ralph Palmer on the first production model scientific computer. Stevens eventually headed the disk memory project and today manages systems development in the nearby Los Gatos Laboratory.



This test bed was used for the extensive reading and recording experiments that led to the development of IBM's random access disk memory in the 1950s.

Computing in the fifties

Stevens emphasizes that in order to appreciate the nature of the disk memory achievement, one must understand how different the computing environment of the early 1950s was from that of today. "IBM was a relatively small company with perhaps $200 million in sales, no research to speak of, and engineering work going on mainly at Poughkeepsie and Endicott.

"All of the early electronic computers for commercial applications—the IBM 702 and others—were just high-speed analogs of punched card systems. They were batch systems, and the only thing electronics provided was higher speed and better cost per transaction. It is important to understand that this was IBM's basic thrust in the early 1950s. Few people were thinking about alternative schemes, they were just looking at bigger and better and faster batch processing operations—faster tape drives, faster memories, faster processors, and better printers."

Against this backdrop, Johnson and Stevens went to San Jose in the spring of 1952 to set up the new lab in a rented building. McDowell had set only two guidelines: keep the number of people to fifty; work on what no one else at IBM is working on.

In pursuit of random access

In retrospect, three factors seem to have led from this broad mandate to the decision Johnson calls one of the best he ever made—the decision to experiment in random access storage. First, Johnson himself had worked on two random access memories of limited capacity in Endicott—one a table look-up device for public utility billing and the other for random access to individual cards in punched card files. Second, after the San Jose laboratory had opened and many of the engineers were working on data recording devices (for wind tunnel and similar applications) and on nonimpact printing, a small company in financial difficulty approached IBM for help in building a random access memory around an X–Y plotter it had. Stevens explains that the analysis of this proposal coincided with a third factor—an investigation into the unique problems associated with inventory control at Air Force bases.

"The Air Force problem called for the ability to find the status of the inventory at any given time. This was really a requirement for a large, random access memory. In late 1952 and early 1953, the two investigations generated the conviction that it would be extremely interesting to be able to process data as it occurred rather than in batches. As a result, we decided to aggressively pursue both the Air Force problem and the need for random posting and random access to summary cards.

"There was no formal project then—just Rey Johnson, myself as a sort of operations manager for the lab, and four or five others who got deeply involved trying to find the best storage medium. Magnetic drums didn't have enough surface area, and after looking systematically at strips, rods, tapes, and lots of different alternatives, we came to a consensus that rotating disks offered the best way of making a file of the capacity we wanted."

Johnson recalls that it was only after this decision that the project really began to move. "A top management decision to kill a wind tunnel instrumentation project freed up one of our strongest groups, which included computer types like John Haanstra, and it helped push us away from straightforward data processing toward on-line applications."

With the group now up to fifteen or twenty people, another important assist came from two experiments that seem trivial now but nevertheless alleviated any concern, on Johnson's part at least, over whether a disk array would actually work. "We knew from our experience with drums that we could coat a disk, but we weren't sure about wear and dynamics. So we ordered 100 2-foot-diameter disks, put them on a shaft and ran them with a motor. That they ran smoothly without drawing excessive power and that a person could place his finger on a disk and follow it while it rotated were critically important. The other important experiment was finding that if we put air through a flat head, it could ride intimately over a surface without touching it. These very crude experiments were what took away my worries about our ability to produce a large, simple, and dynamic disk memory array."

Others were less certain, however. Some ridiculed it as the "San Jose meat slicer." Stevens recalls one of the early company-wide technical conferences when the project was first described to the hundred-odd engineers who at that time comprised the bulk of the IBM engineering community. "A few guys were extremely enthusiastic but for most it was sort of 'ho-hum'." Stevens explains that IBM had just undergone a "wrenching transition" from electromechanical punched-card systems to electronics. "While people like Thomas Watson, Jr., and Mr. McDowell believed in electronics and guided it, there were many people in the company who were not then advocates of electronics. Furthermore, over the years our competition had largely been from ledger cards and ledger posting machines; IBM salesmen had battled for years to convince customers of the efficiency of batch processing as contrasted to ledger posting. Therefore, it was much easier to maintain our corporate momentum and move toward making punch card systems faster and cheaper via electronics than to also try and switch to random access, which was not only a whole new concept but had a number of fundamental problems no one had yet been able to resolve."

Making disks work

Probably the biggest of these problems, reflects Stevens, was: "How in hell do you make the disks work? How do we get a magnetic head to follow this moving, wavy disk very closely? The disk might wobble as much as 0.015 or 0.02 inch at 1200 rpm and yet it was necessary to keep the head to within 0.001 inch of this surface. This was a very big problem in those days, roughly equivalent to trying to keep a large airplane flying within a few feet of the ground.

"We looked at many different ways of doing this and, in late 1953, the key technical breakthrough came when we found that an air bearing would work. Of course, supporting the head on air was an obvious idea, but when it first occurred to us, we only had one existence theorem to show it would work. We had no design characteristics and needed a great many experiments before we had a working configuration. The specific embodiment was done by William Goddard and John Lynott, with the help of John Haanstra. They also devised a servo that controlled the access mechanism so that a pickup arm could locate a track to within 0.001 inch on a 5-inch disk surface in about half a second. During 1953 and 1954, we built several models of disk files. The first ones weren't very good, but by 1954 we had pretty well identified the specifications and rough physical characteristics. By October of that year, we had a pretty good model running. It was an array of 50 laminated 2-foot disks stacked 2 feet high which could store 5 million characters organized into magnetic records of 100 characters each."

The model was still a model, however, and crude enough so that there was a great deal of skepticism about whether it could ever lead to a real business machine. Recalls Stevens, "It was very impressive to watch the arm jump up and down and go in and out, because it was very high speed. But the disks wobbled, and the array looked like a Rube Goldberg arrangement. Not many people believed we'd be able to make such a thing practical, because it hadn't been done before; there was much, much skepticism as to whether we would solve the direct addressing problem; whether we would solve the mechanical, magnetic, and electrical problem; and whether we would ever be successful in pushing the business toward anything different from a batch processing scheme.

"But we were too young to be discouraged by this skepticism. We were on a crusade then and everybody who was involved was absolutely determined it was going to happen. It was like a religion among us—we were going to make the damned thing work for sure, and we were going to solve those systems problems and those technical problems in spite of 'those guys.' Because we knew that if we failed in this environment, the whole San Jose experiment would fail, and, with it, the whole idea of planting a new seed far away from home base and giving creative people enough freedom and enough rope to do something would fail. None of us was going to allow that to happen if he could avoid it."

That they eventually succeeded was due to the skill of a dedicated group in solving a number of tough technical problems under the leadership of "a tremendously inventive guy who would have four —maybe fourteen—different answers to a problem."

But Stevens also credits Johnson with an important marketing move in the early days—bringing in talented senior marketing people including a very experienced IBM salesman named Ed Perkins.

October 1954 saw an important breakthrough on the political front. Executive vice president L. H. LaMotte became convinced by a crucial memo from his assistant, F. J. Wesley, saying this was an important new capability and IBM should really push it. As a result, in November a formal development program was launched under Stevens' direction called RAMAC. It would consist of a small electronic accounting machine, based upon a random-access file of fifty disks. In addition to that, another random access file was to be attached to the 650 computer, which was becoming a bread-and-butter computer at that time. At this point one could say the disk memory had become "official." From now on it would be a matter of the hard work of building a manufacturing organization and developing a finished product.

Only in San Jose

As Johnson and Stevens (and others familiar with the disk memory) reflect on the project, they are convinced that the establishment of a new—and remote—laboratory was vital to its success. Exclaims Stevens, "There's no conceivable way this kind of project could have been done at Poughkeepsie or Endicott in those days. We would never have been able to get enough people assigned to it because there were too many high-priority items that were in the mainstream of the company's business. They would never have diverted the resources that were needed to prove the feasibility of this approach."

Being twelve hours away by plane didn't hurt either. Recalls Stevens, "California was a tough trip then. It would really take a full week, and this kept down visits from the East. We were on our own; nobody was telling us what to do and we just did what we thought was right." Says Johnson, "We ran ahead of management's control; they never caught up with us."

What might a more obtrusive management have done? It might, for example, have stopped the project entirely after what Johnson calls one of the accidents that frightened the daylights out of him. "This two-foot pile of aluminum disks was spaced half an inch apart in the center by cast iron spacers. At 1200 rpm, this made a dynamic flywheel. One day the spacers broke and flew around the room, severing a tendon in one engineer's hand, cutting the nose of another, and barely missing the eye of a third. Coming on top of all the skepticism, this very frightening accident made us extremely worried that we'd lose our project. But nobody did anything, so we repaired the damage and started over."

Johnson contrasts this experience with one several years earlier when he was developing a key punch that punched upward instead of downward. "We had punched tens of thousands of cards when one day Tom Watson, Sr.—who ran the engineering as well as the business side then—walked by. The device for taking away the chips thrown off by the punch was not attached that day, and so the chips were spilling all over the floor. He saw this, got red in the face, and ordered me to punch downward, which, of course, was 'the common-sense way to do punching.' So I had to spend months redesigning the machine.

"Strong executives of the type IBM has always had are people who make gut decisions based upon their best judgment, and when they see something working as badly as that key punch—or as those wobbly disks or as those cast iron spacers—they will make a decision that can radically alter the course of a project. That accident might well have killed the disk project."

Reflections on managing invention

In a sense, the disk memory project was not really beyond management's control, of course. It had been a conscious management decision to set up a research laboratory and then leave it essentially alone under an inventive leader in whom at least some executives had great confidence. And this leads to some conclusions about what the stories of Gordon Teal and Rey Johnson demonstrate.

Perhaps R&D is simply so complex that management cannot count on always being able to make the right choice between research it should push and research that may be intrinsically valuable but nevertheless represents an uneconomic diversion of corporate resources. However, what should be expected from an able management is that it find room for at least a few researchers who are so good they not only recognize the promise of a new line of research but have the courage and skill to pursue it "after hours" if need be. As a successful R&D manager once said to this author, a company where some bootlegging is *not* going on is a company in trouble. Some of Gordon Teal's colleagues at Bell Labs feel his experience demonstrates just this strength on the part of the Labs, that people could cut across department lines and, somehow, find ways to work on things they considered important.

It is no easy matter to create this kind of environment, as many companies learned during the 1960s when their misguided romance with R&D caused them to open short-lived research labs in the mistaken belief that all they needed was to throw a group of Ph.D.s into a lovely new building far out in the countryside. There was little, if any, "pure" research going on at Bell Labs or IBM—researchers there were mission-oriented, but the missions were broad (e.g., communications and not telephones). In addition, there was room for the maverick.

Is there still room for the maverick? The concern expressed by IBM's Lou Stevens in this regard is sobering because it stretches beyond just IBM itself. Says Stevens, "There's no way something like our project could happen in today's environment. It would be difficult, if not impossible, for a group of 30 or 40 guys to be working on a project as ill-formulated as that was, whose marketability was as ill-perceived. We did not have crisp numbers to defend our marketplace; we did not have crisp numbers to defend, in a business sense, whether we could make money. We were not even interested in that at the time, though we became very much interested later. But the question of how many could we sell, and how many could we sell profitably was not a key element then. As a result, there was great suspicion on the part of the "business man" in the company that we would not be able to make a viable business of this. If you viewed it from a hard-core business point of view at that time, it would have been a terrible waste of development effort."

All too often as industrial R&D labs "mature" they develop a managerial superstructure that tends to suppress opportunities for people to be creative. Moreover, for several years now R&D has been facing increasingly jaundiced scrutiny from the profit-and-loss people. Budgets have been squeezed—dangerously so in the opinion of many observers. So one must conclude by asking: How many organizations today have the kind of environment that made it possible for Gordon Teal and Rey Johnson to do what they did? The answer will have an important bearing on our future technological progress. ◆

EEs' salaries: up but down

Returns from IEEE's 1975 U.S. member survey suggest that you may or may not be better off today than you were in 1972

According to nearly 50 000 returns from the latest IEEE membership survey, although most of the members are working (1.7 percent of the Institute's U.S. members reported that they were involuntarily unemployed), many are working for less "real" money. To update membership statistics derived from surveys conducted in 1972 and 1973, IEEE mailed out 112 707 questionnaires, to U.S. members only, between late January and mid-February of this year. The questionnaires requested not only employment and salary data but also opinions of the respondents on a variety of topics ranging from job discrimination to the IEEE's responsiveness to the nontechnical professional needs of its members. Over 40 percent of the recipients responded by the March 14, 1974, cut-off date, thereby providing an excellent picture of the status and feelings of the U.S. member.

To begin with: salary

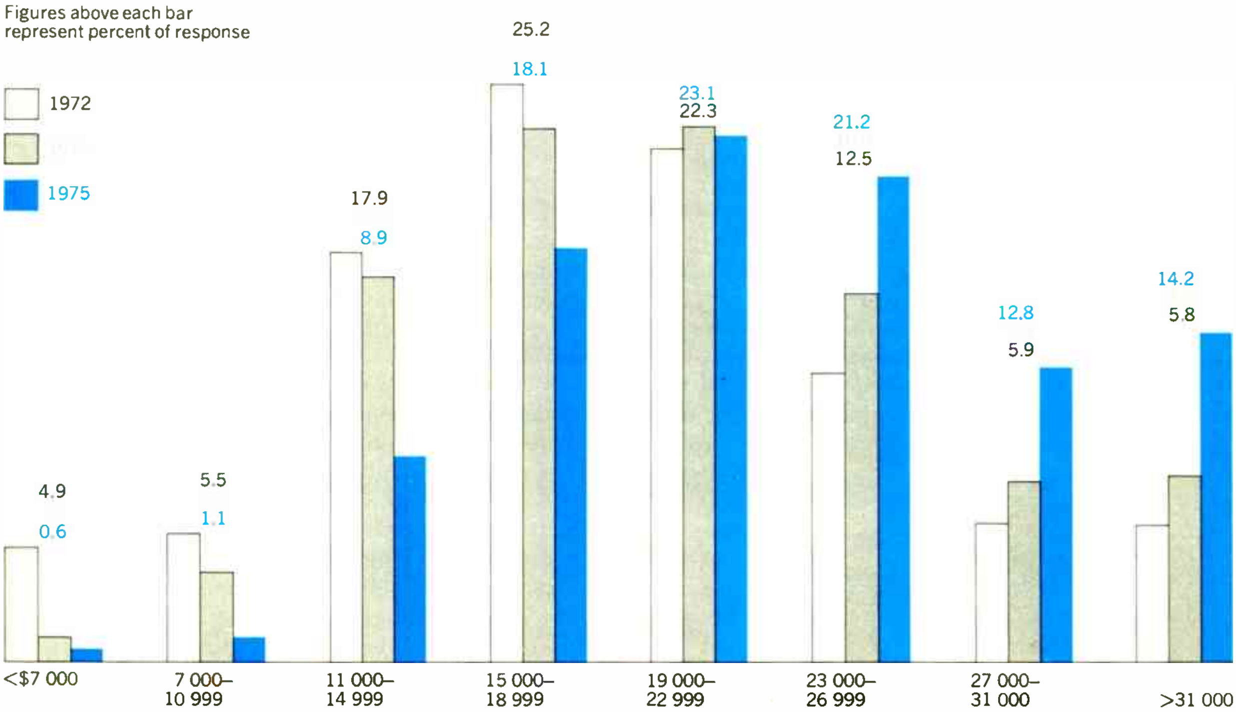
Immediately apparent from the survey results is the fact that IEEE members in the U.S. are making considerably more money than they were in 1972 and 1973 (for further details on the 1972 and 1973 surveys, see Bibliography). Figure 1 shows that far smaller percentages of EEs are making under $19 000 (less than 29 percent in 1975 compared with 45 percent or more in 1972 and 1973). Similarly, although less than one of every three EEs was making over $23 000 only two years ago, very nearly half of the Institute's U.S. members are making at least $23 000 today. In fact, the number of members making over $31 000 has nearly doubled in the last two years. (See Fig. 2 for salaries of members employed full time in their primary area of technical competence.)

Unfortunately, however, the last several years in the U.S. have marked a period of rampant inflation. From survey to survey (May 1972 to February 1975), the Bureau of Labor Statistics' Consumer Price Index (CPI) for Urban Wage Earners and Clerical Workers*—the most commonly used indicator of changes in the cost of living—has skyrocketed a hair-raising 26.1 percent. Naturally, the effects of inflation have been

* The CPI measures monthly cost changes in commodities (including food, apparel, gasoline, appliances, etc.) and services (including housing, transportation, utility costs, medical care, etc.) Each is weighted according to its relative importance in the average household's budget, as well as according to seasonal usage. While the CPI can be criticized as more applicable to the spending patterns of blue-collar workers than to those of professionals, it is the best available measure of cost of living.

Ellis Rubinstein Associate Editor

[1] Distribution of the salaries of those U.S. members who responded to the 1975 IEEE U.S. Membership Survey compared with distributions of U.S. members' salaries garnered from the 1972 and 1973 IEEE member surveys.



a servo-pantograph for very high speeds; it consists, essentially, of a conventional pantograph to which a hydraulic servo unit was added to reduce the inertia of the pantograph head. A 3-km-long run of dynamically scaled overhead wire has been erected on the high-speed test track at Old Dalby. The performance characteristics in this installation at 125 km/h correspond as favorably as if a train were traveling at 250 km/h under the wire.

New signaling

Before the electrification of the Anglo-Scottish mainline between London and Glasgow was completed, British Rail began the installation of a completely new signaling system over the route from Weaver Junction northward, replacing what was a semaphore-type of wayside block signal.

Modern electrical and electronic equipment, with multiaspect color signals are now in use, incorporating British Rail's standard automatic warning system of train control on the main passenger lines. (This equipment and automatic train control—ATC—will be discussed in detail later in this piece.)

Four new power signal boxes at Warrington, Preston, Carlisle, and Motherwell—together with the existing modern center at Glasgow Central—cover all train movements over a total of 1000 single-track kilometers (630 miles) of electrified mainline between Weaver Junction and Glasgow. A similar system has been in service over the remainder of the route from London since 1966.

In the new power signal boxes, an illuminated wall display diagram shows all the signals, blocks, and switchpoints in the area controlled from the box—as well as the instantaneous position of all trains.

Mainline electric traction and rolling stock

Along the mainline Anglo-Scottish route, and other Inter-City service lines (see Fig. 1 map), a "new breed" of high-speed all-electric locomotive, the Class 87, has been designed and developed by the British Railways Board to provide the motive power necessary for hauling passenger trains at speeds of 160 km/h. The Class 87 is a four-axle, 72-tonne machine, with an overall length of 17.8 meters (58 ft, 6 in) and a continuous rating of 3730 kW; its accelerating tractive effort is 22 500 kg.

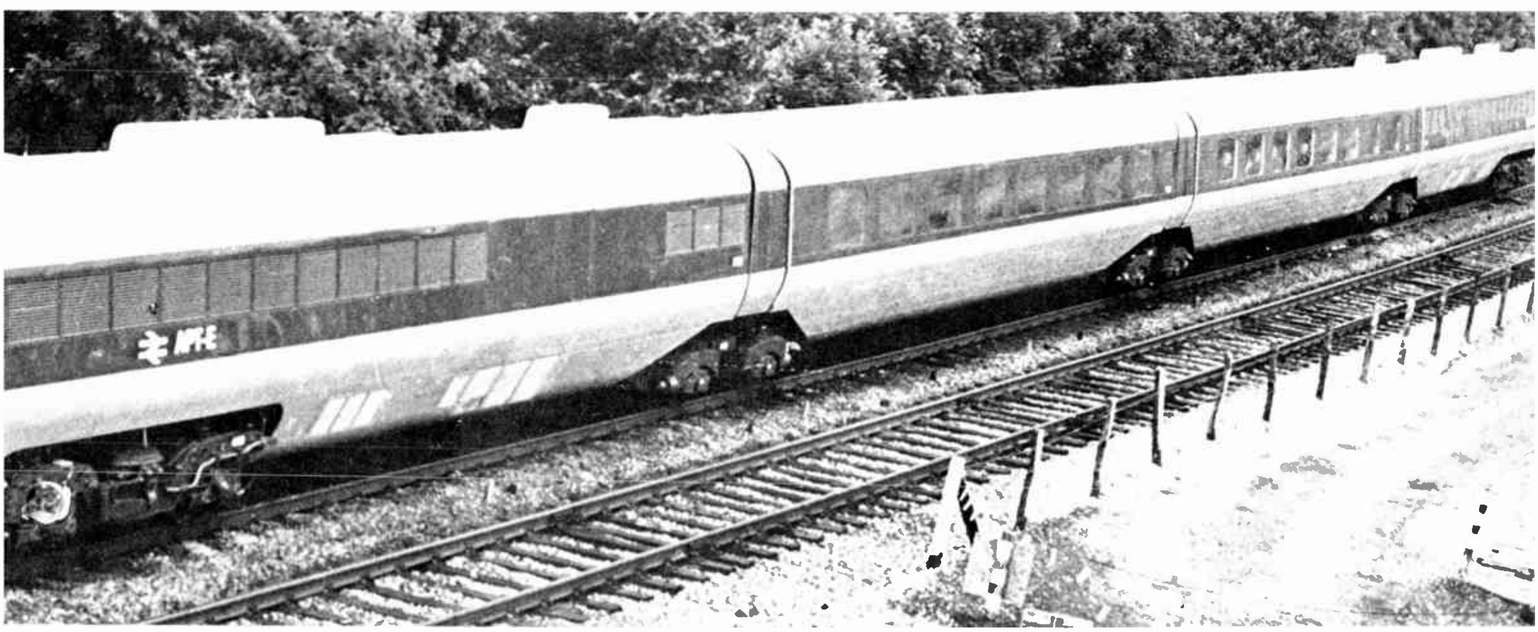
Power for the locomotive is taken from the 25-kV, 50-Hz overhead supply by a single General Electric Company (GEC) "cross-arm" pantograph that is fitted with copper-impregnated carbon rubbing strips and designed to provide a nominal static contact pressure of 9 kg. The pantograph system incorporates low-friction joints and features the automatic dropping device, developed by British Rail, which ensures that the pantograph is immediately lowered in the event of carbon loss or pan-head displacement. Other roof-mounted equipment includes a 250-MVA, 25-kV air-blast circuit breaker, grounding switch, and rheostatic-brake-exhaust outlet louvres.

The main transformer, also manufactured by GEC, incorporates high-voltage tap-changing (38 taps) equipment. The transformer windings are so arranged that the four secondaries operate almost independently, with a minimum of coupling in the event of fault currents in one of the windings. The low-tension power circuits are divided into four separate (but identical) "power pack" groupings, each of which consists of a

- Transformer secondary winding
- Bridge-connected silicon-rectifier assembly
- Smoothing inductor
- Traction motor

The advantage of the power-pack grouping technique is that, in the event of a component fault arising within one of the groups, the entire circuit can be isolated by the locomotive's driver without the need for any fault-finding analysis. The locomotive can

stringent test program ever devised for a railway train. The APT embodies lightweight construction and refined aerodynamic shape. Its salient technical feature, however, is a unique suspension system that will enable the train to negotiate curves at speeds up to 50 percent higher than those of conventional trains, without discomfort to passengers.



For the rail buff: some historical notes

The British started it all. In fact, it was George Stephenson and his son, Robert, who built the first steam locomotive, *The Rocket*, in 1825. By 1830, the Liverpool and Manchester Railway was completed for the "transportation of goods and passengers." In swift succession, during the 1930s, lines were built in the Midlands with the manufacturing cities of Birmingham, Liverpool, and Manchester as their hubs.

But there were also developments in the south of England; a line was constructed from Birmingham to Warrington to connect the Midlands with Liverpool and Manchester via the junction at Newton. This was the Grand Junction Railway, completed in 1837; and, the following year, when the London and Birmingham Railway service was inaugurated, passengers could travel by rail from London's new Euston Station to Preston (a distance of about 350 km) in 11 hours.

From the 1840s, through the 1860s, rail lines proliferated in both England and Scotland—and their were some notable achievements in both civil and railroad engineering. For example, deep ravines and unusually hilly terrain along the 112-km route of the Lancaster and Carlisle Railway required the construction of high viaducts and bridges. Fortunately, a civil engineer of great ability, Joseph Locke, designed the necessary structures and the line was completed in the record time of 27 months. Most of these stone bridges and viaducts, erected more than a century ago to span the valleys and streams of Westmorland and Cumberland, are still in use.

The first electrics

In Scotland, the first application of electricity to rail traction occurred in 1842, when a battery-powered locomotive was used on the Edinburgh and Glasgow Railway. However, this interesting early experiment failed for the same reason that bedevils vehicular propulsion engineers today—the difficulty of obtaining sufficient power from batteries over an extended period. But aside from the use of electric power for local tram routes in several Scottish cities, and on the circular underground line in Glasgow, it was not until 1960 that electric traction was applied to mainline railways.

Despite a historical commitment to steam traction as the logical end use of one of Great Britain's few natural resources, Welsh coal, electric railways were developed in the U.K., in the late 19th century. These were to provide a solution to air pollution on the London underground (subway) system, where smoke and steam made conditions for passengers virtually unendurable. Therefore, in 1890, the City and South London Tube introduced electrically hauled trains. They were not only cleaner than their steam-powered predecessors, they were also capable of rapid acceleration—a very desirable feature on suburban lines where trains were required to start and stop at frequent intervals.

Over the next 20 years, several railways adopted electric traction, in conjunction with third-rail conductors, for suburban services. By 1914, electric trains were operating on North Tyneside, between Liverpool and Southport, Manchester and Bury, and in the Greater London area. Two railways preferred an overhead catenary system and this system was introduced on the lines between Lancaster, Morecambe, and Heysham, and between London Bridge, Victoria, and Crystal Palace.

In the two decades between world wars, the Southern Railway extended its third-rail lines to encompass all suburban routes and mainlines to the South Coast of England; and, another third-rail system was installed in Cheshire. The route from Manchester to Altrincham was catenary equipped. During this period, Britain's railways were privately owned, and the four major companies were all considering the feasibility of mainline electrification as an option for the future.

Mainline electrification program

Until 1932, there was no accepted standard for electrification; but, in that year, a Government committee recommended that future mainline projects should use 1500 volts dc for catenaries, and 750 volts dc for third-rail conductors. Two projects, using the overhead scheme, were started: the important commuter route from Liverpool Street (London) to Shenfield, and the lines linking Manchester–Sheffield–

then proceed on 75 percent of full power. Each of the four full-wave rectifier units supplies one traction motor, and every full-wave bridge arm contains two parallel strings of two diodes rated at 1860 amperes, continuous, and 1340 volts direct current, in series.

A Class 87 locomotive contains four GEC traction motors. These four-pole series-wound fully compensated dc machines were designed for operation over the severe gradients encountered on the West Coast mainline, and have high short-term rating capabilities: the full-field one-hour rating is 1134 volts, 885 amperes, and 945 kW. To limit the ac ripple effect from the 50-Hz power supply, the magnet frame is of a partially laminated construction and a 16-percent permanent divert resistance is connected across the main field.

Safety provisions in the drivers' cabs

Maximum protection for the locomotive crew is afforded by Triplex "high-impact" electrically heated windshields. These incorporate a new clear resistance film for demisting and defrosting.

The locomotives also contain a "driver's vigilance system," which basically consists of a two-position foot pedal, incorporating an electric switch, audible signal device, and relay unit. When the master controller is in the driving position, the pedal must be kept depressed. After 60 seconds, a continuous audible signal commences; and, if the pedal is not released and depressed to reset the system, an emergency brake application will occur within the next 5–7 seconds. The system can be reset at any time during the cycle, at the driver's convenience; and, to assist in operating the driving controls, an alternative desk-mounted hand switch is provided. Resetting the standard automatic warning system equipment, in response to a caution signal (amber) aspect also resets the time cycle.

Another new cab feature is the introduction of a push-button-operated electrohydraulic parking brake. This employs an electric motor to drive the hydraulic pump unit (that is located in the body of the locomotive) to generate the necessary oil pressure to apply to the brake actuators on the bogies. This action automatically "locks on" the parking brake.

Prototype thyristor-controlled machine

Locomotive 87036 of Class 87 was built as a prototype thyristor-controlled all-electric to gain operating

Wath. However, the work was interrupted by World War II in 1939, and the lines were completed in 1949–54.

After World War II, a new system of catenary electrification came of age: adopted by the French National Railroads (SNCF), it utilized 25-kV 50-H_3 alternating current; and, the British Transport Commission, then planning large-scale mainline electrification of the trunk route between London, the West Midlands, Liverpool, and Manchester, investigated the possibilities. It concluded that the costs of installation and power supply would be more economical than the 1500-volt dc system and that all-electric locomotives, using a 25-kV ac supply, would give superior and more efficient performance.

In 1956, the Commission received Government approval to install the 25-kV lines over 640 route kilometers (400 route miles) and 2400 km (1480 miles) of single track. In 1957, work began on the line from Manchester to Crewe; it was opened for electric train service in 1960. Then, in 1962, construction was completed on the Liverpool–Crewe route. By 1965, electric traction at this voltage was extended south to London, and, in the 1966–67 time frame, this service was expanded into a comprehensive network covering the West Midlands. The culmination of this effort is the 640-route-kilometer-long Anglo-Scottish Electrification.

experience with this advanced design, and to test its performance characteristics in tractive capabilities, maintenance record, and effect of its power factor, harmonics, etc., in operation at 25 kV, 50 Hz. The rectifiers and smoothing reactors are air-cooled by the traction motor blowers, and the transformer radiators and braking resistors are cooled by common fans.

The use of thyristor control, of course, eliminates the tap changer and the 25-kV autotransformer. For both the thyristors and diodes of the armature circuit bridges, the arrangement per bridge is series, four parallel, all of normal polarity. With two series bridges per motor, there are 64 thyristors and 64 diodes. As in the conventional Class 87, there are four traction motors—one per axle.

Special deluxe coaches—and the "HSTs"

The "Electric Scots" and some other electrically hauled passenger expresses in service on the Anglo-Scottish route, have a consist of specially designed 23-meter-long (75-ft, 6-in) Mark III passenger coaches that are fully air-conditioned. These air-cushioned vehicles, with disk-braked bogies, ensure a smooth, quiet ride at the trains' top speeds. And, the Mark

Facts and figures on the HST

The High-Speed Train (HST) is shown during trial runs on the East Coast mainline. The HST is undergoing extensive testing before entering passenger-evaluation service. During the tests, the train has attained a top speed of 230 km/h (about 143 mi/h), a world's record for a diesel–electric-powered train. Some of the power car statistics (there is a power car at each end of the train) include an initial service rating of 1689 kW; a Paxman "Valenta" 12RP 200L diesel engine; an engine-driven alternator and rectifier, supplying 280 kW maximum direct current to the train. The net power at the rail, for the two power cars, ranges from 2420 to 2700 kW, and the weight of each power car—with supplies—is 68 tonnes.

The maximum service speed of the HST is 200 km/h (125 mi/h); the balancing speed on level track is in the range of 194 to 200 km/h, while the balancing speed on 5° superelevation (for curved track) runs from 165 to 174 km/h. The nominal operating range of the train is 1600 km.

The Mark III carriages are built in four styles: first-class saloon, with 48 seats; second-class saloon, equipped with seats for 72 passengers; kitchen/saloon, seating 23 persons; and buffet/saloon, with provision for 34 seats. The Mark III carriages vary in weight from 33 to 39 tonnes.

Among the distinctive features of the train are its lightweight welded-steel shell, grouped equipment modules on underframes, and air-spring disk-braked bogies.

IIIs are also adaptable for service with the new High-Speed Train (HST), shown in the box on p. 53, that is presently being tested in various power and tractive configurations.

The HST, designed for 200 km/h (125 mi/h) maximum speed, embodies the extension and further development of the best features and principles to be found in conventional railway technology. The prototype train consists of two 17-meter-long power cars (one at each end) and seven Mark III coaches. Each power car contains a 12-cylinder Paxman 1680-kW diesel as part of the diesel–electric drive.

There are four traction motors—one per axle—arranged in a series/parallel circuit that comprises two parallel groups of two motors in series. Each motor is fully suspended in the bogie frame and propels its axle through a flexible drive. The armature shaft drives a special type of cardan shaft, the other end of which turns the pinion.

As the result of test experience in running the prototype train, a number of modifications will be made in the production sets. These will include:

- Increasing the power of each diesel engine to 1865 kW by modifying the turbocharger.
- Installing an engine noise silencer and an engine-room exhaust fan.

The first of 27 production trains is scheduled for completion about the time this piece goes to press. Thereafter, British Rail hopes that an additional 42 trains will be ready for service by April 1977.

Advanced passenger train (APT)

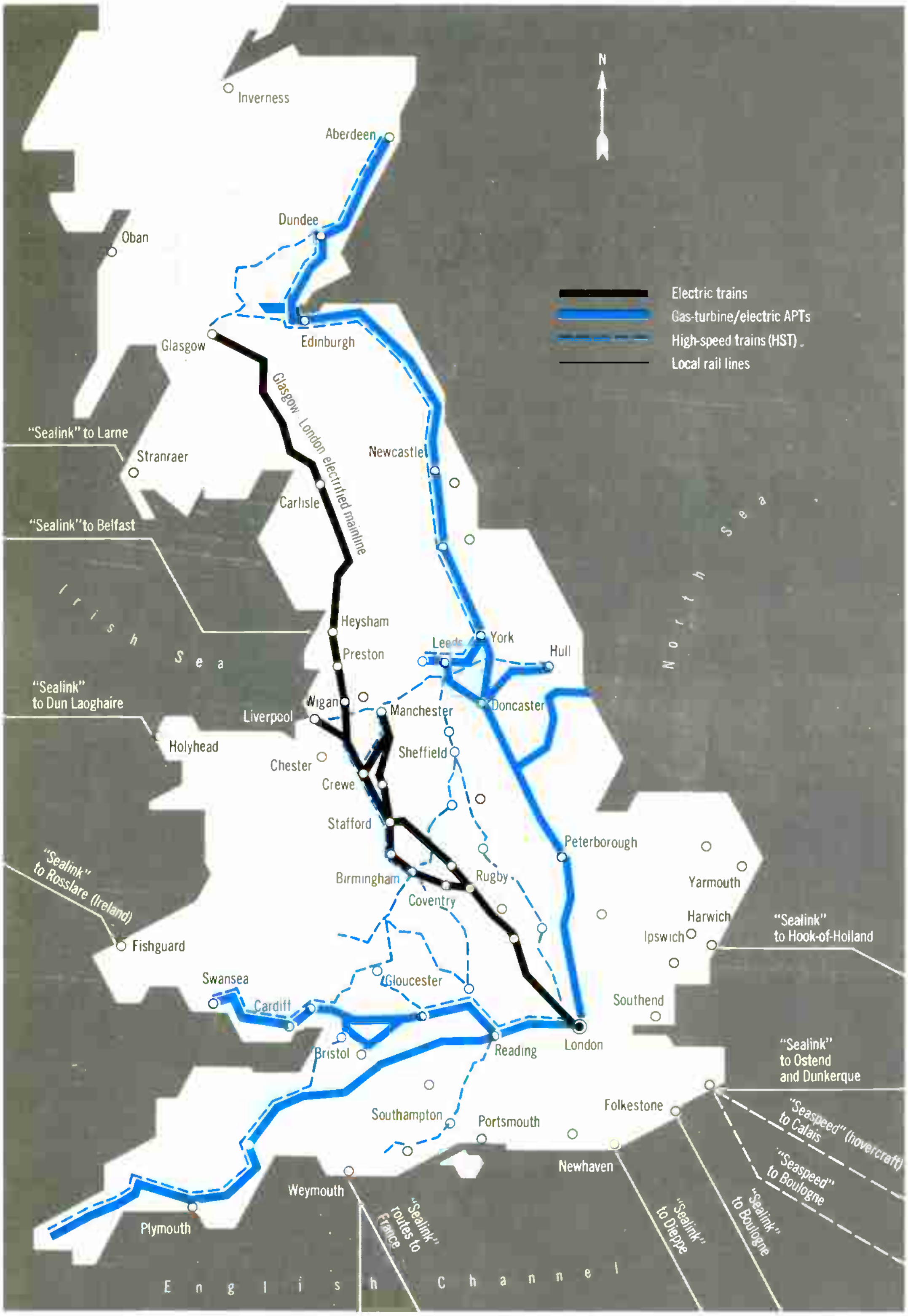
The APT has been, since the origin of its concept in 1967, a high-performance passenger train scheme for operation, over existing rights-of-way, at speeds of up to 250 km/h (155 mi/h). APT's potential to reduce journey times substantially on Inter-City routes stems from:

1. Its high-speed capability on straight track.

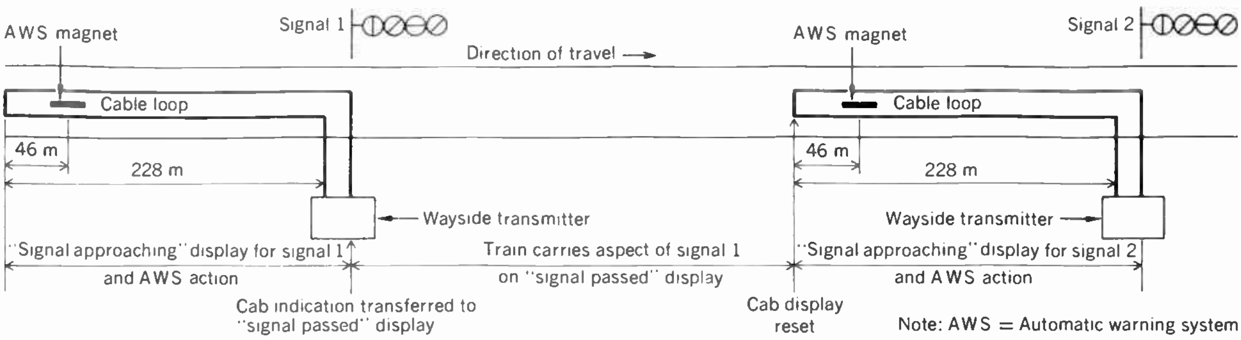
2. Its ability to negotiate mainline curves at speeds up to 50 percent higher than the permissible speeds for conventional vehicles.

3. Its superior braking performance.

The feasibility of such improved performance is the result of advances in vehicle dynamics research and design. A notable feature of the APT has been the tilting of car bodies (undercant compensation) on curves by up to 9° to maintain passen-



[1] **Principal rail, "Sealink" and "Seaspeed" hovercraft routes of the British Rail system in the United Kingdom.**



[2] Automatic Warning System (AWS), with signal aspects displayed in the driver's cab, is one of British Rail's on-board train-control operating aids.

ger comfort. This work has been based upon tests on an experimental train, designated APT-E (title illustration, pp. 50–51), and a series of component test programs both in the laboratory or on the test track.

APT-E presently comprises two power cars and two trailer cars. Since June 1973, this turbotrain has been undergoing extensive trial runs. The train has been running over some mainlines, but principally the tests have been conducted on British Rail's test track at Old Dalby. Here, it has reached a maximum speed of 205 km/h (128 mi/h) and has negotiated a curve of 1140 meters radius at a speed of 161 km/h (100 mi/h), with a cant deficiency of 8°. The ride quality at maximum speed is reported to be up to expectations, except for a high-frequency vibration component (arising probably from the coupling arrangement between coaches). Nevertheless, the ride quality at 250 km/h will compare favorably with the best conventional train running at 160 km/h. By May 1974, APT-E had already covered more than 4800 km in 178 hours of experimental running time.

Ushering in an "all-electric" era

A new epoch in high-speed rail travel between England and Scotland began on May 6, 1974, with the introduction of 160-km/h all-electric service along the 640-km-long Anglo-Scottish mainline that links London and Glasgow. Travel time between the two cities was cut to an even five hours by *The Royal Scot*, the crack train on this route, and to an average time of 5 hours, 10 minutes for the other "Electric Scots," thereby representing a reduction of about one hour from the previous time required for the run.

Between 0745 and 1745, there are eight trains daily from Euston Station (London) to Glasgow (with the same number in the opposite direction between 0710 and 1730). This represents an increase of three trains per day, in each direction, over the previous schedule.

And, electric traction has made it possible to introduce a daytime train, *The Clansman*, between London and Inverness (a distance of about 850 km). This train runs via Coventry and Birmingham, with stops at principal intermediate stations. Passengers from South Wales have connecting services to Birmingham to enable them also to travel by day to the Scottish Highlands.

Trains from Birmingham to Edinburgh and Glasgow, too, run on reduced time schedules and increased frequency as the result of the extension of the electrified Inter-City network. Swifter passenger service—and an enlarged timetable of trains—between Liverpool, Manchester, and Scotland—has also been inaugurated, with five trains in each direction daily. These include direct early morning and evening trains between Liverpool and Edinburgh, and Manchester and Glasgow, with interchange facilities at Preston. The average journey time between Liverpool and Glasgow is 3 hours, 50 minutes; between Manchester and Glasgow, 3 hours, 45 minutes. These schedules reduce the previous travel times by about one hour.

Automatic train control—British style

For British rail, there are two basic approaches to train-control philosophy:

1. To improve and extend present control methods and operating practices successively, thereby making maximum use of existing equipment and investment (modular approach).

2. To devise a train-control system which is complete in itself and replaces any existing system (integrated approach).

British Rail has devoted considerable effort to the first approach and has evolved train-control criteria that involves a gradual increase in sophistication by means of a series of functional modules. Management believes this approach will result in a cost-effective solution for improving existing railways. However, for a new or rebuilt right-of-way, the alternative integrated technique may be more attractive; thus, both concepts are presently being pursued.

Coded track circuits vs. track conductors

The use of coded track circuits to detect the presence of a train has the obvious advantage that the communication medium already exists; but, there are some disadvantages:

- Major alternatives to existing signaling equipment are required.
- The poor transmission qualities of running rails seriously limits the rate at which information can be transmitted over a useful distance.
- "Crosstalk" problems occur on electrified lines.
- The additional complexity tends to degrade the reliability of the basic signaling system.

However, most of the disadvantages of coded track circuits, British Rail feels, are removed by providing a separate data-transmission path. A pair of parallel conductors is placed between the rails to form a two-wire transmission line. Track conductors perform well in the frequency range of 20 to 150 kHz, and offer the additional advantage of allowing train-to-track communication. On British Rail, track conductors have been engineered to withstand the railway environment and are proving to be adaptable to a wide range of train-control systems.

Train-control driving aids

An automatic warning system (AWS) with cab signaling (Fig. 2) provides a cab display of the signal aspect for a distance of about 200 meters on the approach to the signal, and demands a different acknowledgment from the train driver for each cautionary signal indication (red, single yellow, double yellow). After passing the wayside signal, a "reminder" of its indication at the time of passing is given on a separate cab display. The system includes refinements to ensure that only valid information is displayed to the driver at all times.

The communication link is a track-conductor loop, placed symmetrically between the rails. A frequency-modulated carrier is fed to the signal end of the loop, where an "end of section marker" provides the system with a definite indication of the signal's location. The signal aspect information is derived from the signaling system and conveyed to the train as audio-frequency modulations of the carrier.

The train-borne equipment receives and decodes the carrier signal and performs the logic operations necessary to ensure correct displays. By detecting both the magnetic and electric fields of the track conductors, the equipment can determine the position of the train and thereby ensure that the data received is appropriate to its direction of travel.

The system used by British Rail for speed supervision, by means of track conductors, is an extension of the AWS just described. Here, the information conveyed must include not only the signal indications but also their locations, the value and location of speed restrictions, and gradient data. Information must be available on-board concerning the train's speed, position, maximum permitted speed, and braking characteristics. The information from the wayside is selected from read-only memories (ROMs) and transmitted to the train as a binary-coded message by phase-modulating a carrier signal. The ROM information is coded in such a way that the small percentage of incorrectly received messages will be rejected. The train-borne logic includes refinements to assure that the data presented to the driver is appropriate to the particular conditions of operation at any point in time.

Speed supervision with transponders

To exploit fully the potential of the APT for running safely at higher speeds than conventional trains, a more sophisticated form of speed supervision is necessary. For this application, British Rail has developed what it calls "C-APT" equipment. The essential feature of C-APT is that speed-supervision information is stored, either on the train or at the wayside, the information being read from storage as the APT proceeds along its route. Apparatus has been built that incorporates a trainborne magnetic-tape program store. With this type of equipment it is necessary to synchronize the reading of data with the actual position of the train. This is achieved by placing along the train's route uniquely identified position markers (transponders), the position and identity of which are also kept in the magnetic tape program storage. As each transponder is passed, its position and identity are checked against the stored data, and speed supervisory information is only presented to the driver if full correlation is ascertained. A speed-supervision equipment, using only track-mounted transponders, has also been built and tested. In this equipment, the necessary speed information is contained in the transponders and is "read" by the train as it passes.

Traffic-control function

The primary objective of the traffic-control function is the minimizing of departures from the planned performance of the system as defined by the timetables. Such departures from schedule can be attributable to a number of causes: delays at stations, failures of the rolling stock or signaling system, etc. Modern signal boxes control considerably larger areas than the earlier mechanical boxes; therefore, today, there are many more possible train movements. Thus, some sort of aid for the traffic controller is essential.

The "train describer" is designed specifically for this purpose: each train is allocated a train description that consists of a four-character alphanumeric code (number, letter, two numbers). The train description is displayed in slots on the signal box display diagram and indicates the position of the train on the track. Once a description has been entered into the system, it is automatically stepped from slot to slot as the train proceeds; the necessary information for this process is derived from the signaling system. British Rail's train describers utilize minicomputers to achieve the high degree of versatility of the procedure. The Railway Board feels that a computer-based system is particularly adaptable to modular developments, since new functions can be "added on" to the existing software.

Other services: "Sealink," "Hovercraft," etc.

It should be emphasized that British Rail's services do not end at the coastline (see Fig. 1 map). British Rail's Seaspeed company is the world's largest and most experienced hovercraft operator. In addition to the original service from Portsmouth to the Isle of Wight, Seaspeed operates cross-Channel runs with giant SR N4 hovercraft that can carry up to 250 passengers and 30 motorcars to complete the journey from Dover to Calais or Boulogne in just over one half hour. Sealink operates cross-Channel and Irish Sea ferry services to Holland, Belgium, the Channel Islands, Northern Ireland, and the Irish Republic.

Finally, British Rail offers "Motorail" car-carrying service for vacationers and travelers who wish to bring their automobiles to their destination while riding as passengers on the Inter-City network. And, British Rail operates hotels in more than two dozen major cities and resort areas in England, Scotland, and Wales. ◆

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Gov. Shapp on what's wrong with rail transportation

An EE turned successful politician suspects a conspiracy of rail interests in the U.S. against business and the public

Milton J. Shapp, Governor of the State of Pennsylvania, thinks the Rail Reorganization Act—a Federal program, currently before Congress, ostensibly intended to rehabilitate the deteriorating rail network in the northeastern United States—may be a conspiracy on the part of the financially sound western railroads to "pick up" profitable eastern mainline business "at the expense of the less well-heeled railroads already in existence." This and other outspoken views were expressed by Gov. Shapp in an exclusive interview with *Spectrum* on a day in April when the Governor was scheduled to attend an Interstate Commerce Commission (ICC) hearing that was held in New York City.

Of the many U.S. politicians who, in one way or another, affect rail transportation policy, none is more qualified to speak out on the topic than Gov. Shapp. Having graduated from Case Institute in 1933, Gov. Shapp, who happens to be an electrical engineer, was a cofounder, in 1947, of the Jerrold Electronics Corp., a major firm producing electronic equipment.

Gordon D. Friedlander Senior Editor

In 1966, he turned to politics and, after winning a primary election, the governor sold his interest in Jerrold to help finance the political campaigns that eventually put him in the State House in Harrisburg, Pa. But even before his political career began, he had become concerned with the problems of intercity, suburban, and intraurban rail transportation.

As early as 1962, then private citizen Shapp, as a Pennsylvania Railroad stockholder, was deeply involved in litigation to stop the proposed merger of the New York Central and Pennsylvania railroads. Nine years later, at the Fifth International Conference on Urban Transportation, held in Pittsburgh, by now Governor Shapp was speaking out on AMTRAK, predicting in the conference's welcoming address, that it would "prove to be a disaster second only to that of the merger of Penn Central," against which he had fought so hard. Some of the Governor's most recent views on the state of U.S. rail—offered once again in the role of welcoming speaker at the Sixth International Conference on Urban Transportation held in 1974—were published in the March 1975 issue (p. 45) of *Spectrum*, and with these trenchant observations in mind, *Spectrum* arranged for the previously mentioned interview during which the following exchanges took place.

Governor Shapp

Shapp on intercity rail

***Spectrum:* Governor, in a country as large as the United States, in which you can span the continent in 5½ hours, or less, by air, will passengers ever again be willing to ride on a train that takes three days from Coast to Coast?**

Shapp: Of course! Look at the "piggyback" *Autotrain* down to Florida. Although you can fly from New York to Miami in two hours, many people are putting their private cars aboard the *Autotrain*, while they ride in comfortable coaches or sleepers. And, take a look at air traffic in Europe. It's heavy, and yet people gladly ride the trains because the train

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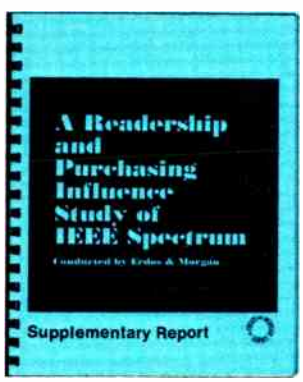

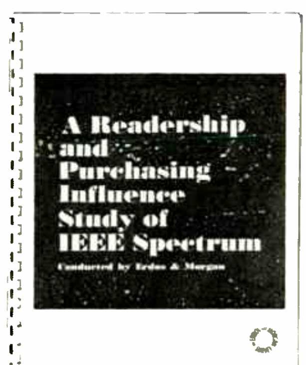

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service is good, comfortable, and on-time. All the U.S. railroads have to do is to provide good service, and both passenger and freight traffic will revive. It's just that simple. When these conditions are met everywhere else in the world, this has been the historical result: people go back to trains. Bad as AMTRAK is, people are crowding onto its trains—and the service is improving somewhat. Just think what the passenger traffic would be if AMTRAK had really first-class rolling stock!

***Spectrum:* Governor, at the Fifth Urban Transportation Conference in 1971, you said that AMTRAK would be a "disaster second only to the merger of the Penn Central." Has anything occurred since then to change your mind?**

Shapp: Well, I think it has done a little better than I anticipated. But, until several things happen, I don't think AMTRAK is going to be much of an asset. First, we need a better mainline railway roadbed throughout this country so that trains can run at scheduled speeds. When an AMTRAK locomotive leaves the track because of a broken rail or track splice [something that happens almost every day on freight runs.—Ed.], I think there is something quite wrong. Although AMTRAK has ordered some new engines, they can't be run at full speed because the condition of the track won't permit it. This certainly tells us something ... Secondly, as far as this agency is concerned, I believe it has to place major contracts for modernization of rolling stock. The two are inseparable—new track bed, plus rolling stock. Toward this end, the Commonwealth of Pennsylvania has proposed a railway trust fund. Thus, there is no reason why AMTRAK shouldn't be able to have substantial funds to buy new locomotives and new cars .... and then pay off the capitalization for this rolling stock over a 25- to 30-year period.

***Spectrum:* Then you think it can be made viable—it can survive?**

Shapp: Oh, sure ... I mean, look at the railroads in every other country. For example, I just came back from China—backward China! I rode their trains, by stages, from Peking to Shanghai. I have a picture of my wife sitting with our interpreter in the restaurant car. On the table are two tall glasses of tea and a glass of milk filled to the top. At speeds of 70 to 75 miles an hour, one cannot see a ripple at the surface of these liquids. That's how smooth the ride is over the roadbeds of "underdeveloped" China!

I've ridden on the "Bullet Train" in Japan and on the "TEEs" (Trans-Europ Expresses) all over Europe. And I've been on the Montreal-Toronto turbotrain. All of the other nations in the world have railroads *that run*—and they run fast and they run comfortably. To think that the United States, the most industrialized nation in the world, can't run its railroads is incredible!

***Spectrum:* The U.S. has a number of railroads, particularly in the Northeast, that are on the verge of bankruptcy; and, like the Penn Central, they are seeking to be "bailed out" by the Federal government. Do you think that it would be preferable that these railroads be taken over by the Government—that they be nationalized? Or should they be run on the basis of large "handouts" granted periodically?**

Shapp: I don't think it's necessary for railroads to have big handouts. I think a properly run railroad *can* make a profit. Now, the reason why they can't make a profit is, first of all, they don't have the track facilities to do it. Penn Central talks about losing $189 million in 1973. And of that sum, about $20 million was lost on their branch lines. So, they're talking about shutting down the branch lines of the railroads. Well, that's like taking a tree and trimming it down to the point where all that's left is the trunk. A tree in that shape is not worth a damn to anybody—and, particularly, to a railroad that depends upon the traffic feeding in from and out to the mainline branches. Now, the reason the railroads are losing money is that their mainline track—a point to which I've already alluded—is *unsafe at any speed.*

Also, their freight classification and marshaling yards are obsolete. Cars are lost for days at a time! For instance, a friend of mine who's in the produce business recently received a carload of moldy lettuce from the West Coast. Why? Because that car was lost from six to eight days in the classification yards before it could be located. By the time he got his lettuce, it wasn't fit for consumption by hogs!

The reason why Penn Central can't make any money today is because it has an obsolete plant. But you can rebuild this plant and make a modern railroad out of it. With new traction equipment and rolling stock, a railroad can't lose money. When a railroad is efficiently managed and operated, a boxcar from Chicago to Philadelphia will arrive at its destination in 48 hours, instead of six days. Another reason why the system is losing money is the "foreign" cars—that is, boxcars of the Union Pacific, Burling-

Interviewer Friedlander

"To think that the United States, the most industrialized nation in the world, can't run its railroads, is incredible!"

ton Northern, or Rock Island that come in on the Penn Central's rights-of-way. And Penn Central has to pay a fee every day that these cars are in its territory. So, instead of a "turnaround time" within four days, 12 days are required. Thus, the line is paying all of that extra time and money for these cars. And, incidentally, those payments just about equal their deficit [close to $300 million for 1974].

Spectrum: **How did Penn Central, and other railroads, get into this mess originally?**

Shapp: One has to go back two decades to get some of the answers. [Patrick Benedict] McGinnis* started it with the New Haven. Up until the time he took over the operation, the New Haven "was keeping a plant" and putting back much of its profits into line maintenance. But he put a stop to that practice. He took all of the income—all the cash flow—and bled it off into payments to the stockholders. So the New Haven went down the drain because it didn't have the necessary money for line maintenance. In later years, both the New York Central and the now-merged Penn Central took their cash flow funds and put them into orange groves, real estate, hotels, and pipelines instead of plowing this money back into their primary concern—the railroad.

However, the Southern Railway and the Norfolk & Western plowed back their profits into maintenance. Today, they're in good shape, while the quality of the lines pursuing "diversification" and stockholder-only interests have suffered from the policies of the financial manipulators.

Spectrum: **Now, when you have these situations in which, through mismanagement, as you say, the railroads pile up huge deficits, and the Federal government has to step into the breach to supply large stopgap funding, do you believe the Government should have some equity in this to insist on a reorganization of management—to put in more efficient people at the top, rather than letting the same group that brought them to disaster do it again?**

Shapp: You said it better than I could! I agree ... Let me go a little further than that. Penn Central got $253 million from the Government. CONRAIL, under the U.S. Railway Act proposal, will require $500 to $600 million in the next year or two. If anything can be 180° "out of phase" with what is required, it's this new proposal which will take a railroad that is already bankrupt—Penn Central—and too big to manage, and merge it with six other bankrupt railroads! So CONRAIL will wind up being a bigger and even less manageable entity. Furthermore, there is no appropriation for modernization of plant anywhere in CONRAIL—which is the primary objection.

* Patrick Benedict McGinnis was president and a director of the New York, New Haven & Hartford Railroad from 1954 to 1956.

Thus, in my opinion, the purpose of CONRAIL is not to rehabilitate the railroads, but to "thin out the branches"—if they can get away with it—so that, sooner or later, Union Pacific or Burlington Northern (or both) can do to CONRAIL what Northwestern wants to do with the Rock Island—"cannibalize" the railroad! Meanwhile, the Southern would like to come up the Delmarva Peninsula and pick up pieces of the Penn Central to Wilmington in order to carry the profitable DuPont freight, without having to take over the lines that provide service to all the shippers that are located out on the branch lines. All they would have to do is to pick up the "cream" of the traffic along the mainlines; the heavy traffic—20 to 50 carloads of goods and dealing with their best customers. That's the CONRAIL plan for Penn Central; and, eventually transcontinental railroads are envisioned operating on this basis—but they will only serve the major cities and the major shippers. And the eastern economy will follow the railroads down the drain.

A good example of what will happen if CONRAIL comes into being is what's happening to the bankrupt Rock Island right now. Union Pacific and Northwestern are saying they will pick up Rock Island's profitable business. But what will be the consequences to the XYZ Corporation, located 15 miles off the main track when Union Pacific says, "We don't want that business; all we want is the profitable freight shipments along the mainline route"? XYZ Corporation with, say, 300 to 600 employees goes out of business. That's all that will happen!

Spectrum: **You are clearly opposed to the merger of the Penn Central. How far back do your efforts go in trying to block that action?**

Shapp: Back in 1962, the idea of such a merger was hatched. At that time, the ICC and the New York Central and Pennsylvania Railroad attorneys wanted to prevent my testimony from getting on the record. They claimed that I was a private citizen and, therefore, had no standing or relevance to the issue. Finally, I laid it on the line: "I own stock in the Pennsylvania Railroad, and I want to testify as a stockholder." Well, the legal boys had a big huddle, and, finally, I was permitted to testify on that basis.

My first testimony against the Penn Central merger was in late 1962. I pursued the issue for six years—from the initial ICC hearings all the way up to the U.S. Supreme Court. By that time, the principals had consummated all their deals. However, the City of Scranton [Pa.] and the nearby Borough of Moosic stayed in the case. Originally, more than 200 counties and municipalities, along with the labor unions and a number of private shippers in Pennsylvania, opposed the deal. But, one by one, the opposition was whittled down to six communities. The final holdouts were Scranton and Moosic—and Milton Shapp—vs. The United States of America. The Supreme Court re-

Shapp ponders the state of U.S. rails

ferred the case back to the lower courts for some additional review and rulings; then we carried it right back to the Supreme Court a second time before the final decision was made.

***Spectrum:* Do you still own stock in the merged company?**

Shapp: I'll tell you a very funny story about that stock. Both my wife and I owned shares. During the gubernatorial campaign of 1970, Penn Central stock was selling in the 50s and 60s. Then the bottom dropped out of the market, and it plummeted down to $6 a share. I sold out around $50 a share, and I urged my wife to do the same. But, like a woman, she resisted: "I like the stock." So, after the nosedive, I said, "See, Muriel, I told you to get out." She replied: "I'm glad I didn't."

"Why not?" I asked in amazement.

"Well, if I had sold out, I would have put all of that money into your political campaign; this way . . ."

All I could do was grin and bear it.

***Spectrum:* Why does railroad management prefer to handle the transportation of freight, but would like to get rid of passenger service?**

Shapp: Very simple. Most freight shippers pay the railroads in advance, and their best [largest] customers pay within five days of shipment. The railroads pay their workers twice a month, and they have 30- to 180-day terms on payment for their fuel supplies and equipment. So, railroads have the prior use of their freight customers' money to ensure a high incoming cash flow. This ensured cash flow cannot be guaranteed in passenger-carrying operations.*

* Most passengers, today, usually pay by credit cards, on which the railroads must pay the card company a percentage for the service fee. Then, it takes from 30 to 60 days for the railroads (through AMTRAK) to collect their share of the fare on the tickets originally sold by credit cards. Furthermore, the flow of passenger traffic is both seasonal and unpredictable. Nevertheless, the scheduled trains must be kept running, filled or not.

Photos by Associate Editor Marce Eleccion

***Spectrum:* We understand you'll be conferring with the governors of 17—or more—states to discuss the revitalization of the railroads. Can you give us any more information on these upcoming talks?**

Shapp: The first thing on the agenda will be a discussion of the reasons why this Federal plan [Rail Reorganization Act] must *not* go into effect. The branch line rail service curtailments, in Pennsylvania alone, will mean the loss of 50 000 jobs.

In Pennsylvania, for instance, the plan envisions the abandonment of track that serves coal reserves of more than 2 billion tons—this at a time when the President has declared that we should be making progress on "Project Independence" to develop coal to replace oil! And here we have this huge quantity of bituminous and anthracite coal that will be denied rail shipment if this plan is passed.

Now, I just point this out—and, maybe it's more my opinion rather than strange coincidence—but the proposal to abandon these tracks in Pennsylvania—plus others—comes at a time when the Burlington Northern and the Union Pacific are starting their "unitrains" to haul Western coal into Eastern markets. Further, I think it's more than just coincidence that the organization act for the Northeastern states was brought up in the House of Representatives by two western Congressmen: one from Montana, and the other from Washington; and, it was strongly supported by Senator Magnuson of Washington. So, you begin to ask yourself: how much of this is coincidence, and how much is prearranged?

It's obvious that the desire of the major railroads is to pick up the profitable pieces of mainline business and scrap the branch lines and the rest. Actually, the track-abandonment theory is phoney, because it represents less than 10 percent of the total losses incurred by the railroads. But you begin to wonder if the whole thing isn't just a means by which the profitable railroads can extend their territories and pick up the business they want at the expense of the less well-heeled railroads already in existence. As I said before, look at what the Southern is doing. They want to come into Wilmington, Del. Why? Because DuPont is there. And they want to come up to the Delmarva peninsula. But Southern isn't interested in serving the communities along the peninsula; they just want to use that route to pick up the profitable business from DuPont and forget the rest! Well, what does that do to a region? It just kills it.

Shapp on intraurban mass rail transit

***Spectrum:* Governor, could we turn to urban mass transit? Is rampant inflation making rail transportation just too costly? For example, recently Mayor Beame of New York City was forced to stop the construction of the Second Avenue subway. Also costs have been escalating steadily in building the new Washington, D.C., Metro and in estimates for Atlanta's MARTA system. Originally, Metro's figure was about $3 billion; now, the costs are projected to the $4.5 billion range. How do we handle situations like these?**

Shapp: The internal systems of our major cities are extremely costly to build. And it may very well be that continuing inflation will have a devastating impact on future systems. However, that doesn't mean that mass transit *per se* is doomed, because there are other alternatives. As a case in point, Philadelphia has hundreds of miles of abandoned railroad track and abandoned rights-of-way; there is no reason why that track cannot be rehabilitated, or new track laid down in those rights-of-way to form urban transportation loops to give that city better mass transit. But when you discuss subways being built in major cities —and especially in downtown or center-city areas, where land must be purchased, existing buildings and streets disturbed, utility lines relocated, etc.— then you run into these tremendous costs. And, it may very well be for these reasons that new subway systems are no longer feasible in the U.S.

As I mentioned earlier on, I just came back from Peking, where an oval-shaped subway loop around the city is being completed in two years' time. Peking already has a straight-line subway, and the loop line will supplement passenger access to all areas of the city. Of course, the Chinese don't have to worry about environmental impact statements; they don't seem to mind construction noise during the night. Thus, all night long, one hears the bang! bang! bang! of pile-driving. Well, you know what would happen in the U.S. if you lived across the street from an all-night pile-driving operation! But, in Peking, they're going all out, with armies of workers on the project, and they're building it in record time.

***Spectrum:* As I understand it, the Lindenwold line out of Philadelphia is very successful.**

Shapp: Very much so—to the extent it is operating. But it could be much more successful if there were a direct connection to the airport, and the line were extended to Media and other suburban towns.

***Spectrum:* Do you think that the diversion of the highway trust fund into the construction of mass-transit systems would be a solution?**

Shapp: The President has indicated that he can divert 2c of the Federal gasoline tax per gallon and give that to the states to be used for regular highway maintenance. By the beginning of 1974, $56.5 billion had been paid out for the Interstate Highway Program; but, incoming monies to the highway fund totaled $59.5 billion. Thus, the income is now greater than the outlay necessary to complete the Interstate projects—even though the most expensive parts of the scheme remain to be finished. Still, there is sufficient money to complete the systems (in view of the continuing inflation) by means of "user taxes." However, I don't think it is necessary to say that the only place money for mass transit can be obtained is from the highway trust fund. What's wrong with setting up a *real* trust fund? That is to say, put a 5-percent surcharge for 30 years on all freight shipments, and use this money to modernize all types of transportation, including passenger trains. Further, there is no reason why the same type of thing can't be done for mass transit by means of a small surcharge per passenger. If this were done, I believe that mass transit would be in a better position to pay for itself.

***Spectrum:* Governor, what about the controversial Pittsburgh "Skybus" project [an automated, driverless elevated monorail system (concrete beamway) carrying a vehicle or train of coupled vehicles]? Has it been abandoned, or are plans still under way to implement the Westinghouse scheme?**

Shapp: I think "Skybus" has been pretty much pushed into the background at the present time. There is a general agreement to move ahead on different forms of mass transit for Pittsburgh and its suburbs.

***Spectrum:* In view of the many operational problems plaguing the Bay Area Rapid Transit Systems [BART], do you feel that automatic train control is the way to go; or, should there be more of a mixed manual/automated mode on urban and suburban systems, such as that planned for the Washington Metro?**

Shapp: I think you need the manual, as well as the automatic, equipment for a number of reasons: one, I feel it is not at all realistic to think in terms of having unmanned trains. Passengers, for psychological reasons, want to see someone "up front" in charge of the train. Secondly, if the equipment should fail (and all equipment can and does fail on occasion, despite backup systems), there should be someone on-board to operate the train manually. And, third, I think our unions are strong enough in most mass transit areas that they will insist upon manual operation override provisions. I spent some time on BART, and its management admitted that [because of accidents and operational failures] it would have to have an attendant on each train; even though, at the outset, the plan was to operate unattended.

Although BART is a very fine system, I think the Montreal Metro is probably the best subway I've seen in North America.

***Spectrum:* What about future traction systems —such as linear induction motors and tracked air-cushion vehicles?**

Shapp: I see linear motors playing a major role, because I think that is a natural development for mass transit. I don't see air cushion coming in as rapidly. Perhaps, once the bugs are ironed out, air cushion may be the answer for high-speed long-distance travel; but, for local travel, I don't see it at all. For commuter and intercity operations, perhaps it may become practical at some time in the future.

***Spectrum:* As a final question, Governor: are there any plans to electrify the mainline of the Penn Central beyond Harrisburg? [To date, the Penn Central mainline is electrified from New York to Harrisburg, Pa.]**

Shapp: Only the plans that the state of Pennsylvania have developed. But, to go one step further, I'd like to see electrification through to Chicago and St. Louis. Electrification *is* the way to go. Right now, we could save 60 million gallons of diesel oil per year by electrifying. We could realize the goals of Project Independence, and the railroads represent the most efficient way toward achieving that objective by the target year.

***Spectrum:* Thank you, Governor Shapp.** ◆