ENGINEERING | AND | SCIENCE

February 1960

Feynman in a new field . . . page 22

Published at the California Institute of Technology

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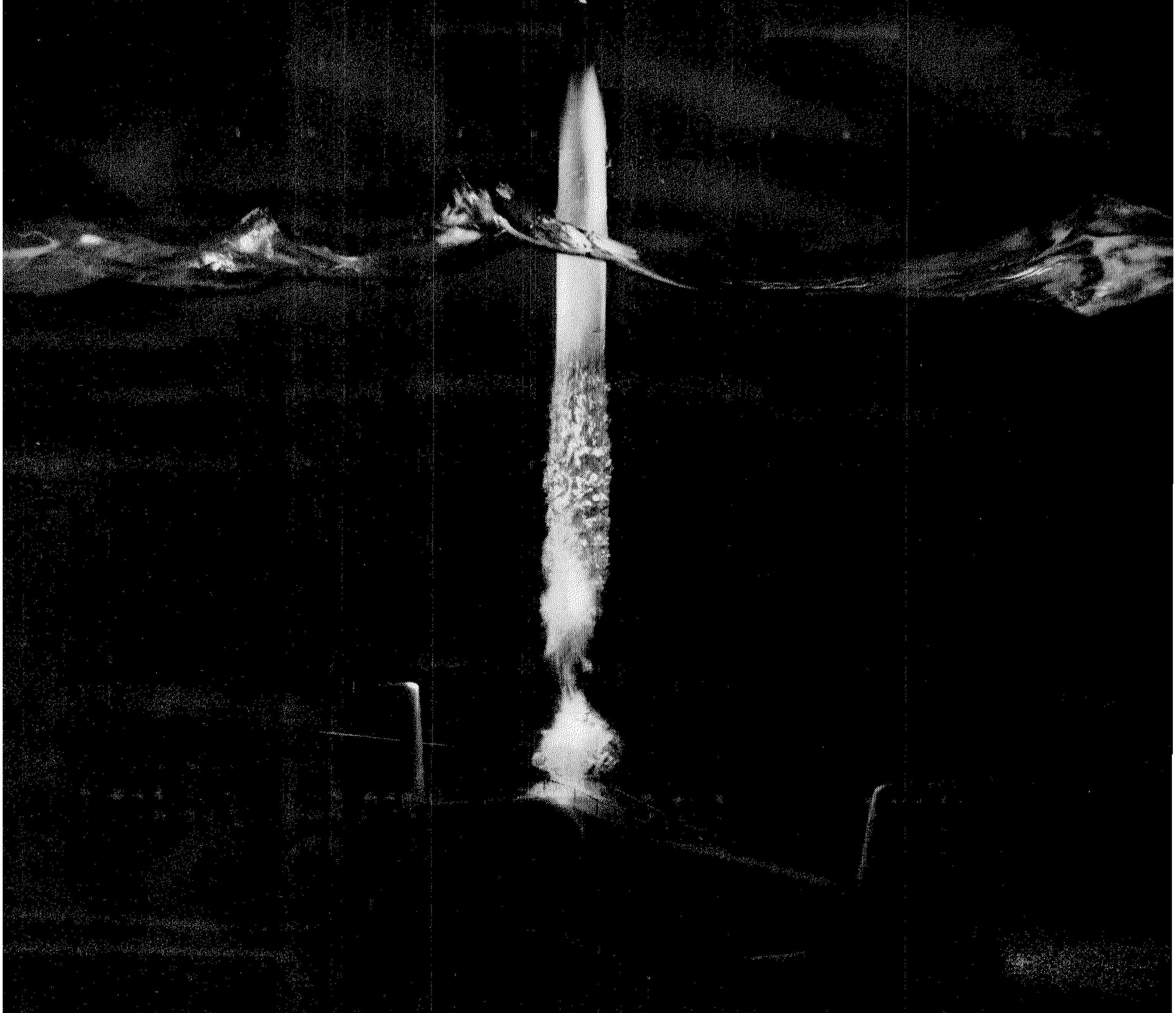

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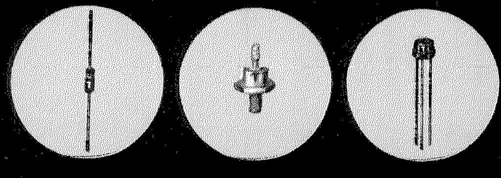

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ENGINEERING AND SCIENCE

FEBRUARY 1960 VOLUME XXIII NUMBER 5

On Our Cover

Richard P. Feynman, who is Richard Chase Tolman Professor of Physics at Caltech, and author of "There's Plenty of Room at the Bottom" on page 22. The article has been adapted from a talk given by Dr. Feynman at the banquet climaxing the American Physical Society's annual meeting at Caltech, December 28-30. In his article, Dr. Feynman describes a new field of physics, and issues an invitation to all scientists – and non-scientists – to start working in this fascinating area.

"The Importance of Space"

by President L. A. DuBridge (page 13) was originally presented as a talk at the Pasadena City College Forum on January 26.

In Memoriam

Caltech lost two eminent professors emeriti last month, Beno Gutenberg and John Robinson Macarthur. On page 20 a tribute is paid to Dr. Gutenberg by Robert P. Sharp, chairman of the division of geological sciences and professor of geology; and on page 21, a tribute to John Robertson Macarthur by Horace Gilbert, professor of business economics at Caltech.

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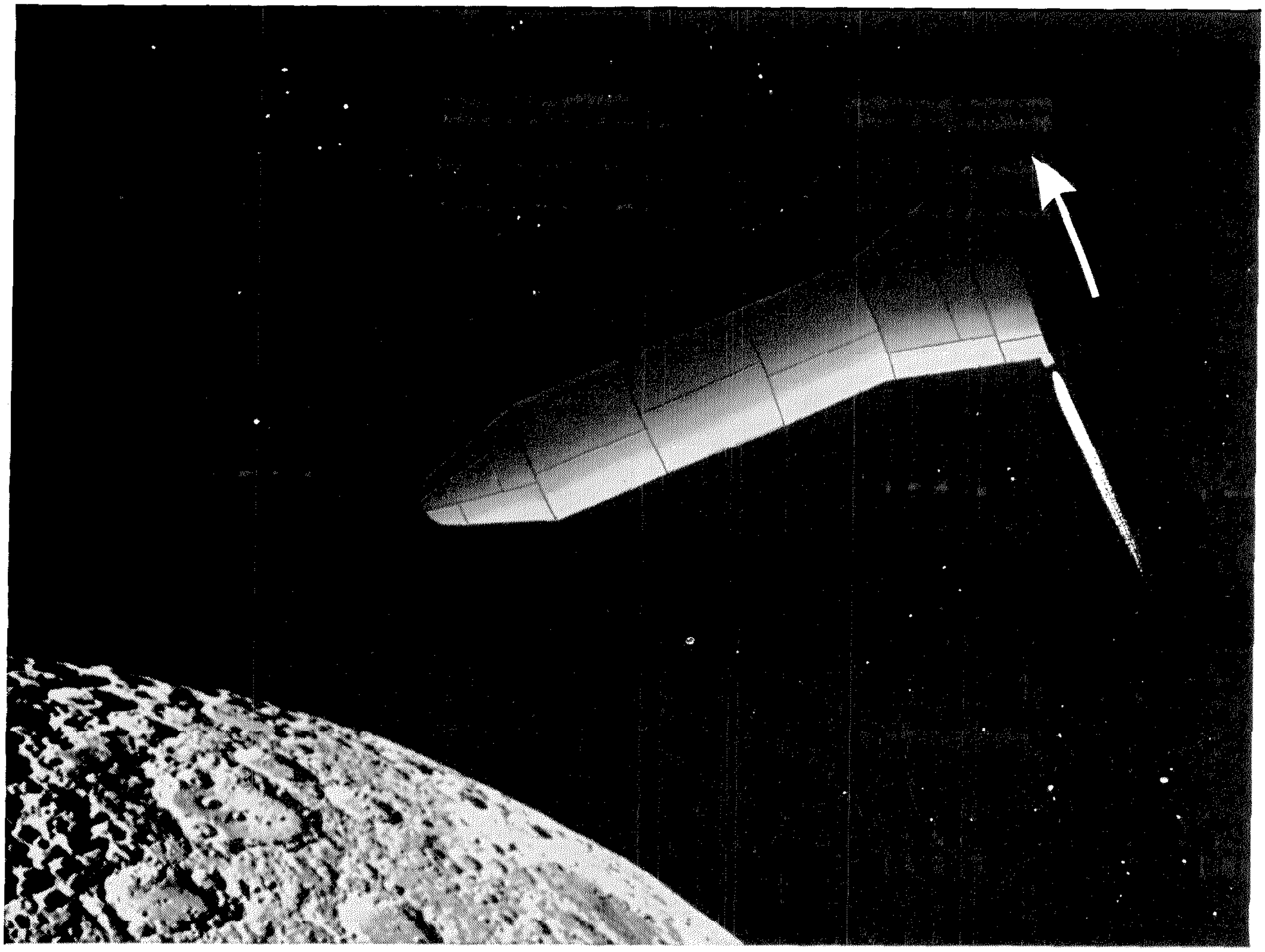
Published monthly, October through June, at the California Institute of Technology, 1201 East California St., Pasadena, Calif., for the undergraduates, graduate students and alumni of the Institute. Annual subscription $4.50 domestic, $5.50 foreign, single copies 50 cents. Second class postage paid at Pasadena, California. Manuscripts and all other editorial correspondence should be addressed to: The Editor, *Engineering and Science*, California Institute of Technology.



HOW TO MAKE A "LEFT TURN" IN OUTER SPACE

(and the "right turn" toward a gratifying career)

Like the dimensions of the universe itself, the future of space technology is beyond imagination. The frontiers of space will edge farther and farther from us as engineering and scientific skills push our knowledge closer to the stars. Bendix Aviation Corporation, long a major factor in America's technological advance, offers talented young men an outstanding site from which to launch a career.

In the field of controls alone, for example, Bendix (which makes controls for almost everything that rolls, flies or floats) has developed practical, precision equipment for steering and controlling the attitude of space vehicles. It consists of a series of gas reaction controllers (actually miniature rockets) which are mounted around the satellite. Individually controlled by a built-in intelligence system, they emit metered jets of gas on signal whenever it is necessary to change the orientation of the satellite.

The development of this unique control equipment is but one of the many successful Bendix projects involving knowledge of the outer atmosphere and beyond. Bendix, a major factor in broad industrial research, development and manufacture, is heavily engaged in advanced missile and rocket systems and components activities. These include prime contract responsibility for the Navy's advanced missiles, Talos and Eagle.

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Books

From Hiroshima to the Moon

Chronicles of Life in the Atomic Age

By Daniel Lang

Simon and Schuster $5.95

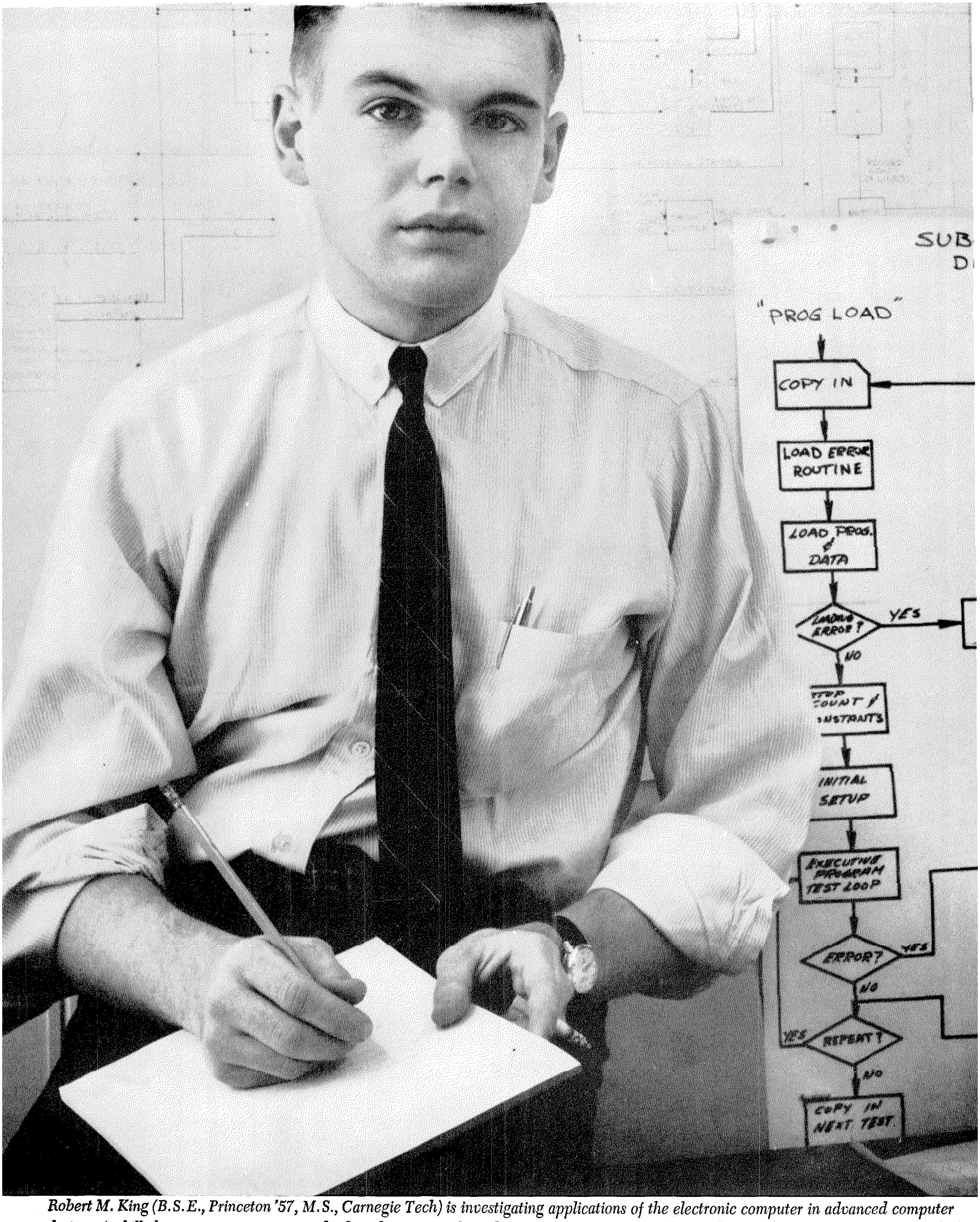
Daniel Lang became a chronicler of the Atomic Age by chance. As a staff member of *The New Yorker,* he was assigned to interview a worker at Oak Ridge in the summer of 1945, after the bombing of Hiroshima. Like most of his fellow-workers, the Oak Ridge man had found out, for the first time, what it was he had been working on all through the war.

Mr. Lang was led on from this assignment to get the story from intelligence agents on how the work of the Manhattan District was kept secret during the war. Then he went on to report on post-war life in Oak Ridge. Since then, most of Lang's reporting has been concerned, in one way or another, with life in the Atomic Age.

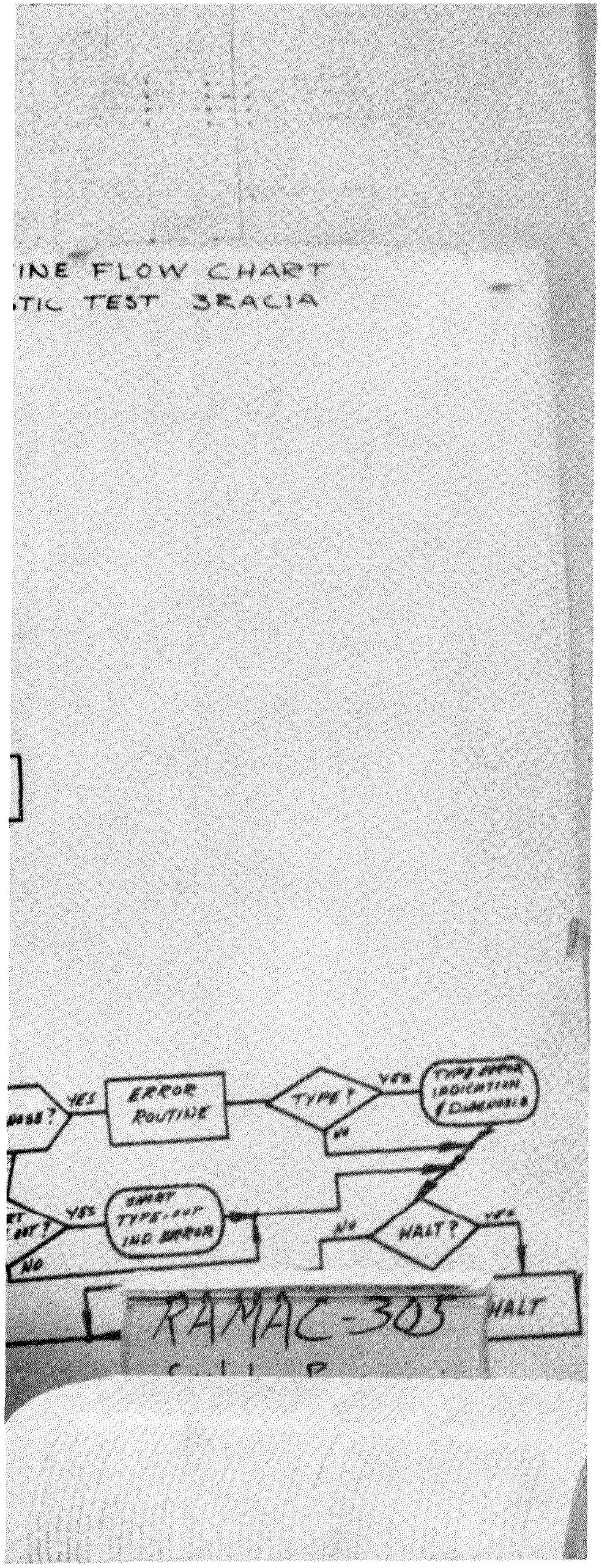
In 1948 a number of his articles were collected into a book called *Early Tales of the Atomic Age.* A second collection, *The Man in the Thick Lead Suit,* appeared in 1954. *From Hiroshima to the Moon* includes selections from these earlier books, as well as a good deal of new material.

Lang calls his book ". . . the chronicles of a layman who, by virtue of his occupation, has been able to wander through the bewildering maze of developments since the Year One, and it is these very wanderings that lend the book whatever shape and form it may possess. Perhaps its contents will afford historians to come a clue as to what went on in the tumultuous era through which we have already lived, an almost perfectly carved-out piece of history in which we have gone from Hiroshima to the moon (and beyond), from earthly ruins to the unspoiled heavens. We will probably be centuries, or whatever time is left to us, assessing the consequences of these past few years, and it may be that one useful way of coping with so concentrated a burst of history is to handle it journalistically. Perspective may come later . . ."

The material in *From Hiroshima to the Moon* is presented as straight journalism – and apparently pretty much as originally written, with updating or second guessing. It is class A journalism, too, and superb science writing. The articles are dated, running from August 1945 ("The War's Top Top Secret" – the Manhattan District) to November 1958 ("Man in Space" – some facts about the human factors in space travel). In between, there are chronicles on Brookhaven, Los Alamos, White Sands, Yucca Flat, and Cape Canaveral; on the AEC and Project Vanguard; on flying saucers, satellites, and fallout; on Wernher von Braun, Samuel Goudsmit, an Indian sheepherder who made a uranium strike, and the Oak Ridge physicist who became an Episcopal deacon.



Robert M. King (B.S.E., Princeton '57, M.S., Carnegie Tech) is investigating applications of the electronic computer in advanced computer design. A skilled computer programmer, he has done original work in organizing programs that make possible computer self-diagnosis.



HE GETS COMPUTERS TO DIAGNOSE THEIR OWN FAULTS

With the increasing size and complexity of modern computers, one of the most interesting problems that engineers face is the rapid and efficient location of failures within the system.

The method which they have found most practical is to use the speed and logical abilities of the computer itself to make the diagnosis. Programming computers to perform this function is the job of Robert M. King.

The Diagnostic Technique

He prepares programs for the computer which actually simulate the deductive processes of a man investigating the faults of the machine. Each program instructs the computer to exercise various segments of its circuitry in a logical order.

The result of each test is checked against the correct result, stored in the computer memory, of previous tests of the same circuitry when in proper working order. If the results do not agree, a message is automatically typed which indicates the failure and which component caused it.

A computer is particularly adept at this job. It can take into consideration simultaneously a large number of factors. It can also work at very high speeds. Once a program is properly written, the computer makes no errors. Appropriately enough, diagnostic programming often aids in designing better computers.

A Programmer's Background

Computer programs are the result of ingenious applications of many intellectual qualities. Computer design and language are based on sound laws of logic. Therefore an important prerequisite is the ability to analyze complex problems and to deduce from them useful methods of solution consistent with machine requirements.

If you think you might be interested in working in one of the many fascinating areas of computer programming, you are invited to talk it over with an IBM representative. The future can be as unlimited as the future of the computer itself.

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ENGINEERING AND SCIENCE
February 1960, Volume XXIII, No. 5

The Importance of Space

What are the *real* goals of space exploration?

by L. A. DuBridge

The Space Age is well over two years old now. But, like a two-year-old baby, it hasn't really begun to make much sense as yet. Fond relatives exclaim that it is the greatest baby ever born. But sharp critics argue that it is not worth so much attention – and that scientists would do well to stay home from their space ventures and try to cure cancer and other diseases. Still other people, noting that the American space baby is neither as old nor as hefty as the Russian infant, are impatient that in spite of all the vitamins and minerals we are feeding the child it persists in remaining both smaller and younger than the Russian prodigy.

It is undeniably true that the Russians have exploited their infant prodigy to the fullest. They are such proud and boastful parents that they have succeeded in giving all the rest of the world a severe inferiority complex. And there appear to be those who believe – or who fear that everyone else believes – that the remarkable vigor of the Russian space baby proves that its parents are the greatest people in the world and have now surpassed all the rest of the world in all matters scientific, military, technological, educational, and possibly even political.

In short – what a lot of commotion the arrival of the Space Age has caused!

Now there is good reason for excitement, of course. Since the beginning of history, man has dreamed of flying to the stars – always fearing, however, that the dream was an impossible one. Actually, flying to the *stars* still is impossible for us; but journeying to the moon and the planets is not. Indeed, manmade packages have already flown to the moon and beyond. Venus and Mars are perfectly feasible targets for "near-miss" trajectories in the near future. It is now a fact that men have learned to launch sizable vehicles with sufficient speed and accuracy to attain satellite orbits around the earth, and even to escape the earth's gravitational field altogether. This is surely one of the greatest human accomplishments of all time.

It is such a magnificent human achievement that it is distressing to see how so many small-minded men have flown into a jealous rage over the fact that the Russians accomplished the feat a few weeks before the Americans did. After 100,000 years or so of human history, why was that last 16 weeks so important? Future historians, I am sure, will have a hard time explaining why that 16 weeks had such an extraordinary effect on world politics.

One reason that the Russian successes have been so exasperating to Americans is that we know we could have been first if we had wanted to. The scientific knowledge and the technical know-how in the United States and Russia were essentially equivalent. No great new secrets of nature were discovered or great new inventions made by the Russians. Their earlier successes were the result of a technological accident combined with a political decision.

The technological accident was that the United States Atomic Energy Commission was able to develop an extremely powerful thermonuclear warhead of rather small weight. To carry this warhead to any conceivable enemy target requires a rocket whose thrust is about 150,000-200,000 pounds. So, such a rocket was developed – now known as the Atlas. And, in fact, to be sure of success, a second development of a somewhat different model, but with similar performance, was undertaken – the Titan. These rockets, plus the associated guidance and launching equipment, are now becoming operational – and have had spectacular success in meeting the military requirements originally set forth.

Now, the "accident" came about through the fact that the Russians apparently did *not* achieve a lightweight thermonuclear warhead, and hence decided that their missile must have a thrust of 300,000 pounds or more. So they developed such a rocket – in great secrecy, of course.

Hence, in 1957, Russia emerged with the first 350,000-pound rocket and we produced the first Atlas, with one-half that thrust. Each nation achieved what it set out to achieve: an operational intercontinental ballistic missile adequate for its needs.

But now came the political decision. The scientists of both nations considered it desirable to launch earth satellites in conjunction with the International Geophysical Year program. The United States decided that, since IGY was a peaceful international effort, it would not use military equipment in the program, but would develop a smaller rocket for the space-launching task. It was called Project Vanguard, and full information about it was released to the public.

The Russians released *no* public information but *in secret* decided to use their large military rocket as a booster for a space vehicle. They apparently put an enormous effort on this project in order to beat the well-advertised Vanguard dates. They succeeded dramatically, of course, and thus exhibited the advantages of very-large-thrust rockets for space expeditions. At that time we did not have any firm military requirement for a rocket larger than the Atlas (nor do we today for ICBM weapons). Hence, no large rockets were even on the drawing board. Hence, we still have none, and won't have for a year or two.

So it came to pass that a technical accident and a secret political decision combined to produce an enormous psychological victory – and brought the entire world to begin to think about the importance of space – and shocked the entire world into an awareness that Russia was no longer a nation populated solely by illiterate peasants. It should not have taken Sputnik to teach us this; there was plenty of other evidence.

Obviously, a substantial part of the initial shock came about because of the possible military implications of the Russian Sputnik. Because the U.S.S.R. launched a bigger space vehicle earlier than we could, it was immediately concluded that military supremacy had now passed to the Communists – and the term "missile gap" or "missile lag" entered the English language.

We have already seen that our Atlas or Titan missiles will carry our best thermonuclear warhead to any possible target – and these missiles are now becoming operational. A missile of twice the thrust would not do that job any better. We don't have to carry larger loads any farther to achieve any foreseeable military mission. Clearly, the fact that the Russians are using a larger rocket to achieve their purposes is of no military consequence to us whatsoever. No military superiority resides in a thrust larger than necessary for our purposes. If "missile lag" means *they* have larger-thrust missiles than *we need*, then the missile lag is not of consequence at all, and we should quit worrying about it and quit using the term!

Does missile lag mean they have more intercontinental missiles than we do? That, of course, would be more serious. However, we must all be confused by the conflicting information being released on how many missiles they have or will have in the near future. And no analysis has been released to the public on whether they would need three times as many weapons to knock *us* out as we would need to knock *them* out. So we don't know – at least, I don't know – whether there is really any numbers lag or not. Let me add, however, that, since we don't know, we would do well to put forth all efforts to increase our number of operational Atlas and Titan and Thor and Polaris and other military missiles as rapidly as possible, until our needs have been met.

Furthermore, until then, we should divert as few as possible of these priceless military weapons to nonmilitary space ventures. I prefer the solid comfort of a good military weapon in our arsenal to the passing psychological satisfaction of launching a bigger vehicle to carry cosmic-ray counters into space. As a scientist, I can assure you that I am *very much* interested in carrying cosmic-ray and many other scientific instruments into space as soon as possible. But scientific experiments can wait if military security is at stake. We should abandon the illusion that launching big space vehicles automatically assures military supremacy.

However, even if we can be skeptical about the existence of a missile lag, we cannot deny the existence of a "space lag." Even if huge booster rockets do not necessarily make any more effective ICBM's, they do undeniably enable one to launch larger space vehicles and to send them farther into space. In this the Russians have acquired a substantial lead which we envy.

We might envy the Soviets their space lead for three reasons: (1) military; (2) scientific; or (3) psychological (or political or prestige). Let us deal with each in turn.

I. MILITARY VALUE

Does it give the Soviet Union a military advantage (at present or in the foreseeable future) to be able to launch larger space vehicles than we can, or launch them farther into space?

There are going to be strenuous arguments on that question for years to come, for no one actually knows whether – or to what extent – there will be important military uses of space vehicles.

The values to military forces of communication networks employing satellites are obvious – and should be vigorously developed. The attractiveness of using space satellites for military reconnaissance is also obvious, provided practical methods for achieving this difficult task can be developed. This, too, should be vigorously pursued. But improved communication and reconnaissance, of themselves, do not give overwhelming military advantage to either side. We are not going to surrender suddenly to the Russians because they can talk to each other better than we can — or even because they can see us better than we can see them. They can do that now!

The question is: What new weapon systems does space provide, or what new methods of using present weapons does it promise?

It is on these questions that our ignorance is so great that only speculations can be made. But speculations are being made very vigorously!

For example, does a space vehicle promise to be vastly superior to an ICBM when it comes to placing weapons accurately and surely on distant targets? My own opinion is that at present no techniques are known by which this superiority can be attained. An ICBM can be made so accurate, so reliable, and (when suitable launching sites are available) so relatively impregnable that space vehicles have a very long way to go to equal them, much less surpass them. Space satellites in orbit are not especially invulnerable; there are a number of methods of observing and destroying them. While they are in orbit, they are extremely difficult to control — i.e., to change orbit. They tend to stay in the same orbit forever, and one must wait patiently for the earth to turn underneath them for a given target to come into position. Finally, the ejection of a weapon from a space satellite with the proper speed and direction and timing to hit a given target accurately is an enormously difficult task for which no present technology is anywhere near adequate or satisfactory. New and better technologies may someday come, and a development effort is certainly necessary. But we need not get hysterical about space-satellite weapons yet.

What about those who say it is of great importance for us to capture the moon as a military base? Here is the ultimate in the "high ground" the military man always seeks!

A long and very learned-looking article in *The Air University Quarterly Review* last summer set forth the arguments why the moon should be "sovereign U.S. territory" — our 51st state presumably. If it was our territory, we could tell the Russians to stay away, and it would then be a "tremendously hard" missile base. No one can quarrel with that. All we have to do is figure out a way to keep the Russians off, or, even more important, keep them from getting there first!

But even if the moon is shared with other nations, the article says, our missile bases would still be hard to see (from the earth, that is) and hard to destroy with nuclear weapons, especially if the bases were underground. Again, no one can deny that. But bases in Iowa or Texas or Maine or Alaska would be hard to see and destroy, too — if they were underground. And these places are much closer to Moscow than the moon is. Viewed from the moon, Moscow is on a spinning ball, about 240,000 miles away and moving (relative to the moon, or the moon relative to it) at about 2,000 miles per hour. There is nothing scientifically impossible about developing guidance and computing equipment able to do the job. But I'll predict we can hit Moscow more often and more cheaply from Iowa — for the rest of *this* century, at least.

The clinching argument for a missile base on the moon appears to be that the acceleration of gravity is only 1/6 as great there as on the earth, and hence the velocity of escape is only 1.5 miles per second instead of 7 miles per second. Splendid! But just how does the missile get to the moon in the first place? And what about the crew, the equipment, the fuel, the food, water, oxygen, the bulldozers that will operate in a vacuum, etc., etc. They have to be lifted from the earth — and then landed very gently on the moon before the missile can be shot off. It will take many times as much fuel to get to Moscow via the moon as to go directly.

Finally, the article suggests that, in order to obtain good observation of the earth, so we can see what the Soviets are doing and can guide our missiles to the target, we should erect a 200-inch telescope on the moon! I hope I can return from the grave the day that the Palomar telescope of the moon is dedicated. It will be a great day for the science of astronomy. But the task of putting a 200-inch mirror on a rocket and delivering it safely to the moon strikes me as being one which presents certain difficulties. I breathed a sigh of relief the day our 200-inch mirror safely completed the 130-mile journey from Pasadena to Palomar Mountain.

I have great confidence in the skill of American engineers, you understand. I just think some of these things may take a little time. Say 100 or 200 years.

Please forgive me if I express certain doubts as to whether lethal military operations in — or from — space are an immediate probability. But again I emphasize that further research and development is justified. New ideas and new inventions may change the picture. I just don't like to bet billions of dollars on discoveries not yet made.

If military security is not obviously or immediately the most essential reason for conducting space exploration and development, what then about the scientific values?

II. SCIENTIFIC VALUE

Here is where I would like to give a complete lecture on the scientific value of space research. To explore the earth, the moon, Venus, Mars, and the great mysteries of interplanetary space presents problems which will challenge men's ingenuity and add to their knowledge for generations, for centuries, to come. If setting up a missile base on the moon appears to be a bit chimerical for the present, it is by no means farfetched to plan soon on sending scientific instruments there in order to make many, many measurements and observations. Instrumented flights to Venus and Mars are also in sight. Someday, too, we will wish to make measurements beyond the capacity of automatic instruments, and then we may want to send trained scientists and engineers along to supplement the instruments and make them much more effective.

I, for one, believe it is worth a billion dollars a year to develop these scientific projects. A great opportunity for the extension of man's knowledge has come to our generation. I hope we can exploit it fully.

Neverthless, when the congressman or the average citizen asks about space projects and about the Russians being "ahead of us," he does not ask whether the U.S.S.R. has obtained more scientific information in space than the U.S. The answer would be "no." The U.S. is ahead in the scientific field. But the citizen knows that the heaviest Soviet space vehicle weighed 3,245 pounds, and the heaviest U.S. vehicle only 1700 pounds. Q.E.D. – the Russians are ahead of us. No one asks what was *in* the Russian vehicle, or whether the U.S. vehicle might have obtained more or better information. Actually, the Soviets have done some fine experiments, but the U.S. has achieved more knowledge. That doesn't count, apparently. The Soviet payload *weighed* twice as much as ours.

III. PSYCHOLOGICAL VALUE

Clearly, then, the "space race" or the "space lag" is based not on military or scientific values, but only on poundage. "The bigger, the better," is a good old American adage – and that is the one we are applying today. Pound for pound, shot for shot, we must catch up with and surpass the Russians. Our good old competitive spirit has been aroused. We must have the biggest cars, the tallest buildings, the largest cities, the fastest runners, the highest jumpers, and the biggest rockets.

Well, I agree! I think we should too; especially rockets – for the whole world is interested in space, and I hate to see us out-classed. But let's be honest about it. It is just a game – a big and serious game, no doubt, but a contest for psychological prestige. I am not going to get hysterical if it takes us a couple of years to get the bigger rockets and bigger space vehicles. We all want to improve the U.S. psychological and political stature in the world. It is probably worth one or two billion dollars a year to achieve this – especially if the rockets are designed to perform valuable scientific explorations too. What is called for is clearly an energetic, well-planned, intensive effort aimed at clearly worthwhile goals and not just stunts.

IV. THE FUTURE

If we do this, what goals can we expect to achieve in the next 50 years – by the year 2010?

First, we shall see many sizable satellites circling the earth taking weather and other observations; serving as communication relays; collecting data on solar radiation, cosmic rays, magnetic storms, and many other phenomena still not yet discovered. I hope, too, that an astronomical telescope in an earth satellite will have come into being. This is not an easy project, but astronomy would move ahead by leaps and bounds once observations could be made above the atmosphere.

Instrumented and manned landings on the moon will have been made by 2010 A.D., and much data on lunar conditions and structure will have been accumulated. I cannot predict what will be discovered (if I could, we would not have to go!) but my guess is that the moon's surface will be found far too unfriendly for continuous human habitation, and any notion of an earth colony on the moon will still – in 2010 A.D. – seem to lie far in the future. The lack of water and oxygen will be the two critical deficiencies, I suspect. Hauling drinking water up from the earth would be a bit expensive. And, though some say that water will be found in the moon's rocks, we have no information on this question.

But even if lunar conditions do not make a self-sustaining moon colony a feasible enterprise, there will be many scientific expeditions achieved, and much information will be gathered.

In a recent TV panel discussion, a well-known English economist predicted that someday the world's excess population would be shipped out into space to live. *To live!* Since, in a few years, excess population will be piling up at the rate of 30,000,000 per year (100,000 per day) it appears that we had better start preparing for quite a passenger business into space. If we could start colonizing the moon, it would take only 20 years (at 30,000,000 per year, plus their *own* babies) before the moon would be as densely populated as the earth. Then Mars? Well, Mars could bear the traffic for 50 years or so. It has only one-quarter the area of the earth, but it is all land. Shall we then go to Venus? Maybe, but then we are through!

Possibly other stars have planets, but the nearest of them would take a thousand years or more to get to, in order to find out. And how do we know that the 20th generation born on that flight will remember to come back and tell us about it? I suggest we try to solve our population problems on earth, and not depend on space.

But the exploration of space offers so many important opportunities and possibilities that it will pay us to pursue an energetic program of space research. It will take some time, at best. It will take quite a lot of money. But the dividends – even the financial dividends – may eventually be very great.

A lunch at the Y — coffee, culture and current events.

The Caltech Y

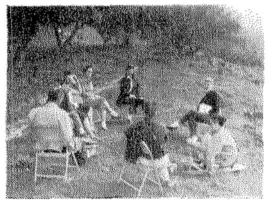
A critical look at the organization which is the "originator and guardian of almost all organized culture on the campus."

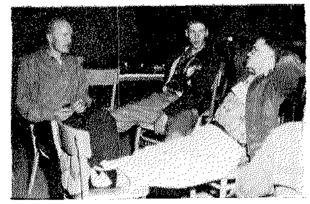
Joe D. Tekmen, typical undergraduate at the California Institute of Technology, makes his first contact with his Young Men's Christian Association the summer before his freshman year, when the Y sends him an impressively heavy Manila envelope chock-full of really-not-too-badly slanted descriptions of its programs. Joe's last contact with his YMCA may be marked by a wan deathbed cackle at an enticingly-written request for more money.

In between, and especially during his four undergraduate years, the Y will have exerted a broad, powerful, and underrated influence on Joe, for it is the self-appointed, unchallenged, and slightly smug originator and guardian of almost all organized culture on campus.

Suppose you wonder, as Joe sometimes does, whether Caltech's famous New Student Camp is really not just a vaguely innocuous waste of time, backed by Higher Authority? Don't question it. The YMCA originated the Camp and Y members are still common there. Or suppose, again like Joe, you want to be an intellectual: you want to know what this guy Camus is all about; you want to be a cultured scientist. The YMCA sponsors discussion groups to fill your need. These give you a chance to sit around and talk in gravid phrases every Sunday about everything from Thales to Existentialist Theology, Bhagavad-Gita to Bertrand Russell. (Neglected is a question about the utility of discussion every Sunday of a book some of the discussers barely skimmed on Saturday night.)

In fact, if you are interested in almost anything, again like Joe, you should by all means go to the YMCA. If one of its myriad programs doesn't cover what you like, you may find yourself heading a committee dedicated to considering your interest for a meeting or so, before it moves on to greener pastures.



If, by the time your committee has finished its deliberations, you haven't decided that Faulkner or Folk Singing is best approached on an individual basis, you may be appointed to a committee in charge of committees. You have taken a step up the Y ladder of Leadership.

The Organization

The YMCA is organized like a holding company, with tiers of committees radiating out from a central core of leaders with fingers in everything that goes on. Core of the core is occupied by Wesley Hershey, executive secretary. Other permanent Y staffers include Alan Green, assistant exec. sec.; Harville Hendrix, Danforth Foundation "intern;" and assorted clerical help. Next in authority come a student cabinet and various commission chairmen; and below these come all the committees, programs, and members which constitute the Y. Most of the upper level leadership justifies the Y's name – it is liberal Protestant Christian. (But there are occasional atheists.)

Wes Hershey, who runs his organization with a minimum of fuss and bother – and a maximum of coffee – is a short, greying, suntanned, and active man of 46 years. His chief occupation (and the chief reason for YMCA success) is scattering oil on the troubled waters that invariably appear when Joe Tekmen and his contemporaries plan anything. One committee chairman called him a "man of many cares and solutions."

Hershey is hired by, and is theoretically advised by, the YMCA Board of Directors. The group, composed of various faculty members and interested Pasadenans, meets monthly. It usually sits as a rubber-stamping session, approving policies set by Hershey or other leaders, but occasionally provides ideas on its own.

Alan Green, chief assistant in the hierarchy, is an *ex officio* member of most of the Y committees, and is more specifically in charge of graduate students. He is 29, blond and married, diligent and earnest. As a committee member, he provides many of the ideas, and usually pushes his own through. He draws cartoons for the "Beaver," the Y's bi-weekly newspaper and announcement of meetings, and is probably as responsible as anybody for the current raging controversy about the loyalty oath in the National Defense Loan Program. (Next to populating the new Student Houses, it has been the most widely argued subject on campus this year).

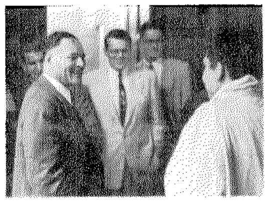
The Activities

The Y was founded in 1916, and its process of cultural aggrandizement has been going on ever since. Over the years, it has started or operated at various times an impressive number of activities: New Student Camp, the Freshman Tea Dance, four different lunch clubs, an indefinite number of semi-permanent discussion groups, the Leaders of America program, a week-long campus visit every year by eight theology students, hundreds of lesser visitors every year, and Sunday evening movies. Just this year, the Y has acquired proprietorship of a Folk Dancing class and two Folk Singing groups.

The YMCA's big production is the Leaders of America program. Every year it imports two or three "leaders of America, molders of American thought and action," to stay two or three days on campus and talk to students and faculty. Past molders have included Abraham Maslow, a psychologist who spent most of his time here saying that really creative people are mentally healthy, and complimenting Caltech students on being by and large mentally healthy; Robert Oppenheimer, who said hydrogen bombs are bad; and non-American Vedantist philosopher Sarvepalli Radhakrishnan. Coming this year are Norman Cousins; and Carl Rogers, who invented non-directive counseling. Notably absent from any Leaders of America roster have been segregationists, warmongers, scientists who think H-bomb tests are useful, writers who think psychologists are useless, Communists or Communist-baiters, anybody who is not liberal, humanitarian and good as defined by the World Council of Churches and the *Saturday Review* set of magazines.

When he gets here, a chosen Leader is not given much of a chance to expound his doctrines. He spends most of his time answering questions put to him at a succession of panel meetings, discussion meetings, after-dinner meetings, and meetings. Most of the questions deal with what he said in his speech last night, and he is constantly explaining and re-explaining the same old stands to a shifting multitude of questioners. Personal contact and individual exchange of ideas is limited to what can filter through the group of Seekers After Truth constantly surrounding him.

The Y's other avowedly intellectual activities follow the same pattern. In the multifarious lunch club meetings, a visitor comes, exchanges small talk across the table with those fortunate enough to sit near to

him, gives a speech, answers fifteen minutes worth of questions, and is escorted away by the ever-present and pleasant committee in charge. Appointments between the visitor and individual students are never set up. Most attempts on the part of a listener to engage in individual conversation at the end of a meeting are broken up by a committee member pointing out that "Mr. So-and-So is very busy and has to go." The Y operates its luncheons on the theory that individual thought will be started by fleeting appearances and sketchy answers on the part of visitors. It usually isn't.

In the seminar-discussion groups (with names like "Critique of Religion" and "Philosophy of Life"), the ideal is extended discussion of books and articles, with each participant knowing what he is talking about. Sometimes this works; usually it doesn't. Most of the discussion groups end up split in two, with the ones who didn't read the books sitting quietly listening to the ones who did read them (usually the Y-appointed group organizers or leaders). Although the talkers often come out with absurdities like, "I was reading Neitzsche last week, so don't pay a bit of attention to me," they are the ones who select the books and do the talking about them. What starts out with hopes of becoming a high-level intellectual-type discussion often ends up as a tired recital of prejudices supported by cursory reading.

The Social Events

The Y takes its role of character-building seriously when it plans and operates its relatively small, but carefully selected, array of social events. Edification, rather than entertainment, is the guiding principle in all of these, and much of the enjoyment is postponed until tomorrow so basic concepts can be learned today.

The Freshman Tea Dance, held the first Sunday after New Student Camp, is designed to impart information on How To Meet College Girls. Tech frosh generally arrive before the dance begins, and congregate like drones under the trees in the garden behind Dabney Hall. The rest of the afternoon, they are herded by selected (self-appointed) upperclassmen toward hovering clusters of giggling Scripps freshmen and high school seniors. Most of the Tech frosh, despite the prodding, are too scared to be successful, and most of the spoils go to the upperclass chaperones.

The Folk Dancing and Folk Singing groups are dedicated to the proposition that anyone can become the master in only five lessons of the curious pleasure-rites of those charming and unsanitary folk who live away over there beyond that hill and who don't speak English. Everybody who attends the class is urged — nay, expected — to become proficient in the arcane subject matter, with entertainment again being offered only as an unprofitable sideline.

In addition to its own local affairs, the Y sponsors conferences and meetings with other colleges. The most popular of these is the Caltech-Scripps conference, held winter term. Its purpose is to allow Techmen and Scrippsies to exchange ideas on matters of such import as "Man at the Crossroads" (meaning what you want it to mean). Discussions are interspersed with square dancing at the conference; presumably agonizing personal decisions about the Destiny of Man are aided by a relaxed atmosphere, inspirational talks by professors, and girls. Despite its high ideals, the conference invariably degenerates into a lot of fun.

Religion and the End

The Y is impressively multi-religious (even militant atheists can belong) and its library provides shelf space to practically every religious innovation from Mary Baker Eddy to Sri Ramakrishna. Its statement of purpose calls it "a fellowship of students motivated by the desire to understand more fully the social problems and moral concerns of mankind and man's place in the universe." Joe Tekmen and most of his contemporaries are interested in these very problems; the Y fills a real need by providing Joe and friends a means for religious exploration.

In fact, the YMCA is extremely successful as a religiously oriented organization on an agnostic campus. It is also successful as a clearing house for organizations and clubs. Its failures, however, stem from its very successes. As a liberal religious organization, it imports liberally religious speakers; as a hierarchal organization, it insures that most of its discussion leaders are of one mind; as an educational organization, it concentrates on quick once-over-lightly doses of culture; as a broad-ranging and powerful organization, it imports most of the speakers, sponsors most of the discussion groups, and disseminates most of the culture on campus. And no organization is good enough to do all this.

— Lance Taylor '62

Beno Gutenberg

A tribute by Robert P. Sharp

An era in the science of geophysics came to an end with the death of Professor Beno Gutenberg of Caltech's Seismological Laboratory on January 25, 1960. Dr. Gutenberg was the dean of modern seismology, and his several hundred published papers and seven books constitute an important segment of the literature in that field published during the past half century.

Beno Gutenberg was born in Darmstadt, Germany, in 1889, took his PhD in geophysics at Goettingen in 1911, and published his first major scientific paper, on the earth's core, in 1912. In 1930, at age 41, when the fruits of years of hard scientific labors were just beginning to bring him recognition and stature in Germany, he chose to cast his lot with a small seismological laboratory in Pasadena. That single act probably did more than anything else to shift the center of seismological research from Germany to the United States.

The act took courage, and courage was one of Dr. Gutenberg's outstanding characteristics. He never lacked the courage to expose his thoughts and concepts to the rigorous inspection and evaluation of the scientific community through publication. More importantly, he always had the courage to admit readily and freely when they were in error. In fact, he seemed to take great delight in seeing someone demolish one of his pet ideas, and on occasion even joined in the mayhem with high good humor and evident enjoyment. This is the mark of a big man.

On the other hand, Beno Gutenberg countless times stood tenaciously and steadfastly in defense of his ideas, and time has proved him right. For years, on the basis of anything but convincing evidence, he defended his concept of a low velocity layer in the mantle of the earth. Now even the Russians sitting in conference in Geneva on the problem of atomic explosion detection ruefully admit he was right. At times, Gutenberg was almost mystically intuitive in his sense of what was right. This is the mark of a great scientist.

Beno was also a realist. He was exceedingly fond of remarking: "In the last 20 years 400 papers have been published on such and such a subject (many of them by Beno Gutenberg himself) and now we know even less about it than we did then."

The man dripped ideas. He couldn't rest until they were in print. He faithfully, efficiently, and effectively discharged his obligations to science. There was no slowing down; his passing leaves no great unpublished backlog; he was always current and up to date. His latest book, *Physics of the Earth's Interior*, was published just last October. The pencil that he laid down, when seized with an attack of influenza that led to complications causing his death, was still warm. He was cut down at the peak of his career; there had been no downturn. What finer statement can be made of a man of 70 years?

As a personality, Dr. Gutenberg sparkled. His enthusiasm bubbled over and he gave it generously to all. The twinkle in his eye and the kindly smile were always there. Even in argument, his points were always made in a gentlemanly manner and a kindly way. Not only was he admired, liked, and respected by all; he was literally adored by those who worked closely with him. Gutenberg is gone but the knowledge he gave us of the earth's core, the mechanism and energy of earthquakes, the structure of the earth's crust, and of countless geophysical phenomena of our globe will remain forever. The sparkle, warmth and kindness of his gentle personality are also firmly entrenched in our memory.

John Robertson Macarthur

A Tribute by Horace Gilbert

To the many Caltech alumni of the period 1920-1945, news of the death of Dr. Macarthur will recall some of the most appreciated personal associations of their college days. He died in Chula Vista, California, on January 31, 1960, in his eighty-sixth year. As dean of freshmen from 1923 to 1937, and again during the war period, Dr. Macarthur met all first year students, and for many of them he continued to be a valued counselor throughout their years at Caltech.

John Macarthur was born in Winnipeg, Canada, and was educated at the University of Manitoba and the University of Chicago. Before coming to Caltech in 1920 he had taught English at the New Mexico Agricultural College and at Kansas State Agricultural College. He was a member of Phi Beta Kappa and of Pi Kappa Delta (honorary forensics fraternity). He served as national president of the latter organization from 1922-26, during which time he established a local chapter at Caltech. He served also as editor of *The Forensic,* the fraternity's national magazine, for several years. He was the author of three books: *The First Part of Sir John Oldcastle, Biblical Literature and Its Background,* and *Ancient Greece in Modern America.*

Most students will remember Dr. Macarthur as the organizer of the Sunday morning breakfasts for freshmen at the home of Caltech's benefactor, Mr. Arthur Fleming, and the suppers at the home of Dr. and Mrs. Millikan. He also escorted groups of students to the Huntington Library, where he instructed them in its art and literary treasures. He was a great admirer of Dr. Arthur A. Noyes, and assisted him in carrying out Caltech's educational objective of developing outstanding students. He was in charge of the Junior Travel Prize program.

In addition to his administrative responsibilities as dean of freshmen, he was professor of languages, and taught the classes qualifying graduate students for their doctoral degrees. He coached Caltech debating teams and promoted forensic competition. He was active in dramatics and a prime supporter of the annual Greek Play. Off-campus, for several years he served as organist at St. James Episcopal Church in South Pasadena. He had traveled abroad extensively.

During World War II, Dr. Macarthur resumed his deanship to meet an emergency caused by Dean Untereiner's leave of absence, but he resigned on V-E Day. After his retirement in 1945, Dr. Macarthur became an ordained minister of the Episcopal Church, and for several years served as vicar of St. Andrews-by-the-Lake, in Elsinore, California.

The Division of Humanities can well be proud of Dr. Macarthur, who exemplified so many of the virtues it professes. Beyond the usual rewards of academic work well done, he gave of himself in such a way that he was able to win the confidence of aspiring, sometimes troubled, students, and to help them rise to the fullness of their capabilities.

There's Plenty of Room at the Bottom

An invitation to enter a new field of physics.

by Richard P. Feynman

I imagine experimental physicists must often look with envy at men like Kamerlingh Onnes, who discovered a field like low temperature, which seems to be bottomless and in which one can go down and down. Such a man is then a leader and has some temporary monopoly in a scientific adventure. Percy Bridgman, in designing a way to obtain higher pressures, opened up another new field and was able to move into it and to lead us all along. The development of ever higher vacuum was a continuing development of the same kind.

I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, "What are the strange particles?") but it is more like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical applications.

What I want to talk about is the problem of manipulating and controlling things on a small scale.

As soon as I mention this, people tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the size of the nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But that's nothing; that's the most primitive, halting step in the direction I intend to discuss. It is a staggeringly small world that is below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction.

Why cannot we write the entire 24 volumes of the Encyclopaedia Brittanica on the head of a pin?

Let's see what would be involved. The head of a pin is a sixteenth of an inch across. If you magnify it by 25,000 diameters, the area of the head of the pin is then equal to the area of all the pages of the Encyclopaedia Brittanica. Therefore, all it is necessary to do is to reduce in size all the writing in the Encyclopaedia by 25,000 times. Is that possible? The resolving power of the eye is about 1/120 of an inch – that is roughly the diameter of one of the little dots on the fine half-tone reproductions in the Encyclopaedia. This, when you demagnify it by 25,000 times, is still 80 angstroms in diameter – 32 atoms across, in an ordinary metal. In other words, one of those dots still would contain in its area 1,000 atoms. So, each dot can easily be adjusted in size as required by the photoengraving, and there is no question that there is enough room on the head of a pin to put all of the Encyclopaedia Brittanica.

Furthermore, it can be read if it is so written. Let's imagine that it is written in raised letters of metal; that is, where the black is in the Encyclopedia, we have raised letters of metal that are actually 1/25,000

"There's Plenty of Room at the Bottom" is a transcript of a talk given by Dr. Feynman on December 29 at the annual meeting of the American Physical Society at Caltech.

of their ordinary size. How would we read it?

If we had something written in such a way, we could read it using techniques in common use today. (They will undoubtedly find a better way when we do actually have it written, but to make my point conservatively I shall just take techniques we know today.) We would press the metal into a plastic material and make a mold of it, then peel the plastic off very carefully, evaporate silica into the plastic to get a very thin film, then shadow it by evaporating gold at an angle against the silica so that all the little letters will appear clearly, dissolve the plastic away from the silica film, and then look through it with an electron microscope!

There is no question that if the thing were reduced by 25,000 times in the form of raised letters on the pin, it would be easy for us to read it today. Furthermore, there is no question that we would find it easy to make copies of the master; we would just need to press the same metal plate again into plastic and we would have another copy.

How do we write small?

The next question is: How do we *write* it? We have no standard technique to do this now. But let me argue that it is not as difficult as it first appears to be. We can reverse the lenses of the electron microscope in order to demagnify as well as magnify. A source of ions, sent through the microscope lenses in reverse, could be focused to a very small spot. We could write with that spot like we write in a TV cathode ray oscilloscope, by going across in lines, and having an adjustment which determines the amount of material which is going to be deposited as we scan in lines.

This method might be very slow because of space charge limitations. There will be more rapid methods. We could first make, perhaps by some photo process, a screen which has holes in it in the form of the letters. Then we would strike an arc behind the holes and draw metallic ions through the holes; then we could again use our system of lenses and make a small image in the form of ions, which would deposit the metal on the pin.

A simpler way might be this (though I am not sure it would work): We take light and, through an optical microscope running backwards, we focus it onto a very small photoelectric screen. Then electrons come away from the screen where the light is shining. These electrons are focused down in size by the electron microscope lenses to impinge directly upon the surface of the metal. Will such a beam etch away the metal if it is run long enough? I don't know. If it doesn't work for a metal surface, it must be possible to find some surface with which to coat the original pin so that, where the electrons bombard, a change is made which we could recognize later.

There is no intensity problem in these devices — not what you are used to in magnification, where you have to take a few electrons and spread them over a bigger and bigger screen; it is just the opposite. The light which we get from a page is concentrated onto a very small area so it is very intense. The few electrons which come from the photoelectric screen are demagnified down to a very tiny area so that, again, they are very intense. I don't know why this hasn't been done yet!

That's the Encyclopaedia Brittanica on the head of a pin, but let's consider all the books in the world. The Library of Congress has approximately 9 million volumes; the British Museum Library has 5 million volumes; there are also 5 million volumes in the National Library in France. Undoubtedly there are duplications, so let us say that there are some 24 million volumes of interest in the world.

What would happen if I print all this down at the scale we have been discussing? How much space would it take? It would take, of course, the area of about a million pinheads because, instead of there being just the 24 volumes of the Encyclopaedia, there are 24 million volumes. The million pinheads can be put in a square of a thousand pins on a side, or an area of about 3 square yards. That is to say, the silica replica with the paper-thin backing of plastic, with which we have made the copies, with all this information, is on an area of approximately the size of 35 pages of the Encyclopaedia. That is about half as many pages as there are in this magazine. All of the information which all of mankind has ever recorded in books can be carried around in a pamphlet in your hand — and not written in code, but as a simple reproduction of the original pictures, engravings, and everything else on a small scale without loss of resolution.

What would our librarian at Caltech say, as she runs all over from one building to another, if I tell

Going down — General Electric's minute new tunnel diode, capable of operating at frequencies above 4 billion cycles, and intended for use in computers, communications equipment, and nuclear controls.

her that, ten years from now, all of the information that she is struggling to keep track of — 120,000 volumes, stacked from the floor to the ceiling, drawers full of cards, storage rooms full of the older books — can be kept on just one library card! When the University of Brazil, for example, finds that their library is burned, we can send them a copy of every book in our library by striking off a copy from the master plate in a few hours and mailing it in an envelope no bigger or heavier than any other ordinary air mail letter.

Now, the name of this talk is "There is *Plenty* of Room at the Bottom" — not just "There is Room at the Bottom." What I have demonstrated is that there *is* room — that you can decrease the size of things in a practical way. I now want to show that there is *plenty* of room. I will not now discuss how we are going to do it, but only what is possible in principle — in other words, what is possible according to the laws of physics. I am not inventing anti-gravity, which is possible someday only if the laws are not what we think. I am telling you what could be done if the laws *are* what we think; we are not doing it simply because we haven't yet gotten around to it.

Information on a small scale

Suppose that, instead of trying to reproduce the pictures and all the information directly in its present form, we write only the information content in a code of dots and dashes, or something like that, to represent the various letters. Each letter represents six or seven "bits" of information; that is, you need only about six or seven dots or dashes for each letter. Now, instead of writing everything, as I did before, on the *surface* of the head of a pin, I am going to use the interior of the material as well.

Let us represent a dot by a small spot of one metal, the next dash by an adjacent spot of another metal, and so on. Suppose, to be conservative, that a bit of information is going to require a little cube of atoms 5 x 5 x 5 — that is 125 atoms. Perhaps we need a hundred and some odd atoms to make sure that the information is not lost through diffusion, or through some other process.

I have estimated how many letters there are in the Encyclopaedia, and I have assumed that each of my 24 million books is as big as an Encyclopaedia volume, and have calculated, then, how many bits of information there are (10^{15}). For each bit I allow 100 atoms. And it turns out that all of the information that man has carefully accumulated in all the books in the world can be written in this form in a cube of material one two-hundredth of an inch wide — which is the barest piece of dust that can be made out by the human eye. So there is *plenty* of room at the bottom! Don't tell me about microfilm!

This fact — that enormous amounts of information can be carried in an exceedingly small space — is, of course, well known to the biologists, and resolves the mystery which existed before we understood all this clearly, of how it could be that, in the tiniest cell, all of the information for the organization of a complex creature such as ourselves can be stored. All this information — whether we have brown eyes, or whether we think at all, or that in the embryo the jawbone should first develop with a little hole in the side so that later a nerve can grow through it — all this information is contained in a very tiny fraction of the cell in the form of long-chain DNA molecules in which approximately 50 atoms are used for one bit of information about the cell.

Better electron microscopes

If I have written in a code, with 5 x 5 x 5 atoms to a bit, the question is: How could I read it today? The electron microscope is not quite good enough; with the greatest care and effort, it can only resolve about 10 angstroms. I would like to try and impress upon you, while I am talking about all of these things on a small scale, the importance of improving the electron microscope by a hundred times. It is not impossible; it is not against the laws of diffraction of the electron. The wave length of the electron in such a microscope is only 1/20 of an angstrom. So it should be possible to see the individual atoms. What good would it be to see individual atoms distinctly?

We have friends in other fields — in biology, for instance. We physicists often look at them and say, "You know the reason you fellows are making so little progress?" (Actually I don't know any field where they are making more rapid progress than they are in biology today.) "You should use more mathematics. like we do." They could answer us — but they're polite, so I'll answer for them: "What *you* should do in order for *us* to make more rapid progress is to make the electron microscope 100 times better."

What are the most central and fundamental problems of biology today? They are questions like: What is the sequence of bases in the DNA? What happens when you have a mutation? How is the base order in the DNA connected to the order of amino acids in the protein? What is the structure of the RNA; is it single-chain or double-chain, and how is it related in its order of bases to the DNA? What is the organization of the microsomes? How are proteins synthesized? Where does the RNA go? How does it sit? Where do the proteins sit? Where do the amino acids go in? In photosynthesis, where is the chlorophyll; how is it arranged; where are the carotenoids involved in this thing? What is the system of the conversion of light into chemical energy?

It is very easy to answer many of these fundamental biological questions; you just *look at the thing!* You will see the order of bases in the chain; you will see the structure of the microsome. Unfortunately, the present microscope sees at a scale which is just a bit too crude. Make the microscope one hundred times more powerful, and many problems of biology would be made very much easier. I exaggerate, of course, but the biologists would surely be very thankful to you – and they would prefer that to the criticism that they should use more mathematics.

The theory of chemical processes today is based on theoretical physics. In this sense, physics supplies the foundation of chemistry. But chemistry also has analysis. If you have a strange substance and you want to know what it is, you go through a long and complicated process of chemical analysis. You can analyze almost anything today, so I am a little late with my idea. But if the physicists wanted to, they could also dig under the chemists in the problem of chemical analysis. It would be very easy to make an analysis of any complicated chemical substance; all one would have to do would be to look at it and see where the atoms are. The only trouble is that the electron microscope is one hundred times too poor. (Later, I would like to ask the question: Can the physicists do something about the third problem of chemistry – namely, synthesis? Is there a *physical* way to synthesize any chemical substance?)

The reason the electron microscope is so poor is that the *f*-value of the lenses is only 1 part to 1,000; you don't have a big enough numerical aperture. And I know that there are theorems which prove that it is impossible, with axially symmetrical stationary field lenses, to produce an *f*-value any bigger than so and so; and therefore the resolving power at the present time is at its theoretical maximum. But in every theorem there are assumptions. Why must the field be axially symmetrical? Why must the field be stationary? Can't we have pulsed electron beams in fields moving up along with the electrons? Must the field be symmetrical? I put this out as a challenge: Is there no way to make the electron microscope more powerful?

The marvelous biological system

The biological example of writing information on a small scale has inspired me to think of something that should be possible. Biology is not simply writing information; it is *doing something* about it. A biological system can be exceedingly small. Many of the cells are very tiny, but they are very active; they manufacture various substances; they walk around; they wiggle; and they do all kinds of marvelous things – all on a very small scale. Also, they store information. Consider the possibility that we too can make a thing very small, which does what we want – that we can manufacture an object that maneuvers at that level!

There may even be an economic point to this business of making things very small. Let me remind you of some of the problems of computing machines. In computers we have to store an enormous amount of information. The kind of writing that I was mentioning before, in which I had everything down as a distribution of metal, is permanent. Much more interesting to a computer is a way of writing, erasing, and writing something else. (This is usually because we don't want to waste the material on which we have just written. Yet if we could write it in a very small space, it wouldn't make any difference; it could just be thrown away after it was read. It doesn't cost very much for the material).

Miniaturizing the computer

I don't know how to do this on a small scale in a practical way, but I do know that computing machines are very large; they fill rooms. Why can't we make them very small, make them of little wires, little elements – and by little, I mean *little*. For instance, the wires should be 10 or 100 atoms in diameter, and the circuits should be a few thousand angstroms across. Everybody who has analyzed the logical theory of computers has come to the conclusion that the possibilities of computers are very interesting – if they could be made to be more complicated by several orders of magnitude. If they had millions of times as many elements, they could make judgments. They would have time to calculate what is the best way to make the calculation that they are about to make. They could select the method of analysis which, from their experience, is better than the one that we would give to them. And, in many other ways, they would have new qualitative features.

If I look at your face I immediately recognize that I have seen it before. (Actually, my friends will say I have chosen an unfortunate example here for the subject of this illustration. At least I recognize that it is a *man* and not an *apple*.) Yet there is no machine which, with that speed, can take a picture of a face and say even that it is a man; and much less that it is the same man that you showed it before – unless it is exactly the same picture. If the face is changed; if I am closer to the face; if I am further from the face; if the light changes – I recognize it anyway. Now, this little computer I carry in my head is easily able to do that. The computers that we build are not able to do that. The number of elements in this bone box of mine are enormously greater than the number of elements in our "wonderful" computers. But our mechanical computers are too big; the elements in this box are microscopic. I want to make some that are *sub*-microscopic.

If we wanted to make a computer that had all these marvelous extra qualitative abilities, we would have to make it, perhaps, the size of the Pentagon. This has several disadvantages. First, it requires too much material; there may not be enough germanium in the world for all the transistors which would have to be put into this enormous thing. There is also the problem of heat generation and power consumption; TVA would be needed to run the computer. But an even more practical difficulty is that the computer would be limited to a certain speed. Because of its large size, there is finite time required to get the information from one place to another. The information cannot go any faster than the speed of light – so, ultimately, when our computers get faster and faster and more and more elaborate, we will have to make them smaller and smaller.

But there is plenty of room to make them smaller. There is nothing that I can see in the physical laws that says the computer elements cannot be made enormously smaller than they are now. In fact, there may be certain advantages.

Miniaturization by evaporation

How can we make such a device? What kind of manufacturing processes would we use? One possibility we might consider, since we have talked about writing by putting atoms down in a certain arrangement, would be to evaporate the material, then evaporate the insulator next to it. Then, for the next layer, evaporate another position of a wire, another insulator, and so on. So, you simply evaporate until you have a block of stuff which has the elements – coils and condensers, transistors and so on – of exceedingly fine dimensions.

But I would like to discuss, just for amusement, that there are other possibilities. Why can't we manufacture these small computers somewhat like we manufacture the big ones? Why can't we drill holes, cut things, solder things, stamp things out, mold different shapes all at an infinitesimal level? What are the limitations as to how small a thing has to be before you can no longer mold it? How many times when you are working on something frustratingly tiny, like your wife's wrist watch, have you said to yourself, "If I could only train an ant to do this!" What I would like to suggest is the possibility of training an ant to train a mite to do this. What are the possibilities of small but movable machines? They may or may not be useful, but they surely would be fun to make.

Consider any machine – for example, an automobile – and ask about the problems of making an infinitesimal machine like it. Suppose, in the particular design of the automobile, we need a certain precision of the parts; we need an accuracy, let's suppose, of 4/10,000 of an inch. If things are more inaccurate than that in the shape of the cylinder and so on, it isn't going to work very well. If I make the thing too small, I have to worry about the size of the atoms; I can't make a circle out of "balls" so to speak, if the circle is too small. So, if I make the error, corresponding to 4/10,000 of an inch, correspond to an error of 10 atoms, it turns out that I can reduce the dimensions of an automobile 4,000 times, approximately – so that it is 1 mm. across. Obviously, if you redesign the car so that it would work with a much larger tolerance, which is not at all impossible, then you could make a much smaller device.

It is interesting to consider what the problems are in such small machines. Firstly, with parts stressed to the same degree, the forces go as the area you are reducing, so that things like weight and inertia are of relatively no importance. The strength of material, in other words, is very much greater in proportion. The stresses and expansion of the flywheel from centrifugal force, for example, would be the same proportion only if the rotational speed is increased in the same proportion as we decrease the size. On the other hand, the metals that we use have a grain structure, and this would be very annoying at small scale because the material is not homogeneous. Plastics and glass and things of this amorphous nature are very much more homogeneous, and so we would have to make our machines out of such materials.

There are problems associated with the electrical part of the system – with the copper wires and the magnetic parts. The magnetic properties on a very small scale are not the same as on a large scale; there is the "domain" problem involved. A big magnet made of millions of domains can only be made on a small scale with one domain. The electrical equipment won't simply be scaled down; it has to be redesigned. But I can see no reason why it can't be redesigned to work again.

Problems of lubrication

Lubrication involves some interesting points. The effective viscosity of oil would be higher and higher in proportion as we went down (and if we increase the speed as much as we can). If we don't increase the speed so much, and change from oil to kerosene or some other fluid, the problem is not so bad. But actually we may not have to lubricate at all! We have a lot of extra force. Let the bearings run dry; they won't run hot because the heat escapes away from such a small device very, very rapidly.

This rapid heat loss would prevent the gasoline from exploding, so an internal combustion engine is impossible. Other chemical reactions, liberating energy when cold, can be used. Probably an external supply of electrical power would be most convenient for such small machines.

What would be the utility of such machines? Who knows? Of course, a small automobile would only be useful for the mites to drive around in, and I suppose our Christian interests don't go that far. However, we did note the possibility of the manufacture of small elements for computers in completely automatic factories, containing lathes and other machine tools at the very small level. The small lathe would not have to be exactly like our big lathe. I leave to your imagination the improvement of the design to take full advantage

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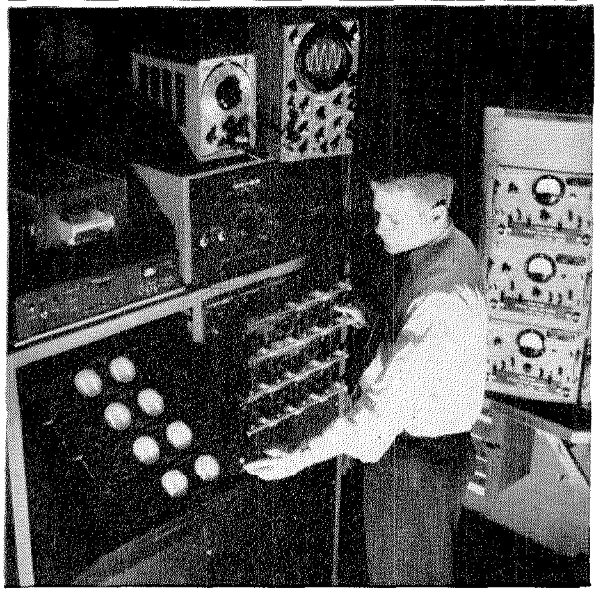
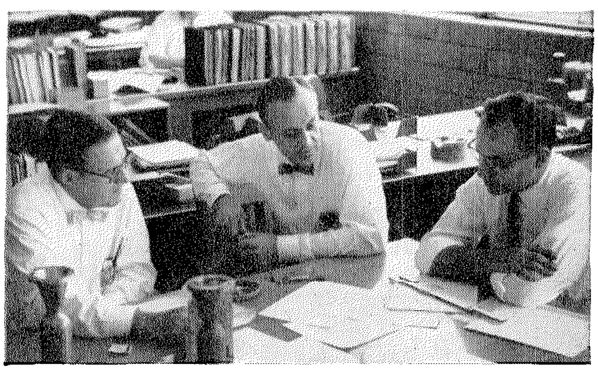
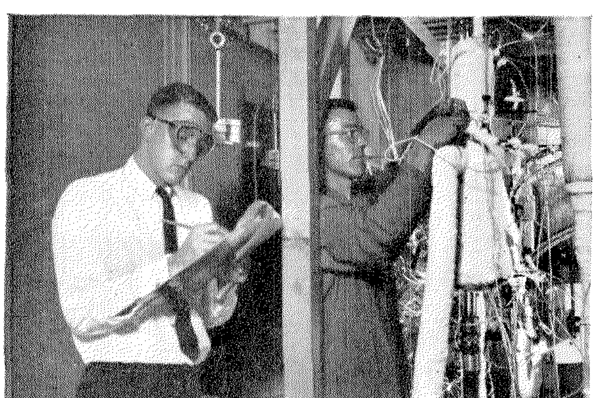
engineers



Automatic systems developed by instrumentation engineers allow rapid simultaneous recording of data from many information points.



Frequent informal discussions among analytical engineers assure continuous exchange of ideas on related research projects.



Under the close supervision of an engineer, final adjustments are made on a rig for testing an advanced liquid metal system.

and what they d

The field has never been broader
The challenge has never been greater

Engineers at Pratt & Whitney Aircraft today are concerned with the development of all forms of flight propulsion systems—air breathing, rocket, nuclear and other advanced types for propulsion in space. Many of these systems are so entirely new in concept that their design and development, and allied research programs, require technical personnel not previously associated with the development of aircraft engines. Where the company was once primarily interested in graduates with degrees in mechanical and aeronautical engineering, it now also requires men with degrees in electrical, chemical, and nuclear engineering, and in physics, chemistry, and metallurgy.

Included in a wide range of engineering activities open to technically trained graduates at all levels are these four basic fields:

ANALYTICAL ENGINEERING Men engaged in this activity are concerned with fundamental investigations in the fields of science or engineering related to the conception of new products. They carry out detailed analyses of advanced flight and space systems and interpret results in terms of practical design applications. They provide basic information which is essential in determining the types of systems that have development potential.

DESIGN ENGINEERING The prime requisite here is an active interest in the application of aerodynamics, thermodynamics, stress analysis, and principles of machine design to the creation of new flight propulsion systems. Men engaged in this activity at P&WA establish the specific performance and structural requirements of the new product and design it as a complete working mechanism.

EXPERIMENTAL ENGINEERING Here men supervise and coordinate fabrication, assembly and laboratory testing of experimental apparatus, system components, and development engines. They devise test rigs and laboratory setups, specify instrumentation and direct execution of the actual test programs. Responsibility in this phase of the development program also includes analysis of test data, reporting of results and recommendations for future effort.

MATERIALS ENGINEERING Men active in this field at P&WA investigate metals, alloys and other materials under various environmental conditions to determine their usefulness as applied to advanced flight propulsion systems. They devise material testing methods and design special test equipment. They are also responsible for the determination of new fabrication techniques and causes of failures or manufacturing difficulties.

of the properties of things on a small scale, and in such a way that the fully automatic aspect would be easiest to manage.

A friend of mine (Albert R. Hibbs) suggests a very interesting possibility for relatively small machines. He says that, although it is a very wild idea, it would be interesting in surgery if you could swallow the surgeon. You put the mechanical surgeon inside the blood vessel and it goes into the heart and "looks" around. (Of course the information has to be fed out.) It finds out which valve is the faulty one and takes a little knife and slices it out. Other small machines might be permanently incorporated in the body to assist some inadequately-functioning organ.

Now comes the interesting question: How do we make such a tiny mechanism? I leave that to you. However, let me suggest one weird possibility. You know, in the atomic energy plants they have materials and machines that they can't handle directly because they have become radioactive. To unscrew nuts and put on bolts and so on, they have a set of master and slave hands, so that by operating a set of levers here, you control the "hands" there, and can turn them this way and that so you can handle things quite nicely.

Most of these devices are actually made rather simply, in that there is a particular cable, like a marionette string, that goes directly from the controls to the "hands." But, of course, things also have been made using servo motors, so that the connection between the one thing and the other is electrical rather than mechanical. When you turn the levers, they turn a servo motor, and it changes the electrical currents in the wires, which repositions a motor at the other end.

Now, I want to build much the same device — a master-slave system which operates electrically. But I want the slaves to be made especially carefully by modern large-scale machinists so that they are one-fourth the scale of the "hands" that you ordinarily maneuver. So you have a scheme by which you can do things at one-quarter scale anyway — the little servo motors with little hands play with little nuts and bolts; they drill little holes; they are four times smaller. Aha! So I manufacture a quarter-size lathe; I manufacture quarter-size tools; and I make, at the one-quarter scale, still another set of hands again relatively one-quarter size! This is one-sixteenth size, from my point of view. And after I finish doing this I wire directly from my large-scale system, through transformers perhaps, to the one-sixteenth-size servo motors. Thus I can now manipulate the one-sixteenth size hands.

Well, you get the principle from there on. It is rather a difficult program, but it is a possibility. You might say that one can go much farther in one step than from one to four. Of course, this has all to be designed very carefully and it is not necessary simply to make it like hands. If you thought of it very carefully, you could probably arrive at a much better system for doing such things.

If you work through a pantograph, even today, you can get much more than a factor of four in even one step. But you can't work directly through a pantograph which makes a smaller pantograph which then

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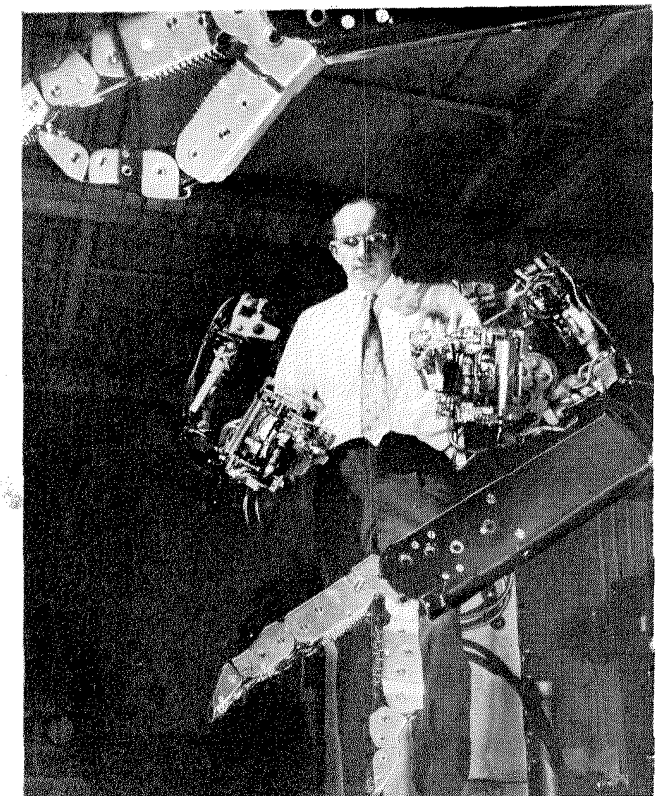
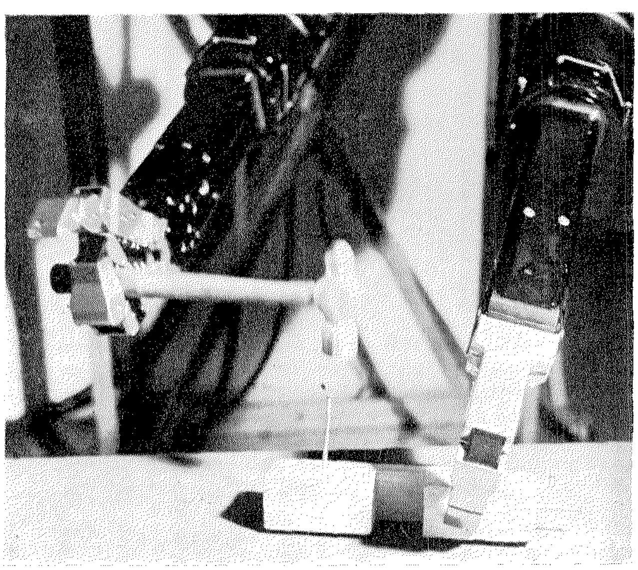
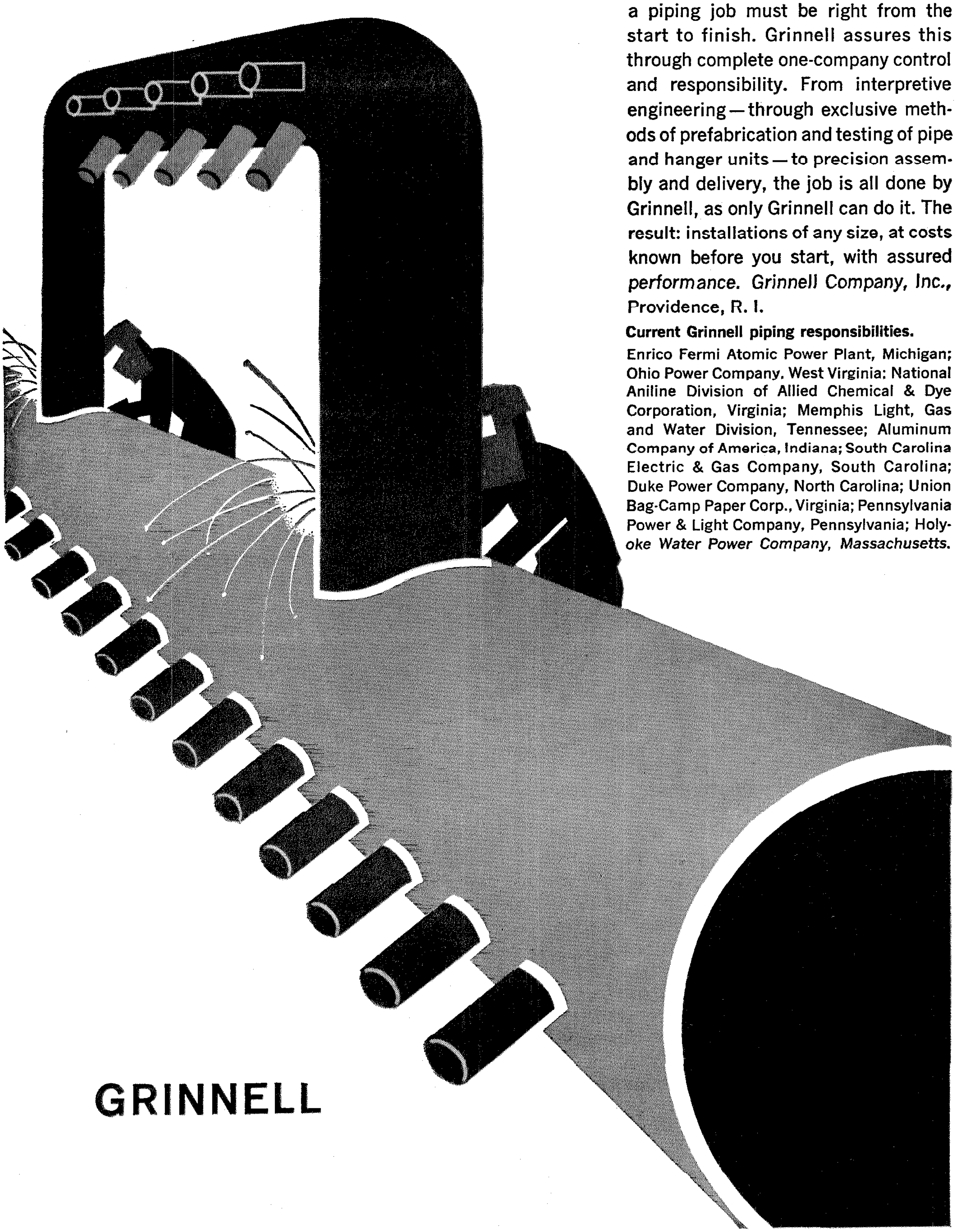


A manipulator, in the form of clutching hands, performs tasks in radioactive areas where no human can enter.



The precise position control of this hydro-mechanical slave enables jointed hands to perform a wide range of mechanical tasks.



makes a smaller pantograph — because of the looseness of the holes and the irregularities of construction. The end of the pantograph wiggles with a relatively greater irregularity than the irregularity with which you move your hands. In going down this scale, I would find the end of the pantograph on the end of the pantograph on the end of the pantograph shaking so badly that it wasn't doing anything sensible at all.

At each stage, it is necessary to improve the precision of the apparatus. If, for instance, having made a small lathe with a pantograph, we find its lead screw irregular — more irregular than the large-scale one — we could lap the lead screw against breakable nuts that you can reverse in the usual way back and forth until this lead screw is, at its scale, as accurate as our original lead screws, at our scale.

We can make flats by rubbing unflat surfaces in triplicates together — in three pairs — and the flats then become flatter than the thing you started with. Thus, it is not impossible to improve precision on a small scale by the correct operations. So, when we build this stuff, it is necessary at each step to improve the accuracy of the equipment by working for awhile down there, making accurate lead screws, Johansen blocks, and all the other materials which we use in accurate machine work at the higher level. We have to stop at each level and manufacture all the stuff to go to the next level — a very long and very difficult program. Perhaps you can figure a better way than that to get down to small scale more rapidly.

Yet, after all this, you have just got one little baby lathe four thousand times smaller than usual. But we were thinking of making an enormous computer, which we were going to build by drilling holes on this lathe to make little washers for the computer. How many washers can you manufacture on this one lathe?

A hundred tiny hands

When I make my first set of slave "hands" at one-fourth scale, I am going to make ten sets. I make ten sets of "hands," and I wire them to my original levers so they each do exactly the same thing at the same time in parallel. Now, when I am making my new devices one-quarter again as small, I let each one manufacture ten copies, so that I would have a hundred "hands" at the 1/16th size.

Where am I going to put the million lathes that I am going to have? Why, there is nothing to it; the volume is much less than that of even one full-scale lathe. For instance, if I made a billion little lathes, each 1/4000 of the scale of a regular lathe, there are plenty of materials and space available because in the billion little ones there is less than 2 percent of the materials in one big lathe.

It doesn't cost anything for materials, you see. So I want to build a billion tiny factories, models of each other, which are manufacturing simultaneously, drilling holes, stamping parts, and so on.

As we go down in size, there are a number of interesting problems that arise. All things do not simply scale down in proportion. There is the problem that materials stick together by the molecular (Van der Waals) attractions. It would be like this: After you have made a part and you unscrew the nut from a bolt, it isn't going to fall down because the gravity isn't appreciable; it would even be hard to get it off the bolt. It would be like those old movies of a man with his hands full of molasses, trying to get rid of a glass of water. There will be several problems of this nature that we will have to be ready to design for.

Rearranging the atoms

But I am not afraid to consider the final question as to whether, ultimately — in the great future — we can arrange the atoms the way we want; the very *atoms*, all the way down! What would happen if we could arrange the atoms one by one the way we want them (within reason, of course; you can't put them so that they are chemically unstable, for example).

Up to now, we have been content to dig in the ground to find minerals. We heat them and we do things on a large scale with them, and we hope to get a pure substance with just so much impurity, and so on. But we must always accept some atomic arrangement that nature gives us. We haven't got anything, say, with a "checkerboard" arrangement, with the impurity atoms exactly arranged 1,000 angstroms apart, or in some other particular pattern.

What could we do with layered structures with just the right layers? What would the properties of materials be if we could really arrange the atoms the way we want them? They would be very interesting to investigate theoretically. I can't see exactly what would happen, but I can hardly doubt that when we have some *control* of the arrangement of things on a small scale we will get an enormously greater range of possible properties that substances can have, and of different things that we can do.

Consider, for example, a piece of material in which we make little coils and condensers (or their solid state analogs) 1,000 or 10,000 angstroms in a circuit, one right next to the other, over a large area, with little antennas sticking out at the other end — a whole series of circuits.

Is it possible, for example, to emit light from a whole set of antennas, like we emit radio waves from an organized set of antennas to beam the radio pro-

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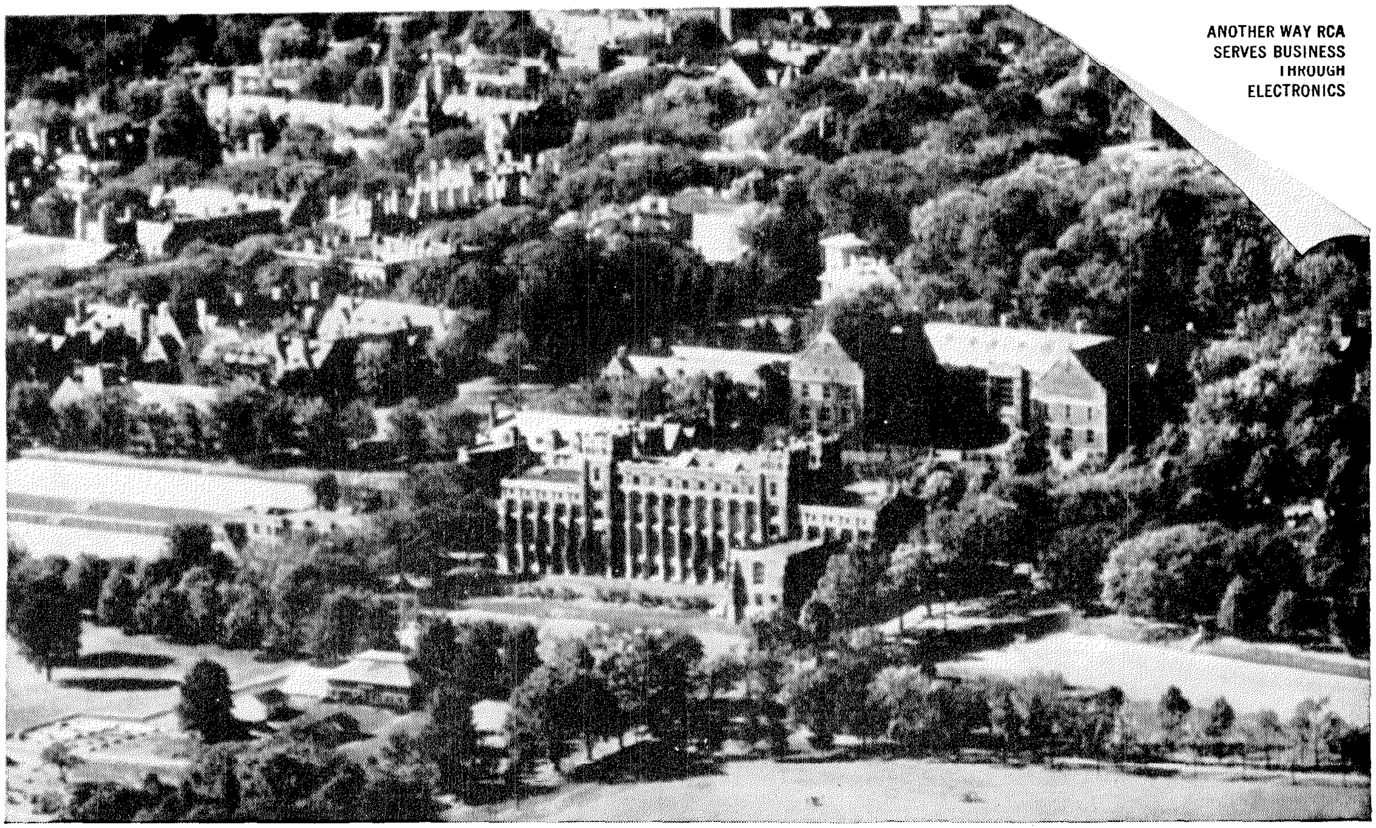


Princeton, N. J: Today the area around this historic educational center is one of the country's foremost communities of scientific research.

RCA Electronics helps build a new capital of science at Princeton, N. J.

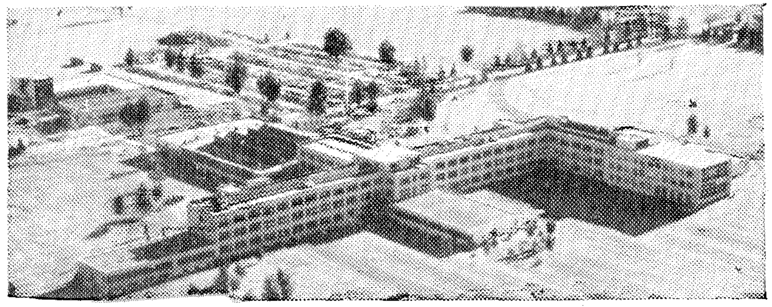
Explorers once looked for new opportunities beyond the mountains and the oceans. Today, our frontiers are somewhere out in space or deep inside the atom. The modern explorer is the research scientist. He seeks new ideas, new knowledge.

Research has been an important activity at RCA ever since it was founded in 1919. And eighteen years ago many scattered operations were united in the RCA David Sarnoff Research Center, which set the pattern for a new capital of industrial research at Princeton, N. J. Here, RCA provided gifted men with fine facilities—and created a climate in which research thrives. Since then, many other institutions dedicated to research in a variety of fields have been erected in the area.

From RCA's vision has grown a reservoir of scientists and research men whose achievements put electronics into service on an ever-broadening front, and with such success that RCA means electronics—whether related to international communications, to the clearest performance of television in color or black-and-white, radio and stereophonic music or to national defense and the electronic conquests in space.

RADIO CORPORATION OF AMERICA

The RCA David Sarnoff Research Center, dedicated in 1942, was one of the first industrial laboratories established in the Princeton area



grams to Europe? The same thing would be to *beam* the light out in a definite direction with very high intensity. (Perhaps such a beam is not very useful technically or economically.)

I have thought about some of the problems of building electric circuits on a small scale, and the problem of resistance is serious. If you build a corresponding circuit on a small scale, its natural frequency goes up, since the wave length goes down as the scale; but the skin depth only decreases with the square root of the scale ratio, and so resistive problems are of increasing difficulty. Possibly we can beat resistance through the use of superconductivity if the frequency is not too high, or by other tricks.

Atoms in a small world

When we get to the very, very small world — say circuits of seven atoms — we have a lot of new things that would happen that represent completely new opportunities for design. Atoms on a small scale behave like *nothing* on a large scale, for they satisfy the laws of quantum mechanics. So, as we go down and fiddle around with the atoms down there, we are working with different laws, and we can expect to do different things. We can manufacture in different ways. We can use, not just circuits, but some system involving the quantized energy levels, or the interactions of quantized spins, etc.

Another thing we will notice is that, if we go down far enough, all of our devices can be mass produced so that they are absolutely perfect copies of one another. We cannot build two large machines so that the dimensions are exactly the same. But if your machine is only 100 atoms high, you only have to get it correct to one-half of one percent to make sure the other machine is exactly the same size — namely, 100 atoms high!

At the atomic level, we have new kinds of forces and new kinds of possibilities, new kinds of effects. The problems of manufacture and reproduction of materials will be quite different. I am, as I said, inspired by the biological phenomena in which chemical forces are used in a repetitious fashion to produce all kinds of weird effects (one of which is the author).

The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. It is not an attempt to violate any laws; it is something, in principle, that can be done; but, in practice, it has not been done because we are too big.

Ultimately, we can do chemical synthesis. A chemist comes to us and says, "Look, I want a molecule that has the atoms arranged thus and so; make me that molecule." The chemist does a mysterious thing when he wants to make a molecule. He sees that it has got that ring, so he mixes this and that, and he shakes it, and he fiddles around. And, at the end of a difficult process, he usually does succeed in synthesizing what he wants. By the time I get my devices working, so that we can do it by physics, he will have figured out how to synthesize absolutely anything, so that this will really be useless.

But it is interesting that it would be, in principle, possible (I think) for a physicist to synthesize any chemical substance that the chemist writes down. Give the orders and the physicist synthesizes it. How? Put the atoms down where the chemist says, and so you make the substance. The problems of chemistry and biology can be greatly helped if our ability to see what we are doing, and to do things on an atomic level, is ultimately developed — a development which I think cannot be avoided.

Now, you might say, "Who should do this and why should they do it?" Well, I pointed out a few of the economic applications, but I know that the reason that you would do it might be just for fun. But have some fun! Let's have a competition between laboratories. Let one laboratory make a tiny motor which it sends to another lab which sends it back with a thing that fits inside the shaft of the first motor.

High school competition

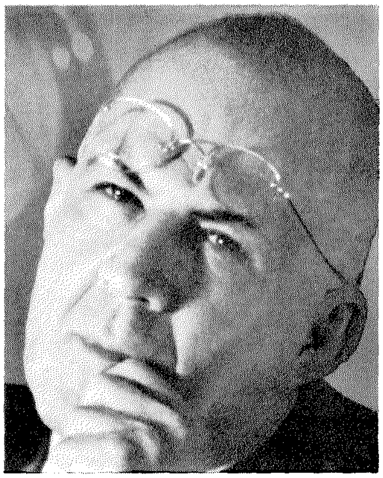
Just for the fun of it, and in order to get kids interested in this field, I would propose that someone who has some contact with the high schools think of making some kind of high school competition. After all, we haven't even started in this field, and even the kids can write smaller than has ever been written before. They could have competition in high schools. The Los Angeles high school could send a pin to the Venice high school on which it says, "How's this?" They get the pin back, and in the dot of the 'i' it says, "Not so hot."

Perhaps this doesn't excite you to do it, and only economics will do so. Then I want to do something; but I can't do it at the present moment, because I haven't prepared the ground. It is my intention to offer a prize of $1,000 to the first guy who can take the information on the page of a book and put it on an area 1/25,000 smaller in linear scale in such manner that it can be read by an electron microscope.

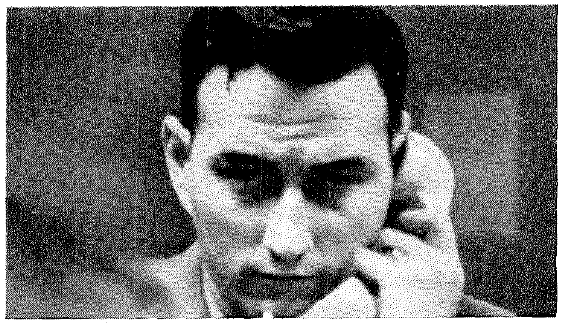
And I want to offer another prize — if I can figure out how to phrase it so that I don't get into a mess of arguments about definitions — of another $1,000 to the first guy who makes an operating electric motor — a rotating electric motor which can be controlled from the outside and, not counting the lead-in wires, is only 1/64 inch cube.

I do not expect that such prizes will have to wait very long for claimants.

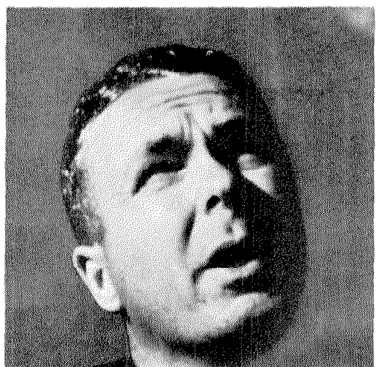
THESE MEN HAVE ONE THING IN COMMON ...BESIDES SUCCESS



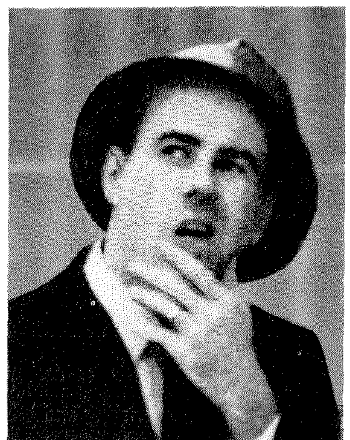
KENT R. VAN HORN, Director of Research, Ph.D., Yale University



HARRY SUMNER, Sales Engineer, B.S. in Business Administration, University of South Carolina



RICHARD C. WILSON, Assistant Manager of Distribution, B.S. in Aeronautical Engineering, University of Kansas



LAWRENCE M. DUNN, Manager of Automotive Engineering Sales, B.S. in Mechanical Engineering, Iowa State University

THOMAS R. GAUTHIER, Cleveland Works, Chief Metallurgist, B.S. in Chemical Engineering, Iowa State University

GUSTAV O. HOGLUND, Division Chief of Alcoa Process Development Laboratories, B.S. in Aeronautical Engineering, University of Michigan

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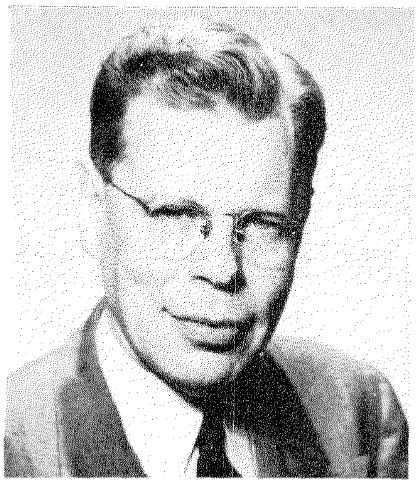
Alumni News

James W. McRae



James W. McRae, vice president of the American Telephone and Telegraph Company, collapsed and died suddenly in New York on February 2. He was enroute to a scientific conference at the Savoy Hilton Hotel, where he was to give the opening address, when he was stricken. He was 49.

Dr. McRae was born in Canada and received his BS in electrical engineering from the University of British Columbia in Vancouver in 1933. He then came to Caltech, where he received his MS in 1934 and his PhD in 1937.

He left Caltech to work in various research fields for the Bell Telephone Laboratories until 1942, when he was commissioned a major in the Signal Corps. During World War II he served as chief of the engineering staff at the Signal Corps' Engineering Laboratories in New Jersey. He rose to the rank of colonel and received the Legion of Merit for his work in developing radar counter-measure devices.

He was serving as vice president in charge of systems development at the Bell Labs in 1953, when he was elected president of the Sandia Corporation and vice president of the Western Electric Company in Albuquerque, N.M. After five years in Albuquerque, he moved back to Madison, N.J., when he became vice president of AT&T. Dr. McRae leaves his wife and four children; two daughters attending Stanford University – and two sons, 15 and 13, at home.

New Assistant Director

Robert C. Poolman, who got his BS in mechanical engineering at Caltech in 1945, has been appointed assistant director of Caltech's Physical Plant Department, in charge of planning and engineering. He comes to Caltech from the United States Government's Housing and Home Finance Agency in San Francisco, where he has been regional engineer for the past two years.

After receiving his degree at Caltech, Mr. Poolman went to the University of Nevada in 1946, eventually becoming assistant professor of civil engineering. In 1956 he organized and developed the Physical Plant Department at the university and served as university engineer until 1958.

Alumni Dinner Dance

The beautiful Crystal Room of the Huntington-Sheraton Hotel in Pasadena will be the setting for the gala 24th Annual Alumni Dinner Dance on March 5th.

Cocktails will be served from the adjoining Patio Room bar starting at 7 p.m. An evening of gaiety promises to follow, with a complete dinner at 8 p.m. (broiled ham steak or breast of capon). Dancing will begin during dinner, with music provided by La Verne Boyer and his Orchestra.

Make it a date now and join your friends for this evening to remember. Invitations have been mailed. Send in your reservations or call the Alumni Office at SYcamore 5-6841 or MUrray 1-7171, Ext. 258. Your tickets will be held at the door.

—Rolf Hastrup '53, Chairman

Save the date of May 7 for the
Annual Alumni Seminar

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COMMERCIAL OPERATIONS:

Graduates planning careers in chemical, electrical or mechanical engineering, will be interested in evaluating the opportunities offered by Food Machinery and Chemical Corporation, with headquarters in San Jose, California—a nation-wide organization that puts ideas to work through creative research and practical engineering.

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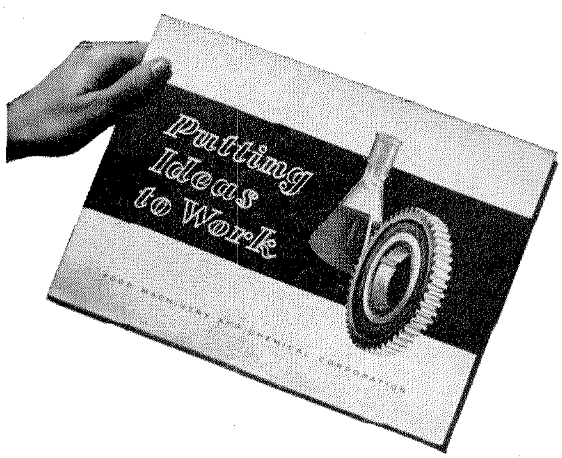
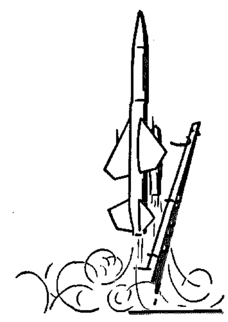


DEFENSE OPERATIONS:

FMC's Ordnance Division, located at San Jose, California, produces mobile support equipment for military programs including amphibious tracked vehicles and missile ground support equipment. This fully integrated organization and its well equipped facilities provide coordinated control of each phase of every project from design concept through development and production.



The division possesses complete prototype and quantity production manufacturing facilities along with a wide variety of test equipment and processes, as well as complete testing grounds for tracked vehicles and missile handling equipment. Young graduates employed by FMC have the opportunity of working with men of outstanding engineering talent and leadership in mechanical, structural, electrical, hydraulic, and metallurgical specialties.

This challenging field offers tremendous possibilities for the young engineer. Because of rapid advancements in this sphere of activity, FMC is constantly looking for men with the special capabilities for creative engineering and development.

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FOOD MACHINERY AND CHEMICAL CORPORATION

Personals

1922

Francis L. Hopper, military development engineer at the Bell Telephone Laboratories in Winston-Salem, N.C., has been made a Fellow in the Institute of Radio Engineers for "contributions in underwater sound research and sound recording."

1927

E. Howard Fisher has been elected vice president in charge of gas operations for the Pacific Gas and Electric Company in San Francisco. He has been general superintendent of pipe line operations since 1954 and was formerly an executive of the Coast Counties Gas and Electric Company, which was merged with PG&E in 1954. An ice skating enthusiast, Howard has served as a director and treasurer of the St. Moritz Ice Skating Club in Berkeley. He is a member of the Engineers Club of San Francisco, and was chairman of the board of trustees of the Orinda Community Church.

1935

Louis T. Rader, MS, PhD '38, is now vice president of the International Telephone and Telegraph Corporation and will have charge of all non-military operations for IT&T's United States companies. Louis comes to IT&T from General Electric, where he had worked for 20 years, most recently as general manager of the specialty control department in Waynesboro, Va.

1940

Robert S. Ray, MS '41, resigned last month as vice president of the Collier Carbon and Chemical Corporation (a subsidiary of Union Oil Company) to become a private consultant. The Rays live in Fullerton and have four children —Marilyn 13, Linda 12, John 8, and Dick 7.

1944

Charles B. Miller, who was assistant to the general manager of Southern Pacific Pipe Lines in Los Angeles, has now been made superintendent of the company's northern district at Roseville, Calif.

George M. Wood, BS, MS, has been appointed branch manager of the Glendale office of the International Business Machines Corporation. He was formerly

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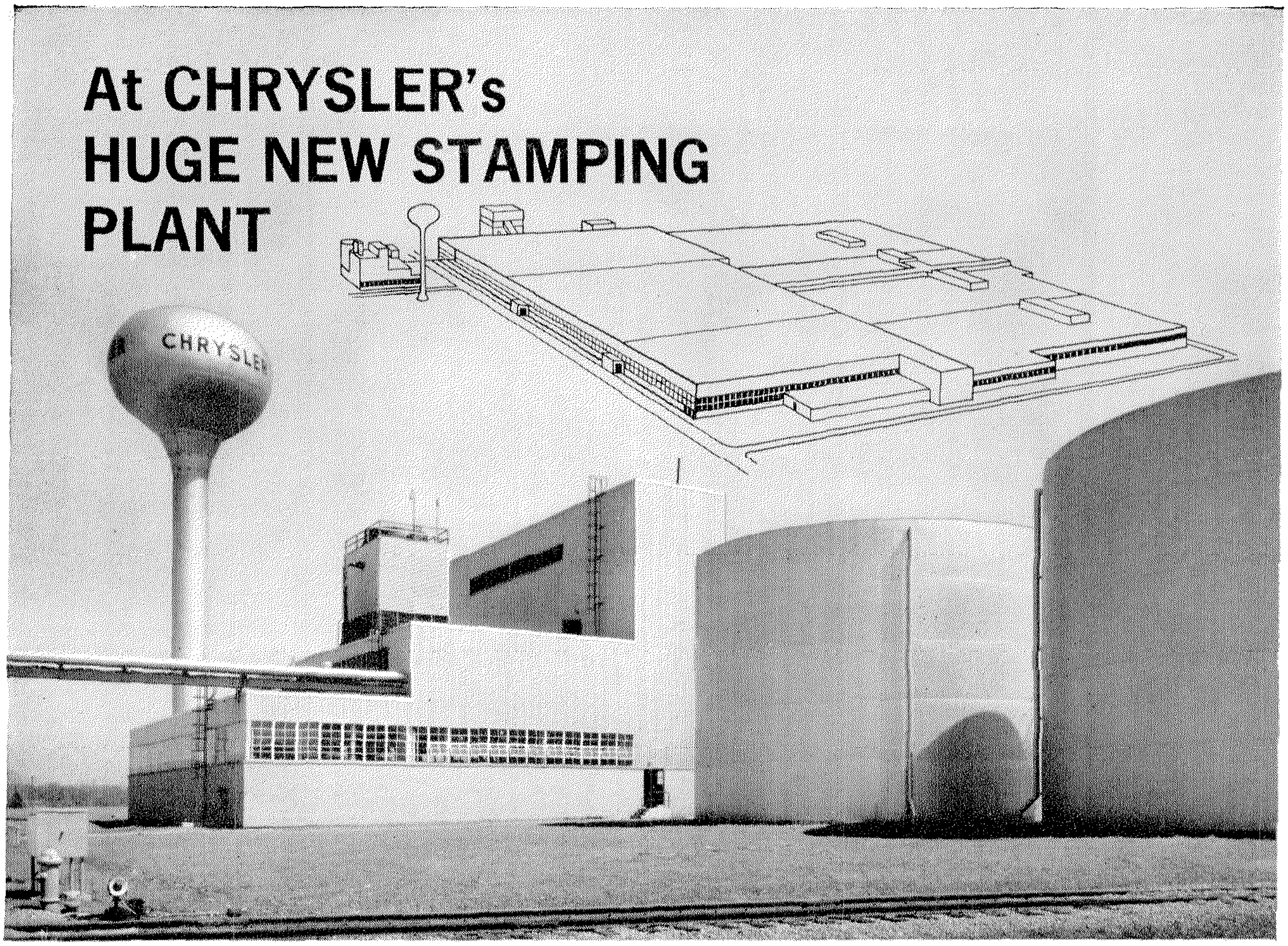
At CHRYSLER's HUGE NEW STAMPING PLANT



Architect & Engineer: F. A. FAIRBROTHER & GEO. H. MIEHLS • *Consultants:* ALBERT KAHN ASSOCIATED ARCHITECTS & ENGINEERS
Mechanical Contractor: THE STANLEY CARTER CO.

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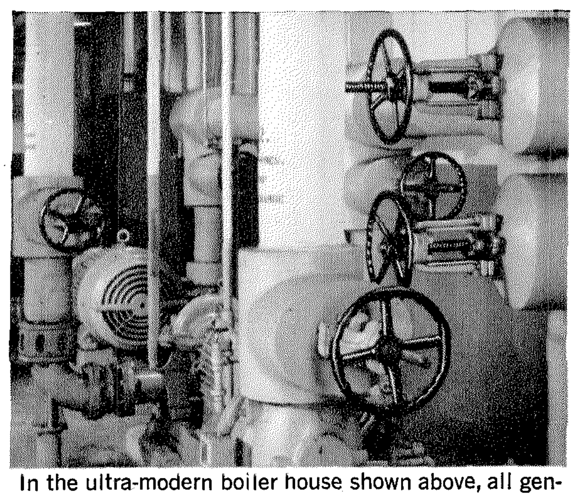
Cited as one of the nation's "Top Ten Plants of the Year", Chrysler Corporation's stamping plant at Twinsburg, Ohio, is a 34-acre model of building and manufacturing efficiency.

Go into the power plant and you will find Jenkins Valves everywhere, controlling "production's lifelines" that supply 150,000 pounds of steam per hour . . . 30 million cubic feet of air per day . . . 7500 gallons of cooling water per minute. Jenkins Valves got the job because "every effort was made to install the finest mechanical and electrical equipment . . . and to insure minimum costs by eliminating excessive upkeep and equipment with a short life span".

It is a highly significant fact that all building experts and operating engineers agree *"there's nothing better than Jenkins Valves"*. Many will always insist on JENKINS for critical services, and will prefer them for general use. After all, Jenkins Valves cost no more!

When you are buying or specifying valves, remember that the best valves are the best assurance of economical service. Jenkins Bros., 100 Park Ave., New York 17.



In the ultra-modern boiler house shown above, all general service valves controlling pipelines are JENKINS

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assistant manager in Glendale, and has been acting branch manager for the past four months.

1946

Howard W. Morgan, Jr., has joined the law firm of George Raymond Drew and Richard H. Ward in Cincinnati. He was formerly a sales engineer with the Lodge and Shipley Machine Tool Company. He received his law degree in 1956 from the Salmon P. Chase College of Law in Cincinnati.

Ali B. Cambel, MS, chairman of the department of mechanical engineering, and director of the gas dynamics laboratories at Northwestern University in Evanston, Ill., received the 1959 G. Edward Pendray Award from the American Rocket Society at their 14th annual meeting last November in Washington, D. C. The award, named after one of the founders of the Society, is given for "outstanding contributions to the scientific rocket and jet propulsion literature."

Fern W. Mitchell, MS, PhD '48, director of the analytical and physical research department of the W. R. Grace & Company research division in Clarksville, Md., has been appointed to the advisory board of *Analytical Chemistry,* a monthly publication of the American Chemical Society. He will serve for three years on the 15-member advisory board.

1947

Richard A. Boettcher, MS, project staff administrator of the engineering division of J. H. Pomeroy & Co., Inc., in Los Angeles for the past two years, has been transferred to the San Francisco office of the company. Dick will assist executive vice president William Pomeroy in the "business development, relations and policy areas of engineering and construction in the company."

Arnold H. Nevis, who has been in a hospital residency in neurology at the UCLA Medical Center since 1957, is planning to move to Gainesville, Florida, with his wife and two sons—Allan and Joel. He has accepted a position in neurology at the medical center there, where he will be doing research, teaching and clinical neurology.

1948

Tom Tracy writes from Palo Alto that "after 10 years with the Minneapolis-Honeywell Regulator Company in Los Angeles, I have accepted a job as northwest district manager of the Ampex Corporation, with headquarters in (sigh) Palo Alto at the Town and Country Village Shopping Center."

S. Dean Wanlass, PhD '53, has been appointed to a newly-created position as manager of product planning at Aeronutronic, a division of the Ford Motor Company, at Newport Beach.

1949

Paul D. Saltman, PhD '53, associate professor of biochemistry at the USC School of Medicine, has received a $75,000 five-year senior postdoctoral fellowship from the U.S. Public Health Service. He will go to the University of Copenhagen, Denmark, next summer for a year of research with Dr. Hans Ussing, famous for his studies of the transport of molecules across membranes in the body. After this sabbatical leave, Paul will return to SC, where his research and teaching will be supported for another four years by the fellowship. He has been a member of the SC faculty since 1953.

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1953

Robert L. Smith received his master's degree from Stanford in 1955 and is now working for his PhD there. He's married (to a girl he met at the Caltech dancing class), and has a 2-year-old daughter, Cecilia. Bob's current hobby is rebuilding an old player piano.

1955

Benjamin E. Cummings, MS '56, writes: "I am now working at Aerojet-General in Azusa, in the systems division. I took the position after I left the Air Force in June. In the AF I was in the Flight Research Branch and worked on jobs that ranged from sonic booms to aircraft accidents, and from transport aircraft to the X-15.

"At Aerojet my duties concern dynamics, including controls, structural dynamics and related problems.

"It may surprise some of my old friends to know that I'm married and have two daughters, Laura and Leslie. Leslie was born last September."

1956

Konrad W. Hubele, MS, died on December 28, 1959. His body was found in his car in a remote section of Angeles Crest near Horse Flats. He had been on leave from Caltech because of illness, but was scheduled to return to graduate work in September, 1960. Konrad received his BS in chemistry at UCLA in 1954 and also had a degree in medicine from the University of Mainz in Germany in 1949.

Curt D. Schulze writes that "I'm still in El Centro in the Air Force and in charge of the instrumentation section of the Joint Parachute Test Facility. We expect to leave the AF next March and move to San Jose where I plan to work for IBM in research and development. On December 1 we had an addition to the family—Curt Richard."

George L. Fletcher, who is doing graduate work in mechanical engineering at Caltech, was married to Janet Gregory on December 27 in Redlands.

1957

Capt. Gerald Medsger, MS, spent two years after leaving Caltech at the Missouri School of Mines in Rolla, Mo., as an assistant professor in military science and English. He shared a house with *Robert Ayers*, MS, who was also an assistant professor at Rolla. In the summer of '59, Bob went to Fort Belvoir, Va., while Jerry was transferred to Germany. He is now a construction engineer with the U.S. Army's Engineer Construction Group in Kaiserslautern.

1958

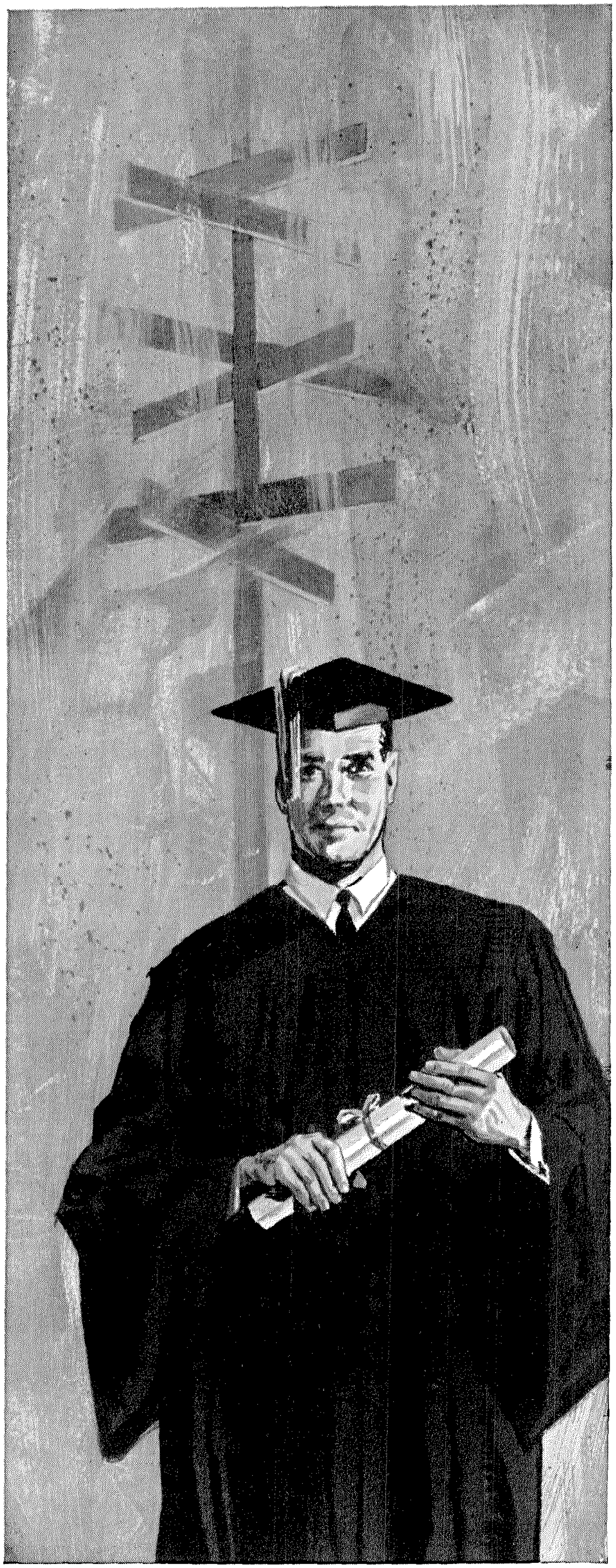
David S. Dennison, PhD, is now an instructor in zoology at Dartmouth College in a part-time research capacity. The Dennisons have a son, Edward Frank, born on April 2.

Lt. John M. McCoy, AE, was lost in an aircraft accident on June 25, 1959 while flying off the *U.S.S. Saratoga* out of Jacksonville, Florida. He had been in the Navy for 14 years. He received his BS in 1949 from the U.S. Naval Academy and a BS in AE in 1957 from the USN Postgraduate School. John received the *Distinguished Flying Cross, the Air* Medal and the Navy Commendation Medal.

Guy de Rimonteil de Lombares, MS, geophysicist with Compagnie Francaise Petroles in Paris, was married to Miss Anne de Galard Cerraube on December 19.

1959

Sol De Picciotto, graduate student at Caltech in electrical engineering, was married on November 30 to Phyllis Landy.



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CALTECH CALENDAR

ALUMNI EVENTS

March 5	Annual Dinner Dance
May 7	*Annual Seminar*
June 8	Annual Meeting
June 25	Annual Picnic

ATHLETIC SCHEDULE

Swimming

February 19
Santa Monica C.C.
at Caltech

February 20
UCLA at UCLA

February 26
UC, Santa Barbara at Santa Barbara

March 3
L.A. State & Cal Poly at Caltech

Tennis

February 20
Pomona at Caltech

February 23
Cal Western at Caltech

February 27
Whittier at Whittier

March 3
Occidental at Caltech

Baseball

February 20
San Fernando State at S.F. State

February 23
Cal Poly at Caltech

February 27
Westmont at Caltech

March 2
San Fernando State at Caltech

Track

February 20
Cal Poly-La Verne at Caltech

February 27
Conference Relays at Pomona

FRIDAY EVENING DEMONSTRATION LECTURES

Lecture Hall
201 Bridge, 7:30 p.m.

February 19
Polarized Light
–Robert B. King

February 26
The Vanishing Engineer
–Frederick C. Lindvall

March 4
The American Image of the Old World
–S. Cushing Strout

March 11
Electronic Brains and Real Brains
–G. D. McCann

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Convair
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U.S. Navy Electronics Laboratory

One of a series

Interview with General Electric's Earl G. Abbott, Manager—Sales Training

Technical Training Programs at General Electric

Q. Why does your company have training programs, Mr. Abbott?

A. Tomorrow's many positions of major responsibility will necessarily be filled by young men who have developed their potentials early in their careers. General Electric training programs simply help speed up this development process.

In addition, training programs provide graduates with the blocks of broad experience on which later success in a specialization can be built.

Furthermore, career opportunities and interests are brought into sharp focus after intensive working exposures to several fields. General Electric then gains the valuable contributions of men who have made early, well-considered decisions on career goals and who are confidently working toward those objectives.

Q. What kinds of technical training programs does your company conduct?

A. General Electric conducts a number of training programs. The G-E programs which attract the great majority of engineering graduates are Engineering and Science, Manufacturing, and Technical Marketing.

Q. How long does the Engineering and Science Program last?

A. That depends on which of several avenues you decide to take. Many graduates complete the training program during their first year with General Electric. Each Program member has three or four responsible work assignments at one or more of 61 different plant locations.

Some graduates elect to take the Advanced Engineering Program, supplementing their work assignments with challenging Company-conducted study courses which cover the application of engineering, science, and mathematics to industrial problems. If the Program member has an analytical bent coupled with a deep interest in mathematics and physics, he may continue through a second and third year of the Advanced Engineering Program.

Then there is the two-year Creative Engineering Program for those graduates who have completed their first-year assignments and who are interested in learning creative techniques for solving engineering problems.

Another avenue of training for the qualified graduate is the Honors Program, which enables a man to earn his Master's degree within three or four semesters at selected colleges and universities. The Company pays for his tuition and books, and his work schedule allows him to earn 75 percent of full salary while he is going to school. This program is similar to a research assistantship at a college or university.

Q. Just how will the Manufacturing Training Program help prepare me for a career in manufacturing?

A. The three-year Manufacturing Program consists of three orientation assignments and three development assignments in the areas of manufacturing engineering, quality control, materials management, plant engineering, and manufacturing operations. These assignments provide you with broad, fundamental manufacturing knowledge and with specialized knowledge in your particular field of interest.

The practical, on-the-job experience offered by this rotational program is supplemented by participation in a manufacturing studies curriculum covering all phases of manufacturing.

Q. What kind of training would I get on your Technical Marketing Program?

A. The one-year Technical Marketing Program is conducted for those graduates who want to use their engineering knowledge in dealing with customers. After completing orientation assignments in engineering, manufacturing, and marketing, the Program member may specialize in one of the four marketing areas: application engineering, headquarters marketing, sales engineering, or installation and service engineering.

In addition to on-the-job assignments, related courses of study help the Program member prepare for early assumption of major responsibility.

Q. How can I decide which training program I would like best, Mr. Abbott?

A. Well, selecting a training program is a decision which you alone can make. You made a similar decision when you selected your college major, and now you are focusing your interests only a little more sharply. The beauty of training programs is that they enable you to keep your career selection relatively broad until you have examined at first hand a number of specializations.

Furthermore, transfers from one General Electric training program to another are possible for the Program member whose interests clearly develop in one of the other fields.

Personalized Career Planning is General Electric's term for the selection, placement, and professional development of engineers and scientists. If you would like a Personalized Career Planning folder which describes in more detail the Company's training programs for technical graduates, write to Mr. Abbott at Section 959-13, General Electric Company, Schenectady 5, N. Y.

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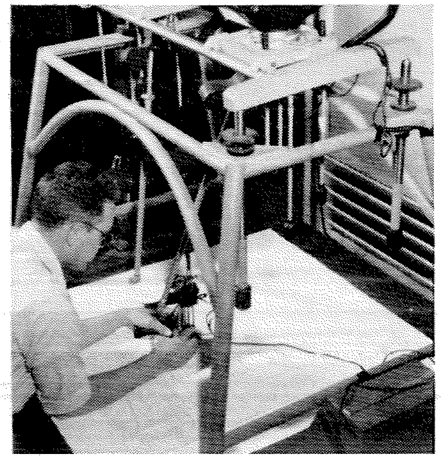
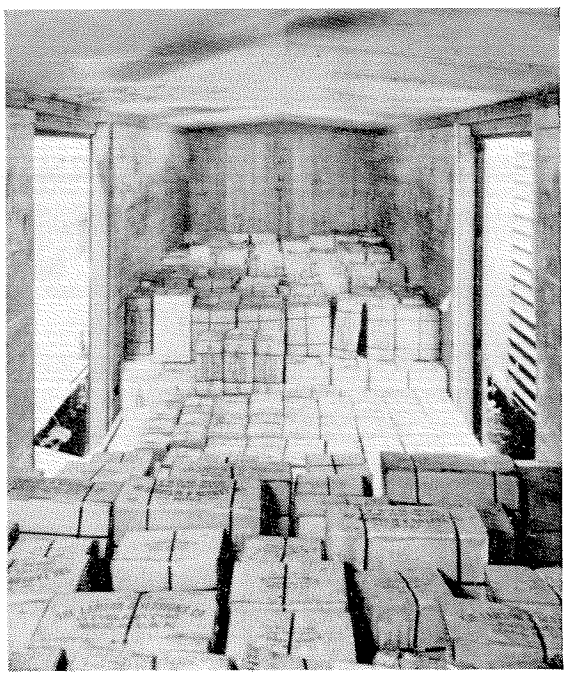
1 By setting templates of standard components on photo-sensitive paper and exposing it, hours of hand drafting are saved.



2 With this plotter, stereo aerial photos become contour maps, show highway routes, mineral-bearing formations, volume of coal piles.

3 Slides give the sales staff quick understanding of the engineering superiority of their product—equip them with facts for their customers.



4 Photographs of freight cars as loaded and as received provide information for engineers to develop better loading practices (as well as data for damage claims).

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