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ENGINEERING AND SCIENCE

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ENGINEERING AND SCIENCE

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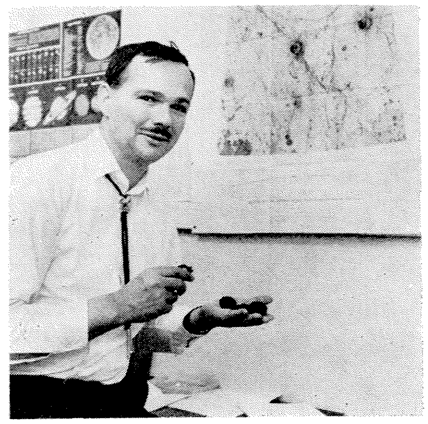

On Our Cover

Eugene Shoemaker, research associate at Caltech and chief of the U.S. Geological Survey's astrogeology branch, holds a handful of tektites—stones that he thinks are remnants of lunar material ejected from the moon's surface during an impact about a million years ago. For several years Dr. Shoemaker has been an active exponent of the theory that most of the large craters on the moon have been formed by impact, and he was a member of the team of American scientists that evaluated the pictures taken during the Ranger missions. On page 11 he presents his version of what happens "When the Irresistible Force Meets the Immovable Object," and also gives some new information on the ages of surface features on the moon.

Donald E. Hudson,

professor of mechanical engineering and applied mechanics, explains in "Earthquake-Resistant Design" (on page 20) how studies of the effects of earthquakes on structures are providing information that can prevent losses of life and property caused by earthquakes.

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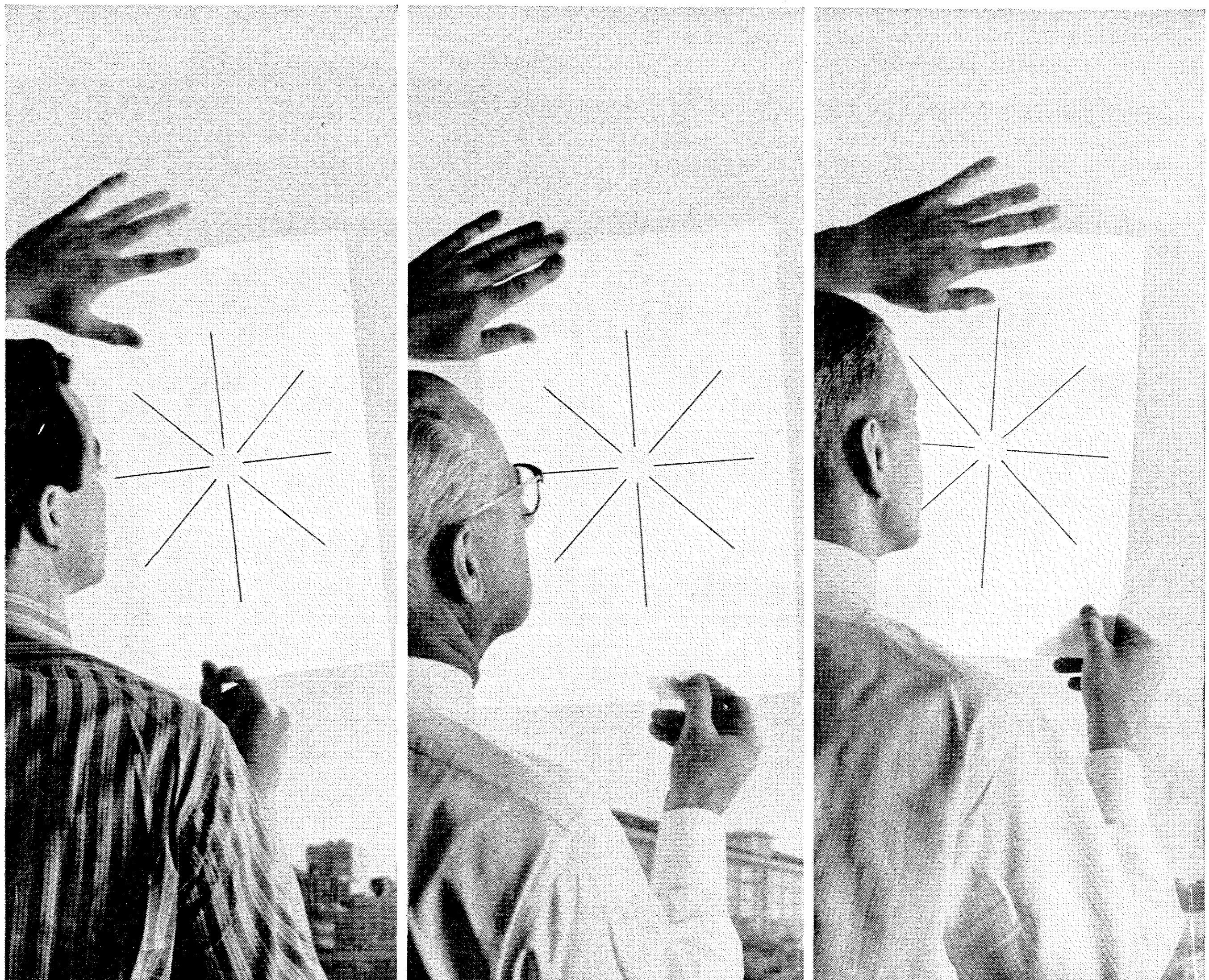


Books

Inventing the Future

by Dennis Gabor

Alfred A. Knopf, Inc. *$4.95*

Reviewed by Joel N. Franklin, professor of applied science

Dennis Gabor, professor of applied electron physics at the University of London, is 65 years old and a fellow of the Royal Society. His *Inventing the Future* defines, and suggests solutions to, the problems of the world he feels will be the most important during the next 50 years. The title reflects Gabor's belief that the future cannot be predicted, but futures can be invented.

Gabor offers these "inventions":

Threat of nuclear destruction. There will not be an all-out war. The certainty of retaliation prevents Russia and the United States from attacking each other. They are prosperous nations and are becoming indifferent to conflicts between political philosophies.

Overpopulation. The extraordinary growth of the world's population must and will be slowed. The recent growth has been due, not to a rise in the birth rate, but to a fall in the death rate. The only answer to this problem is increased birth control. When overpopulation becomes more serious, the world's religions will relax their opposition to birth control.

Automation and leisure. In the advanced countries most of the useful work will be done by a small fraction of the people. What will the rest of the people do? Men are psychologically unprepared for a life of leisure. Men must have work to be mentally healthy, and their work must seem meaningful and important. The solution to this problem is a change of values. Increased industrial production and the saving of lives cannot be the supreme values in an automated, overpopulated society. We must learn to value knowledge and beauty for their own sakes. We must move toward a life of abundance and satisfaction for the common man and toward a life of creative struggle for the uncommon man.

Depletion of natural resources. In 50 years there will be serious shortages of lead, zinc, copper, tin, petroleum, and other natural resources. This is a challenge to technology. Because technological problems are met the most readily by mankind, they are the least of our worries.

Poverty and political immaturity. The underdeveloped countries are poor and politically immature. The problem is serious because the least advanced countries respond the slowest to scientific progress. Two percent of the income of the United States and of the other most advanced countries should be devoted to improving the technology of the rest of the world. As the rest of the world becomes economically self-sufficient, it will become politically more mature and less volatile.

This is an extraordinary book. It is at least 50 times as good as the average book of its type. It would be hard to describe adequately the author's brilliant literary style, the depth of his insight, and the scope of his knowledge. Reading Gabor's book is like having a series of coffeeshop conversations with the most learned and witty of your colleagues. To this reviewer the book has only one serious fault, and that is a fault of omission. Gabor is unduly complacent about the threat of nuclear destruction. His complacency is based on a sound analysis of two countries, the U.S.S.R. and the U.S.A. He ignores the great problem which will come in 10 or 15 years. Then there will be *more* than two countries with nuclear-missile capability. If a nuclear submarine of unknown origin deposits a bomb on New York City, *against which country will we retaliate?*

General Genetics

by Adrian M. Srb, Ray D. Owen, and Robert S. Edgar.

W. H. Freeman & Co. *$9.00*

This book is the second edition of a standard college textbook of genetics. Two of the authors are members of the Caltech faculty — Ray D. Owen, chairman of the division of biology, and Robert S. Edgar, associate professor of biology. Adrian M. Srb, of Cornell University, was research associate in biology at Caltech in 1949.

The new edition incorporates the essential details of the many spectacular developments which have occurred in genetics since the first edition of this work appeared in 1952. The book begins with a discussion of the principles of heredity as exemplified in higher plants and animals. The student is then introduced to the intricacies of the physical and chemical basis of heredity as elucidated by experiments with the lower organisms, especially the phages, bacteria, and fungi. The book remains broad in scope, and the student will find comprehensive and thorough discussions of such topics as plant and animal breeding, the role of the genes in development, and the genetics of man.

Letters

EDITOR:

This letter is written in response to the article "Student Life—Some Problems and Proposals," by Fred Lamb '68, in *Engineering and Science*, December 1965.

Subject article definitely requires some attention to clear the air in this puzzled world of student life as portrayed by Fred Lamb.

California Institute of Technology and all other accredited educational institutions in this country and all other parts of the world function for only one purpose, i.e.: To instruct students in the courses respectively chosen by the students.

Coffee houses, beer joints, an associated women's college, and similar environments are certainly not essential to the successful pursuit of an engineering science course.

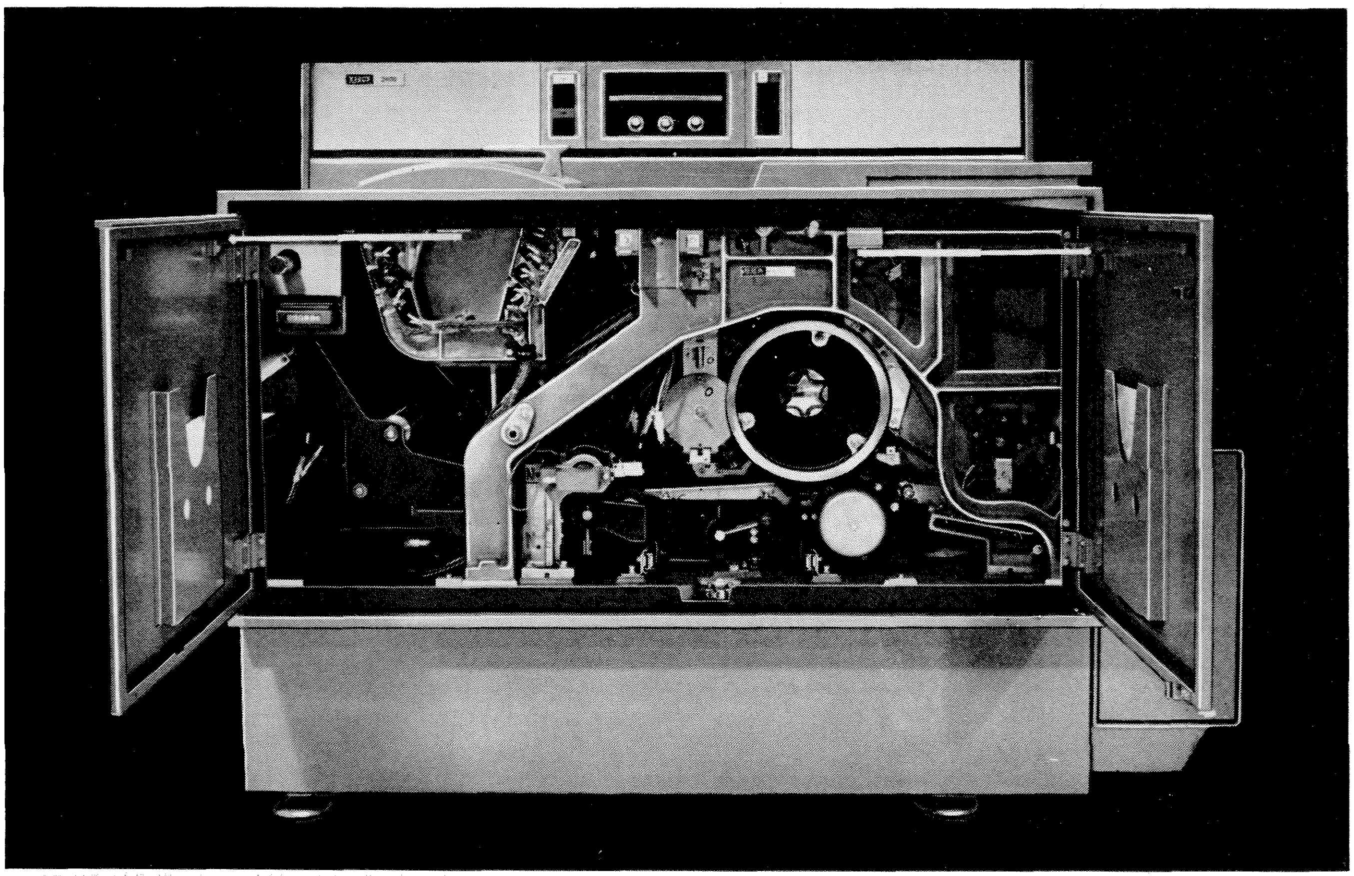
My academic years, which began with high school and the Far Eastern State Institute of Technology in Russia, and later, Willamette University, were completed at California Institute of Technology. While at Caltech, my fellow students and I did not experience any necessity for "a course for credit involving work projects on cultural, social, and political problems in the Los Angeles area, perhaps in cooperation with a girls' school." I imagine it could be lots of fun — if that's what Caltech is for.

It appears that the problems described lie not with the Institute, but with some students who, unfortunately, were brought up on "ice cream and mashed potatoes."

During my college years and thereafter, I have found that the Caltech Board of Directors and members of the faculty have performed an excellent job in every respect. Considering their outstanding record, I would leave such matters to our experienced educators and administrators, many of whom have received international recognition and great respect. Let's not tinker with the best.

As for those who find the development of their social skills and emotional maturity being stifled, let them transfer to one of the many second-rate colleges which offer everything except a good education.

BORIS N. SAMMER '26
Registered Professional Electrical & Mechanical Engineer, California.
Vice President & Member Board of Directors, Halliburton Enterprises, Inc.



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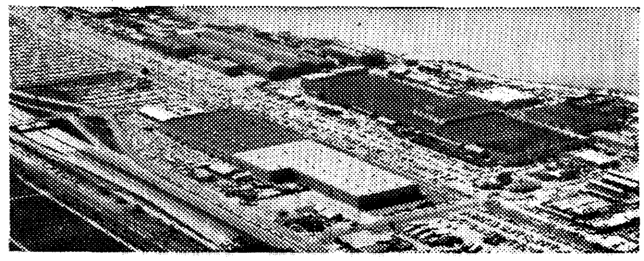

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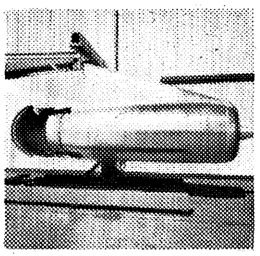
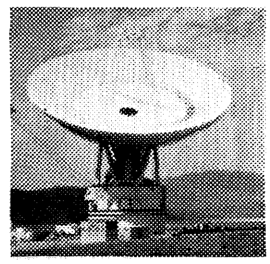
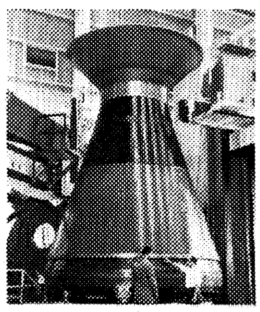


better at lower cost than the airframe builders themselves. The rest is history. Today Rohr is the nation's largest subcontractor to the aerospace industry. Typical of the acceptance of our product is this: Rohr is building major assemblies for every commercial and military multi-engine jet transport in production in America today. Yet, we're widely diversified . . . designing, building and erecting very large tracking antennas around the world, for instance





. . . and fabricating large missile and space components such as rocket engine nozzles and liners. Recently Rohr has acquired large, new, long-term contracts. More are still un-announced. The future looks bright here, and we're looking for bright, young engineers to help keep it that way.

On February 25, 1966

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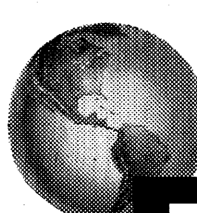

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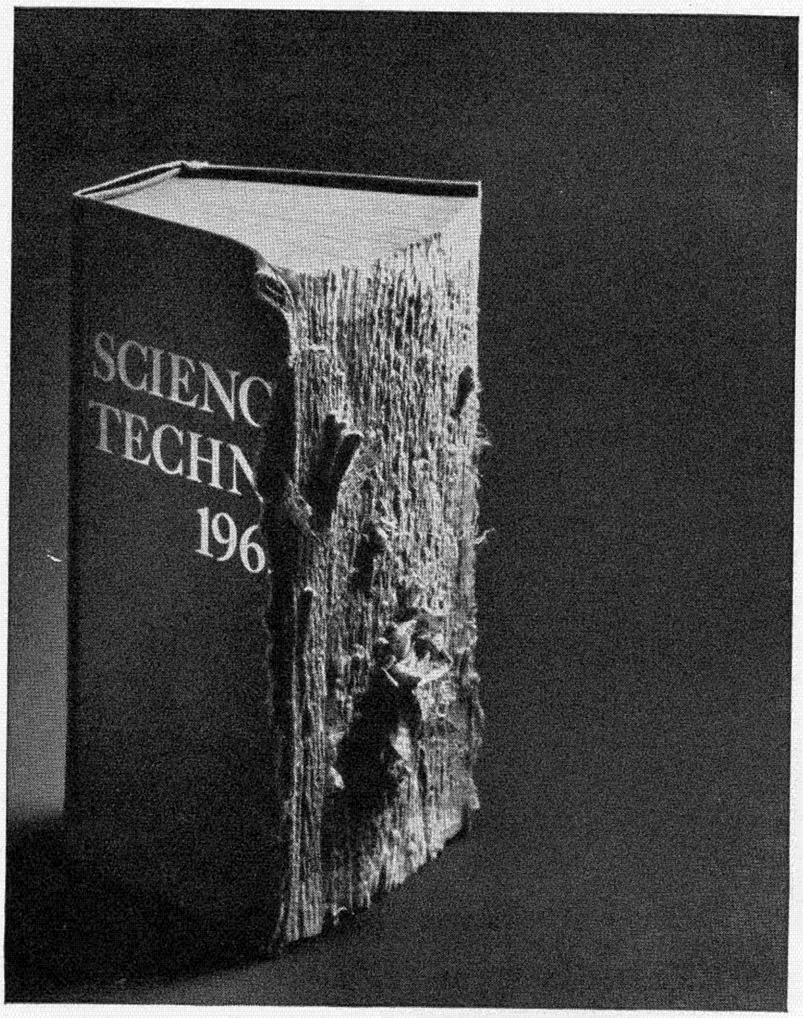

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February 1966, Vol. XXIX, No. 5

When the Irresistible Force Meets the Immovable Object

The results of such encounters are plainly visible on the surfaces of the moon, Mars, and the earth

by Eugene Shoemaker

A solid object moving at speeds of many kilometers per second or faster creates a truly irresistible force if it strikes another solid object. Such fast-moving objects abound in the inner part of the solar system, and they occasionally collide with the solid surfaces of the terrestrial planets and the moon. Most of these cosmic projectiles are so small that, when they collide with a planet, the planet may for most purposes be considered immovable. A complex series of events take place, however, in the near vicinity of the impact point. A shock, which decelerates the projectile, is propagated back to the projectile from the impact interface, and another shock is propagated out into the planetary target where it sets a small region within the target in motion. Rarefaction waves, reflected from the free surfaces of the projectile and target behind the shocks, deflect the moving, shocked material so that it flows away from the target in a diverging spray, leaving a cavity in the target. Thus, the answer to the old paradox about what happens when an irresistible force meets an immovable object is: *It will make a crater.*

High-speed impact cratering is a process that geologists, with a few exceptions, have almost entirely ignored. Other scientists who ought to be concerned about it, such as astronomers, have generally ignored it too. So it has only been in the last few years that the significance of impact phenomena in the evolution of solid planetary surfaces has come to be appreciated.

Normally we are not conscious of the relatively big pieces of solid debris in the vicinity of the earth except on those occasions when there is a near-miss. One of the best documented near-misses was discovered by the late Walter F. Baade of Caltech on a photographic plate taken in 1949 with the 48-inch Schmidt camera at the Palomar Observatory; he found a long streak on the plate that represented an object moving very rapidly near the earth. Subsequent exposures permitted a calculation of its orbit which showed that this body, usually called an asteroid (although we have good reason, I think, for calling these objects something else), not only comes close to earth but crosses the orbit of Venus and Mercury and passes close to the sun. Because of its close approach to the sun it was named Icarus.

Icarus is only one of a family of more than 15 telescopically observed objects that cross the orbit of the earth (i.e., their perihelion distance, the nearest point in their orbit of the sun, is less than the average distance of the earth from the sun). Some of them have been observed to pass much closer than Icarus, which came within eight million miles of the earth at the time of its discovery. In 1937, Rheinmuth at Heidelberg discovered a very near object, later called Hermes, which passed within less than half a million miles of the earth, a little less than twice the average distance to the moon.

If the earth is pictured as a bullseye on a target with a radius of half a million miles, the frequency with which it is hit by things like Hermes can be calculated by a simple probability argument. It turns out that this frequency, from the geological viewpoint, is rather high. If there is a population of objects like Hermes in space near the earth, with more or less randomly distributed orbits, then the earth ought to be hit by objects as large as Hermes at a rate of about once every 100,000 years. This is a minimum estimate of the rate because we don't know what other telescopically resolvable objects may have gone whizzing by that we didn't see. We have discovered only a small fraction of them, and most of the discoveries have been accidental.

An object has to be of substantial size to be telescopically observable even in a fairly close passage by the earth. Hermes is probably about a kilometer in diameter. On the other hand, much smaller objects may be observed indirectly if they actually enter the earth's atmosphere. These objects are entering the atmosphere almost constantly and are seen as meteors (bright streaks of light in the sky, produced by shock-heating of the atmosphere along the entry trajectory).

The Tunguska fireball

In the size range between the very small things that are seen indirectly as ordinary meteors and the smallest asteroid seen at the telescope, there is a class of objects which is extremely difficult to detect. From time to time these objects encounter the earth and produce very bright meteoric fireballs (bolides). The most spectacular of these on record was the great Siberian meteor of 1908, sometimes called the Tunguska meteor.

The Tunguska bolide entered the atmosphere over a remote part of central Siberia, and the site was not visited by scientists until almost 20 years later. Some phenomena associated with the meteor, however, were recorded on scientific instruments at great distances from its path. A train of low-frequency acoustic waves and gravity waves radiated out from the Tunguska region and was recorded on ordinary weather station barographs in central Asia. The air-wave train was also recorded on microbarographs in western Russia and in Great Britain, and even the reverse wave, formed after the air-wave train had converged at the antipodes, was recorded at some of the microbarograph stations. Moreover, when the air wave slapped the ground near the end point of the meteor's trajectory, it generated a seismic wave train that was recorded as far away as Jena in eastern Germany. Thus, we have a surprisingly good record of some of the more energetic responses of the earth to the entry of the Tunguska bolide into the atmosphere.

In 1927 the Russian scientist L. A. Kulik organized an expedition to the Tunguska region to search for a meteorite crater at the end point of the trajectory. Kulik failed to find any genuine impact craters but did find one very spectacular effect on the ground, which was later documented in great detail by aerial photographs. Fallen trees made it possible to find the end point of the trajectory from their radial pattern of fall, which extended out to a distance of about 40 kilometers. In addition, the trees were scorched out to a distance of about 15 kilometers from the end point. If a bolide like the Tunguska object entered the atmosphere today, anyone under the end point would be quite sure that he had been blitzed with a nuclear bomb. The immediate effects, except for gamma and neutron radiation, are strikingly similar to those of an airburst of a megaton-sized nuclear weapon.

It is possible, with the data now available from large atmospheric nuclear explosions, to calibrate empirically the response of the atmosphere to very large, very strong shocks. It is also possible to calculate what modes of vibration should be observed on the air-wave train propagated away from the region of strong shock. David Harkrider, a Caltech graduate now at Brown University, has worked out in detail the theory of these wave trains.

The total energy released by the Tunguska fireball can be estimated, using the nuclear explosion data, to have been about 10 megatons. The photovisual radiation, which set the trees on fire, was comparable to the scorching that would be produced by a 5-megaton nuclear device. I became concerned, after I had run through these calculations, over what might happen if a similar bolide were to fall over the Soviet Union or the United States today, and whether the resultant fireball would be recognized as a natural phenomenon. As it turns out, smaller events of this type have occurred in the last 10 years, and a number of them have been detected on sensitive microbarographs.

Asteroid or something else?

Another interesting phenomenon accompanying the Tunguska meteor was observed on the night following the fall in a broad region extending westward all the way to western Europe. The sky that night never became completely dark. People were able to read newspapers at midnight at latitudes as far south as southern Russia. The actual sky brightness was about one ten-thousandth that of the ordinary bright sunlit sky. By the following night the phenomenon had disappeared.

From its geographic distribution, it is possible to show that the bright night sky resulted from scattering of sunlight by very high dust, extending as high as 800 kilometers. The dust particles settled rapidly enough that the sky returned to normal darkness the following night.

Apparently the Tunguska meteor was produced by a small comet, and the dust was derived from the tail of the comet. This comet was not bright enough to have attracted notice prior to its entry into the earth's atmosphere. The diameter of the nucleus was small, probably no more than 25 to 30 meters. It weighed about 20,000 tons and was coming in at a velocity of about 60 kilometers per second. It never reached the ground because the pressure on the front end built up rapidly, and the stress difference between the front and back sides finally exceeded its shear strength; it came apart at an altitude of about 15,000 feet.

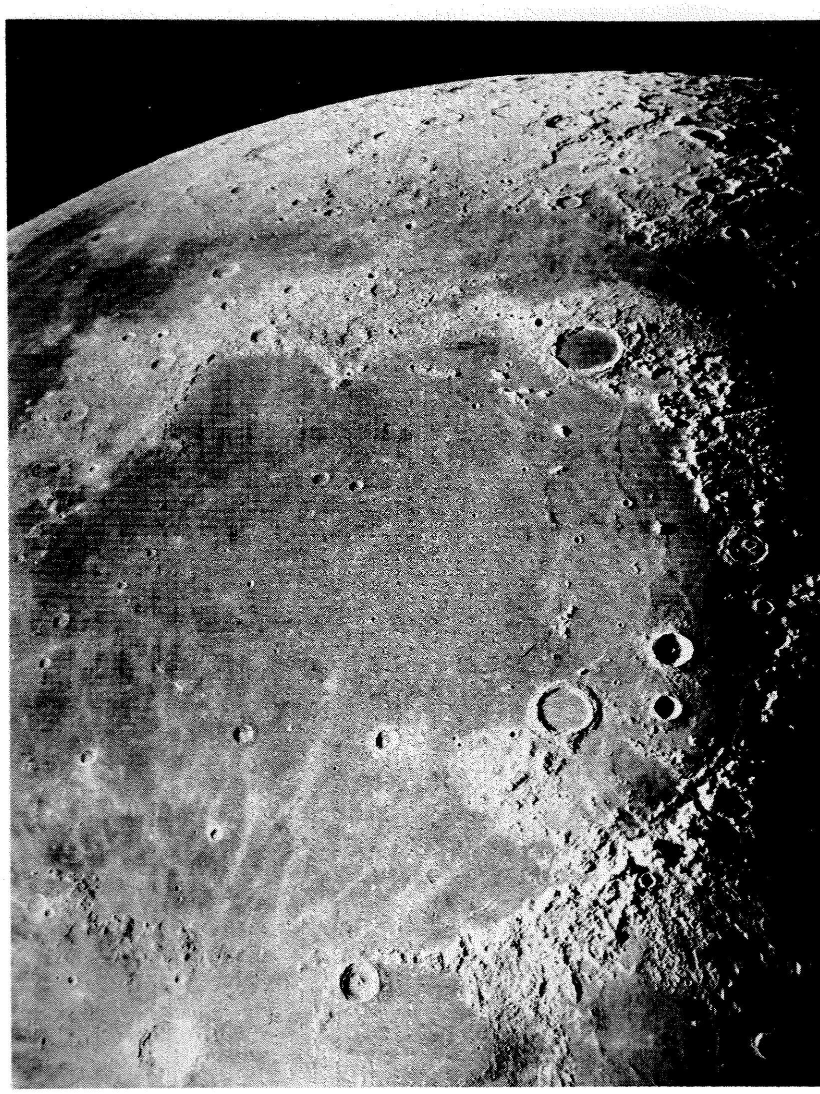
I suspect that the so-called asteroids like Hermes and Icarus are also comets which have passed near the sun so many times that their volatile constituents have been almost entirely driven off. These objects have orbits that are more like those of the comets than of the normal asteroids, which are in orbits between Mars and Jupiter.

Most small bodies that enter the earth's atmosphere are decelerated to very low velocities before they reach the solid surface; also, objects in the size range of 1 millimeter to 100 meters are generally torn to pieces by aerodynamic forces. Iron meteorites are the only objects in this size range that are strong enough to survive passage all the way through the atmosphere and make a crater. The iron meteorites constitute about five percent of the meteorites observed to fall. At present, craters formed by impact of iron meteorites are known at 12 localities on the earth. The biggest of these craters is the Arizona meteorite crater, near Flagstaff, which is about 1.3 kilometers in diameter. The energy required to produce this crater was about 4 to 5 megatons TNT equivalent, and the meteorite was probably about 30 meters in diameter.

Age of the lunar surface

If an object like the Tunguska bolide hits the earth once every 50 years, which is the approximate expected rate of encounter, similar objects will hit the front side of the moon about once every 1500 years. An object the size of the Tunguska bolide would make a crater about 1.5 kilometers across on the moon—which would be easily resolvable telescopically. Objects the size of Hermes and larger hit the moon at least once every three million years and form craters tens of kilometers across.

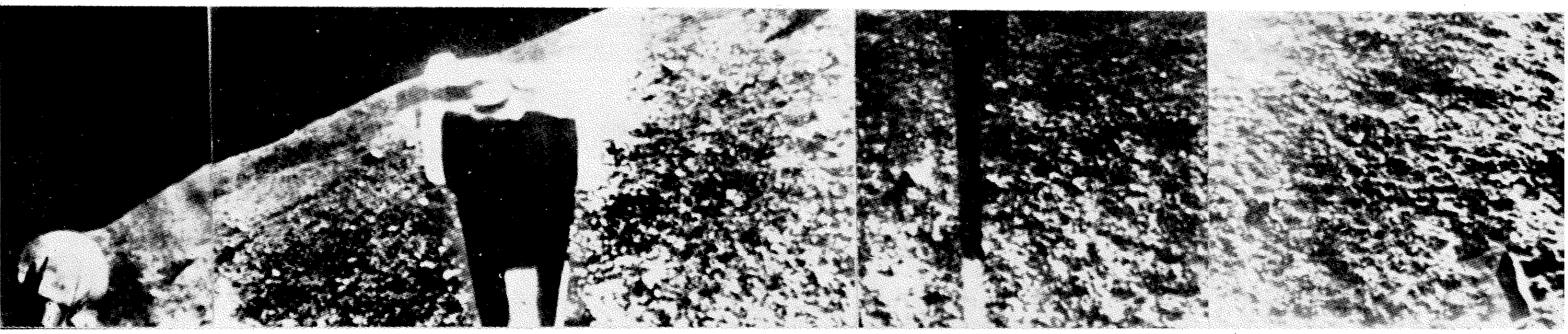
If this present rate of encounter is approximately the same as the rate in the past, we may use the number and distribution of observed craters to estimate the age of different parts of the lunar surface.



Mare Imbrium, the moon's largest circular basin, may be only one billion years old. This makes it considerably younger than the moon itself, whose age is probably on the order of four and one-half billion years.

One of the most obvious things about the moon is that the lunar terrain can be divided into two fairly distinct classes. One terrain class consists of the rather smooth, dark parts of the surface (which can be recognized with the naked eye). Galileo called the dark, smooth regions *maria* (seas) because, with his small telescope, he couldn't see the craters and other features on them, and he thought the maria were actually water surfaces. The other terrain class includes the bright, higher, more heavily cratered regions, which he called the *terrae*.

The spatial densities of the small, telescopically resolvable craters on the different maria are about the same, which leads us to suspect that most of the individual mare surfaces were formed at about the same time in lunar history. When observed in close



The best view of the moon so far—pictures from the Soviet Union's Luna 9, from about two feet off the moon's surface.

detail, the maria are found to have features similar in form to small volcanoes and volcanic flows on earth. Probably the mare surfaces were built up as a series of overlapping volcanic deposits. This episode of volcanism is a significant part of the history of the solar system, and the question is: When did it happen?

One idea is that the maria are very old. Estimates that these dark, smooth surfaces are almost as old as the earth itself—about four and one-half billion years—are common in the literature of the moon. At the present rate of impact, however, all the craters on the maria could be accounted for by the accumulated influx of about half a billion years. Thus, the maria may be only about one-tenth the age of the earth.

This estimated age for the maria is radically different from the age I would have given half a year ago. I would have said then that the mare surfaces were several billion years old. It was a recalculation of the energy of the Tunguska object, along with new data on other very large meteoric fireballs, that has permitted this drastic revision of the time scale of the moon. The maria now appear to be about as young as some of the older fossiliferous rocks here on earth. Placed in the geologic time scale, they would be late pre-Cambrian or early Paleozoic in age.

Thus, it is possible to revise the estimated ages of some of the other prominent features on the moon as well. For example, the largest circular basin on the moon is the Mare Imbrium basin, which appears to be a very large impact crater almost filled with lava. On the basis of the number of smaller craters superimposed on the exposed rim of the basin, it turns out that the basin was formed about a billion years ago, which makes it much younger than the moon. Moreover, existence of this "young" basin on the moon suggests that similar huge impact scars may have been formed on the earth during the latter part of geologic history. While normal surface geologic processes tend to obscure most craters formed very long ago, one as big as the Imbrium basin (several hundred kilometers across) might be more difficult to hide in a billion years. The large circular basin in the southern part of Hudson Bay in Canada may well be a crater like Mare Imbrium, as suggested by the Canadian astronomer C. S. Beals several years ago.

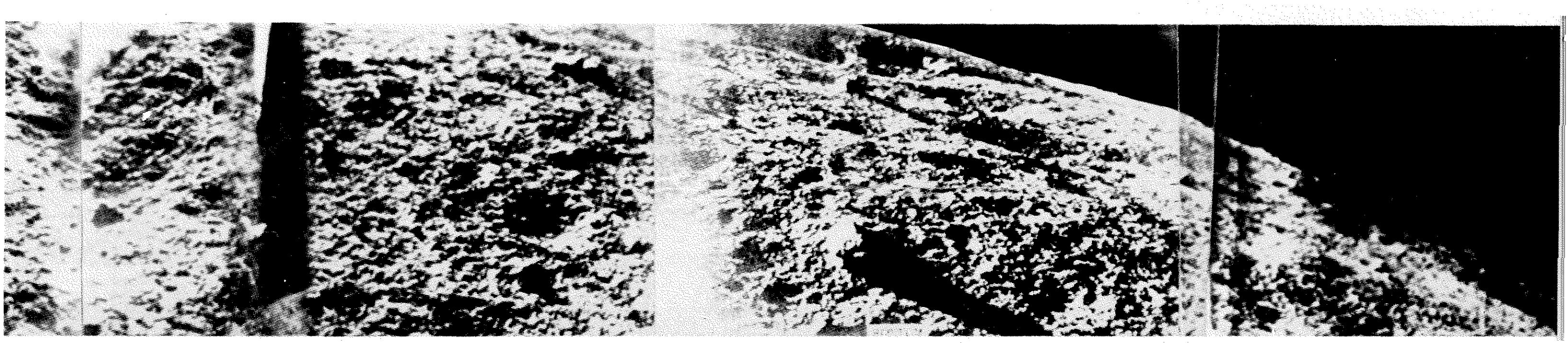
The parts of the moon most densely populated with craters have roughly 10 times as many large craters as do the maria. These heavily cratered parts of the terrae may be nearly as old as the moon.

The pictures transmitted from Mariner IV showed that parts of the surface of Mars look rather startlingly like the terrae of the moon; the regions observed on Mars are populated by large, overlapping craters. A good deal of argument has transpired in the last half year about how old the Martian surface is. I think most of the arguments are unsound. It has been assumed by most people that the craters were formed by asteroids, because the asteroids have orbits relatively close to Mars. If most of the craters on earth and the moon are formed by comet nuclei, however, the impact rate of comets on Mars may be greater than that of asteroids. The impact rate of comets per unit area on Mars probably is within a factor of two or three of the estimated rate for the earth and the moon. For a given area, craters should be formed more rapidly on Mars than on the earth and moon, but we do not have sufficient information as yet to know what the difference in impact rate should be.

Pieces of the moon

One of the consequences of a high-speed impact is that some material is ejected from the target at very high velocity. A projectile striking a dense solid surface on the moon at speeds greater than 6 kilometers per second will eject more than its own weight at escape velocity (2.4 kilometers per second). Thus, one of the things to look for on the earth would be pieces of the moon that have been thrown off during the formation of impact craters.

Little pieces of the moon must be falling on the



The lunar surface around the landing site is covered with a debris layer in which there are some small craters.

earth all the time. Moon dust is in the air we breathe; the trouble is we don't know how to tell the moon dust from earth dust. On rare occasions, however, a great squirt of shock-melted material ejected from a big lunar impact crater should hit the earth. When the liquid jet diverges as it goes out into space, it will break up into little globs that surface tension will tend to make into spheres (or other rounded shapes if they are spinning). The melt will congeal to glass before it hits the earth. Thus, we might expect to find small spherical and rounded bodies of glass scattered about the earth, and indeed we do. They are found in a number of restricted, but still large, strewn fields on various parts of the earth and are called tektites.

Evidence that tektites are likely to have come from the moon rests on surface features produced by aerodynamic ablation as they entered the earth's atmosphere. Dean Chapman, a Caltech graduate now at the Ames Research Center of NASA, has shown that the amount of ablation, the thickness of the remelted layer, and the spacing of ring waves on the ablated surfaces on some tektites from the Australasia field indicate that these objects entered the earth's atmosphere at about 11 kilometers per second, which is very close to the escape velocity from earth. Thus, Chapman's analysis indicates the Australian tektites came from some place essentially on the earth's orbit. The most likely place is the moon. These silicious glasses might be derived from silicious volcanic rocks in the maria.

Other lunar material

In addition to tektites, there are some other materials that are possible fragments of the moon. Harold Urey has suggested that most of the stony meteorites are derived from the moon and have been knocked off by cometary impact. I think it even more likely that the meteorites known as basaltic achondrites, which are similar to terrestrial basalts, may be pieces of the moon. These too might be samples of volcanic rocks in the maria.

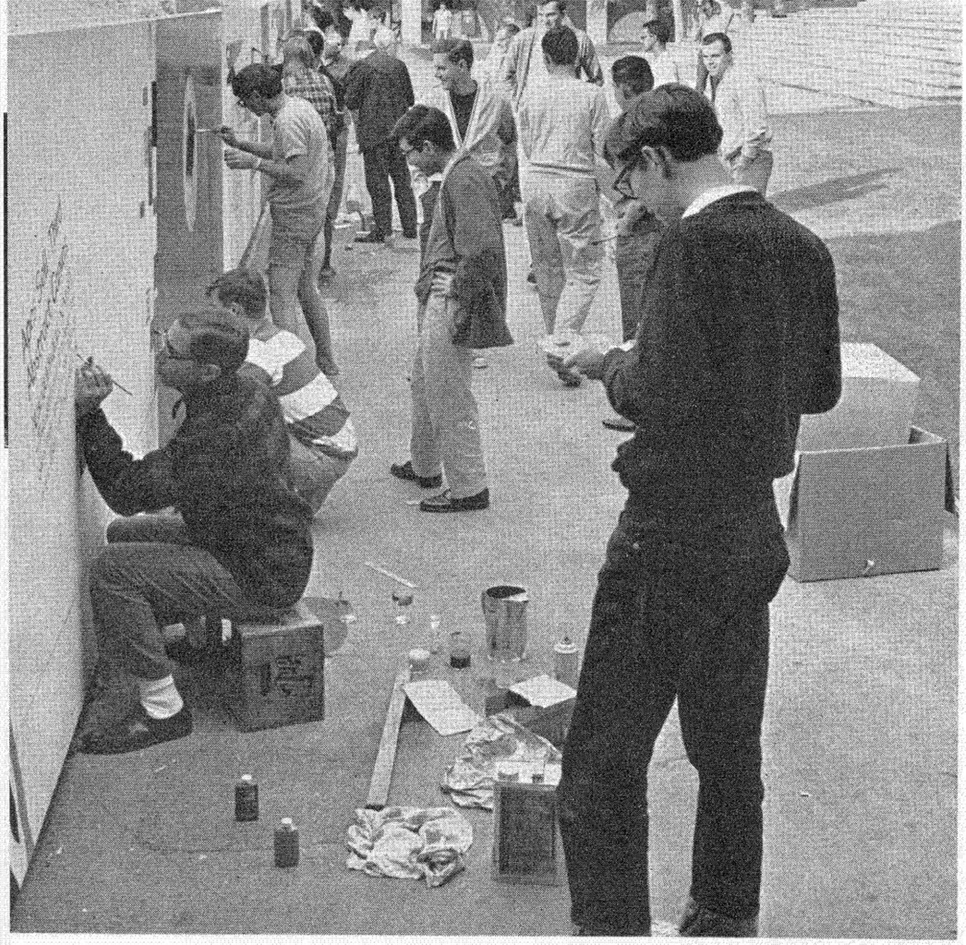
The Luna 9 pictures

Most types of meteorites and much smaller particles of the type that produce the ordinary meteors in the earth's atmosphere are striking the moon's surface at about the same rate per unit area as they encounter the earth. These form craters of the size observed in high-resolution Ranger pictures and in the pictures obtained from the Soviet Union's spacecraft, Luna 9, which soft-landed on the moon on February 3, 1966.

In addition to craters formed by extra-lunar particles, large numbers of small craters are produced by flying fragments of the moon ejected from large impact craters. It turns out that the secondary fragments of the moon produce far more small craters than does the primary flux of interplanetary debris. The cumulative effect of this bombardment is the formation of a layer of fragmental debris covering most parts of the moon, the upper surface of which is pockmarked with small craters.

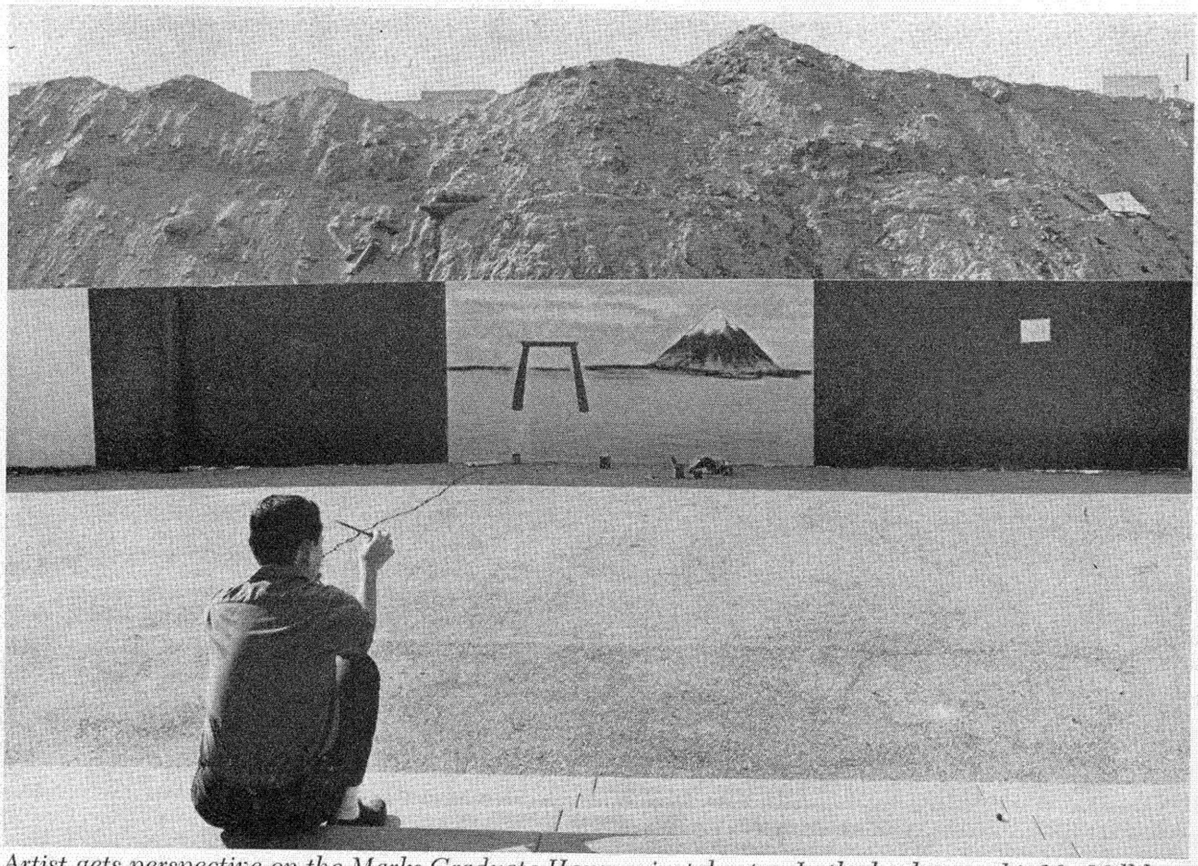
This debris layer with small craters on it is well portrayed in the Luna 9 pictures above. The pictures were acquired by a rotating scanning system located about two feet above the lunar surface. The axis of the scanning system is inclined eastward, toward the sun; and, near the central part of the panorama, fragments only a few centimeters across can be seen near the spacecraft. To the north and south larger fragments and small craters are scattered about the surface, and craters that are probably many meters in diameter occur near the horizon. Much of the near surface has a rubbly appearance.

A debris layer such as this will be of great interest for study in the first manned lunar landing. In most places it will contain pieces derived from both local and distant parts of the moon. By careful sampling of the debris layer it should be possible for us to learn a great deal about the variety of rock types that are exposed over the lunar surface and to determine whether, in fact, tektites and certain kinds of meteorites really are pieces of the moon.

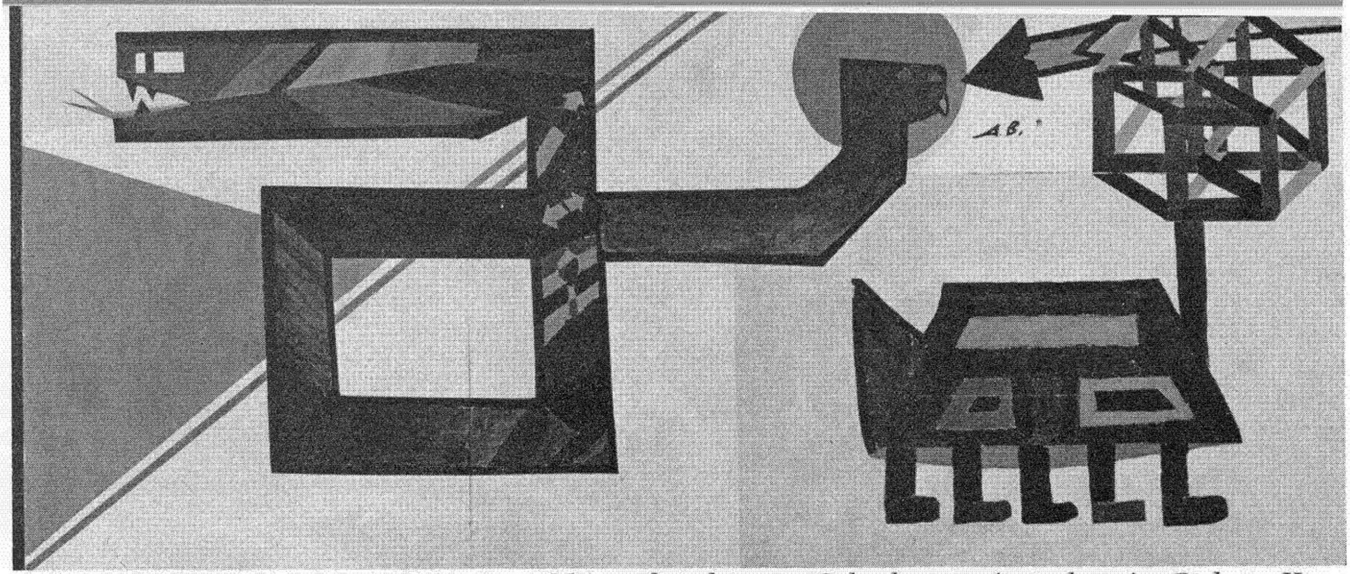


Construction on Caltech's new R. A. Millikan Memorial Library is under way behind 800 feet of plywood fence — now handsomely decorated with the results of an interhouse outdoor art competition. The masterworks occupy 16 fence panels and include volunteer efforts by a faculty member, a professor's wife, and the Fleming House Mickey Mouse Club. The top three winners got $50, $20, and $10, but to at least one student house the real rewards were the side bets: three weeks of Wednesday sundaes.

Brushing Up the Campus

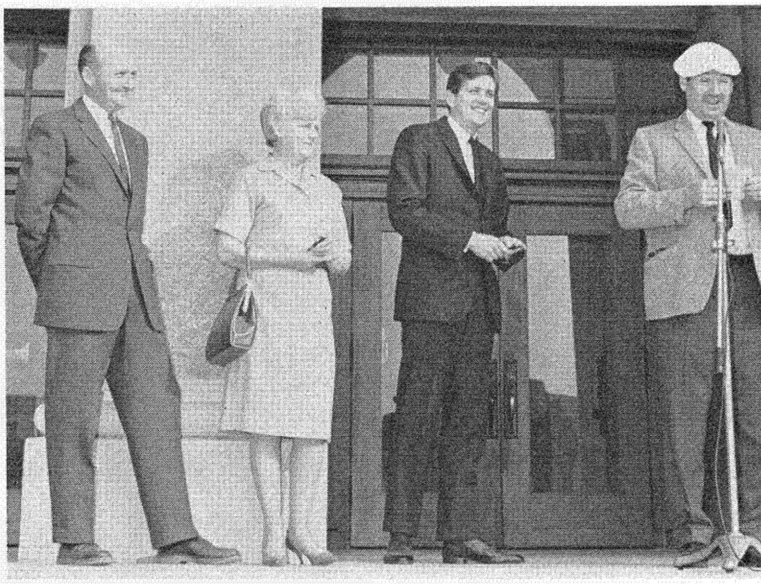


Artist gets perspective on the Marks Graduate House oriental entry. In the background is Mt. Millikan.



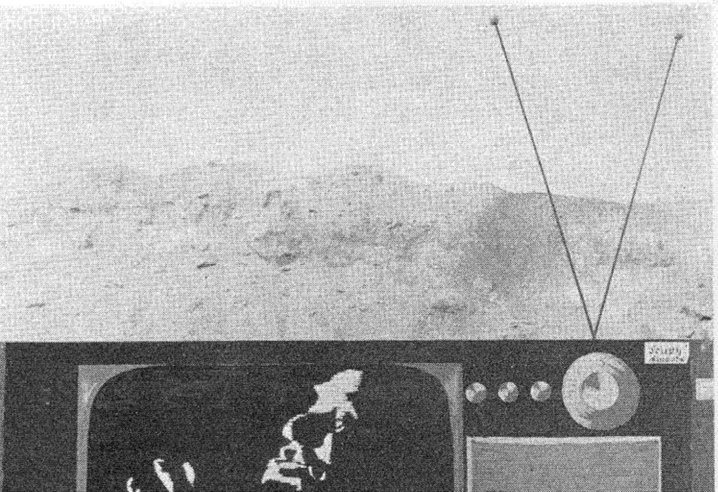
"Turtle and Snake," abstract symbols of social life and studying at Caltech, wins first place for Ricketts House.

Judges — Robert Wark, art curator of the Huntington Library and Art Gallery; Mrs. Jennifer Ross, art coordinator for Caltech's humanities division; and Morris Smith, owner of the Add-Art Gallery in Pasadena, with contest originator Dr. Robert Huttenback, Caltech master of student houses.

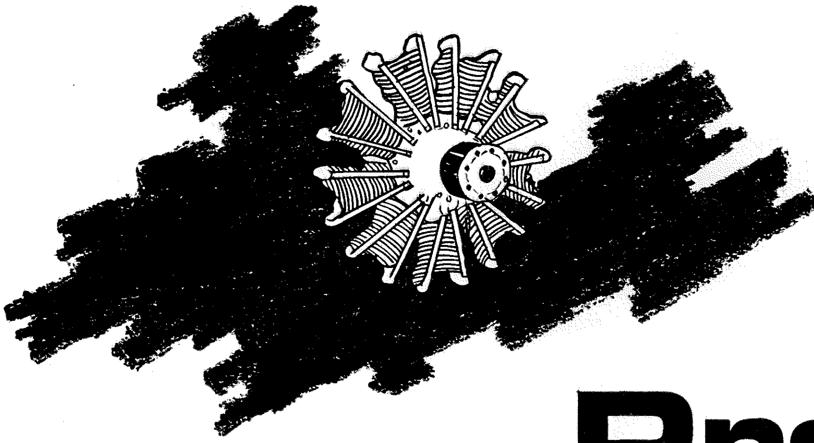


"Soupy," (below) on fence-panel TV, makes use of scan lines, burlap, and tennis balls on metal tubes and gets second prize for Ruddock House.

Pop artists from Fleming House take third prize with a graphic tribute (right, below) to their heroes Nick Fury and The Mighty Thor.



Past



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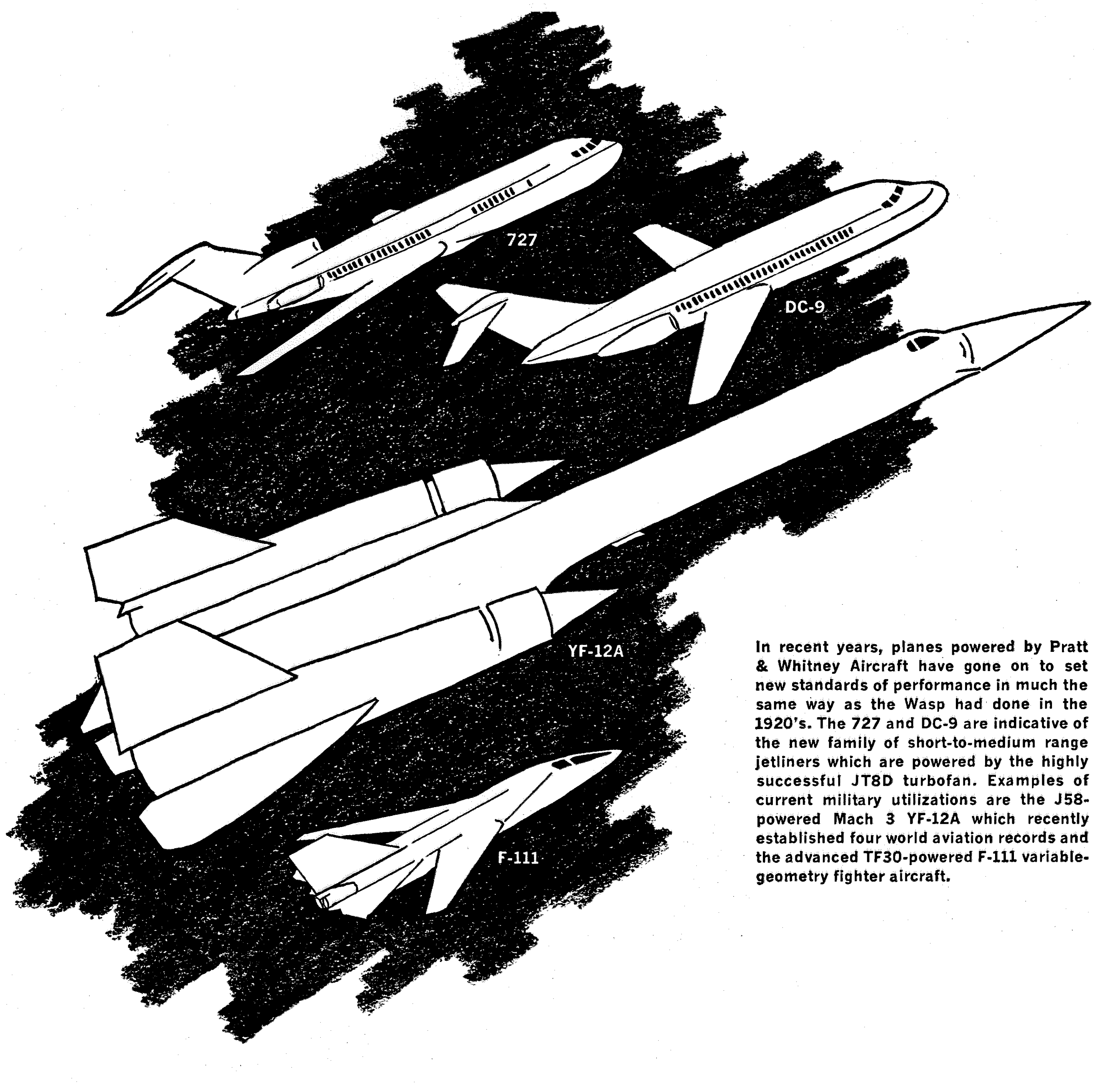

In recent years, planes powered by Pratt & Whitney Aircraft have gone on to set new standards of performance in much the same way as the Wasp had done in the 1920's. The 727 and DC-9 are indicative of the new family of short-to-medium range jetliners which are powered by the highly successful JT8D turbofan. Examples of current military utilizations are the J58-powered Mach 3 YF-12A which recently established four world aviation records and the advanced TF30-powered F-111 variable-geometry fighter aircraft.

Your

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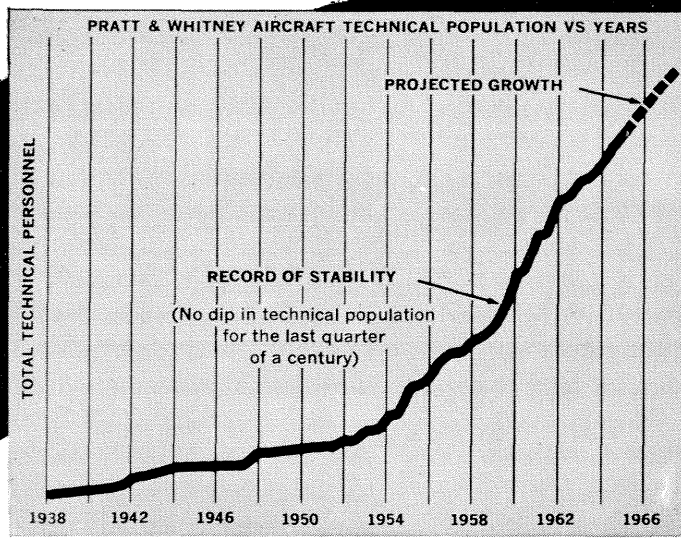

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EARTHQUAKE-RESISTANT DESIGN

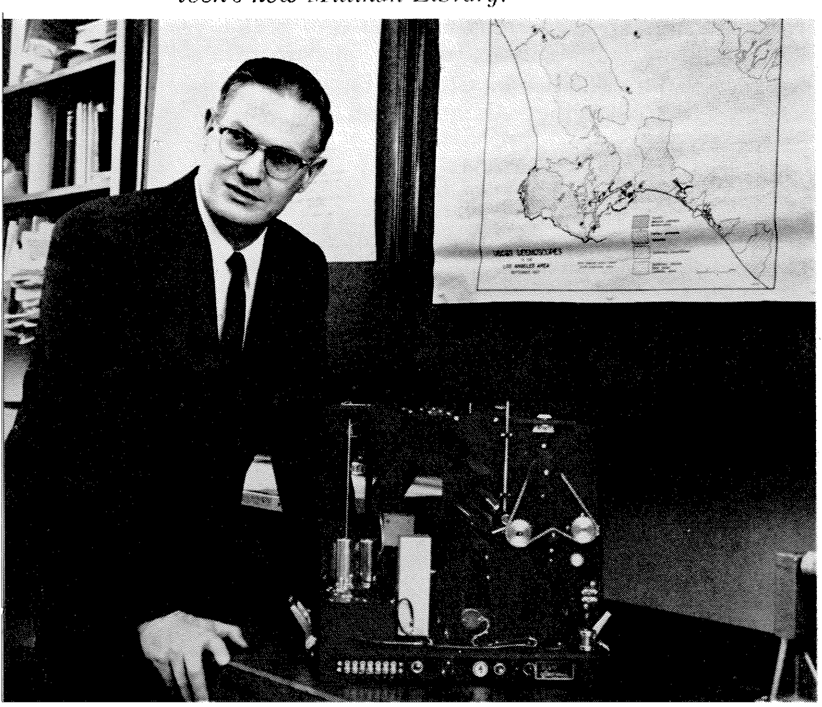
Proper design and construction can prevent loss of life and minimize economic loss

by Donald E. Hudson

Every year there are about 1,000,000 true earthquakes occurring in the earth. Most of these are so small that they can be detected only by sensitive instruments, but about 100,000 of them could be felt to some degree by human beings located near the origin. Fortunately, only about 100 are of a size sufficient to cause severe damage, and most of them occur far from any man-made structures. As an average there are each year perhaps a dozen or so earthquakes that cause significant damage somewhere in the world. These dozen are enough to represent a heavy economic loss and a continuing hazard to life and limb in many areas of the world. According to a recent UNESCO report, earthquakes between 1926 and 1950 resulted in 350,000 human deaths and an economic loss estimated at $10 billion.

Even though the number of earthquakes is not expected to increase significantly, the severity of the problem is sure to grow, because the world is rapidly filling up with people and structures. For example, had the Alaska earthquake of 1964 occurred a few years earlier, there would have been much less damage, because there would have been few structures in the area.

Donald E. Hudson, professor of mechanical engineering and applied mechanics, with one of the strong-motion accelerographs that will be installed in Caltech's new Millikan Library.



Studies based primarily on the work of Caltech seismologists Charles Richter and the late Beno Gutenberg and reported in their book *Seismicity of the Earth* have shown that the distribution of earthquakes over the earth is far from uniform. About 80 percent of the world's earthquakes occur in a relatively narrow belt circling the Pacific Ocean. The most seismic parts of the United States are the Pacific Coast states, which form a segment of this basic circum-Pacific belt. It cannot be assumed, however, that destructive earthquakes will not occur in other parts of the country. Very large earthquakes occurred in the central Mississippi Valley (1811-1812) and in Charleston (1886), and several sharp shocks have been felt in the Boston area during the past 100 years.

Earthquakes are commonly described by their magnitude, measured on the Richter scale, but many of the most destructive in terms of property and lives were seismologically "moderate or small." A brief survey of recent well-known earthquakes shows that the Alaska earthquake was perhaps not quite as large as the 1960 Chile earthquake, and both were probably exceeded by the Assam [India] earthquake of 1950. The San Francisco earthquake of 1906 is definitely down the scale a little, and the Kern County earthquake of 1952, the most recent one to cause appreciable damage in Los Angeles, was of an intermediate size. Of equal interest is the low end of the scale; Agadir [Morocco] and Skopje [Yugoslavia], which did immense damage and killed thousands of people, were relatively small earthquakes that happened to occur close to densely populated areas with many very weak structures.

Similarly, the destructive Santa Barbara and Long Beach earthquakes, which made a deep impression on the southern California consciousness of the earthquake hazard, were relatively small. The number of small earthquakes far exceeds that of large earthquakes; there are on the average about 12 shocks of magnitude 6 each year, but only one of magnitude 8.

A magnitude 8.5 earthquake would cause structural damage over an area of about 100,000 square miles (the area of southern California); the Long Beach earthquake (magnitude 6.3) caused damage over some 300 square miles. In light of the greater number of smaller earthquakes, however, it can be concluded that there is almost as much total damage from smaller earthquakes as from the larger. The bigger ones nevertheless present more of a problem, since damage over a very wide area complicates relief and rescue work and intensifies the economic problems of recovery and reconstruction.

Considering past data on the numbers of earthquakes of various sizes occurring in California and the areas of damage associated with each, one can arrive at the number of years that should elapse on the average between destructive ground motions at any particular point. It is found for any point in California that the expected frequency of experiencing ground motion equal to or greater than that in Long Beach during the 1933 earthquake is about once per 70 years. Smaller magnitudes of shaking will be felt more often, but the 70-year figure is a good one to keep in mind in relation to the expected life of structures.

One cannot "run away from earthquakes" in California by locating structures far from known faults; there are too many faults distributed throughout the state. A common opinion now is that perhaps the whole of California should be considered to have approximately the same earthquake risk.

Effects of earthquakes on structures

Structural damage caused by earthquakes falls into two broad classes: that caused primarily by a disruption of the foundation, and that caused by shaking of the ground. The dangers of foundation disruption were clearly shown in the Alaska earthquake, where landslides caused great damage. In one instance a hospital, which withstood the shaking of the earthquake as it had been designed to do, narrowly escaped destruction when a landslide came within a few feet of it. Although the hospital site has obvious scars that are evidence of former landslides, those warnings were ignored, and a water supply tank was erected right on the edge of a previous slide. This whole situation illustrates one type of precaution that should certainly be taken in locating buildings. No amount of skill in structural design could withstand an undermining of the foundation by such landslides. Other areas in Anchorage were not as fortunate, and a large fraction of the damage there was the result of houses being engulfed in massive slides.

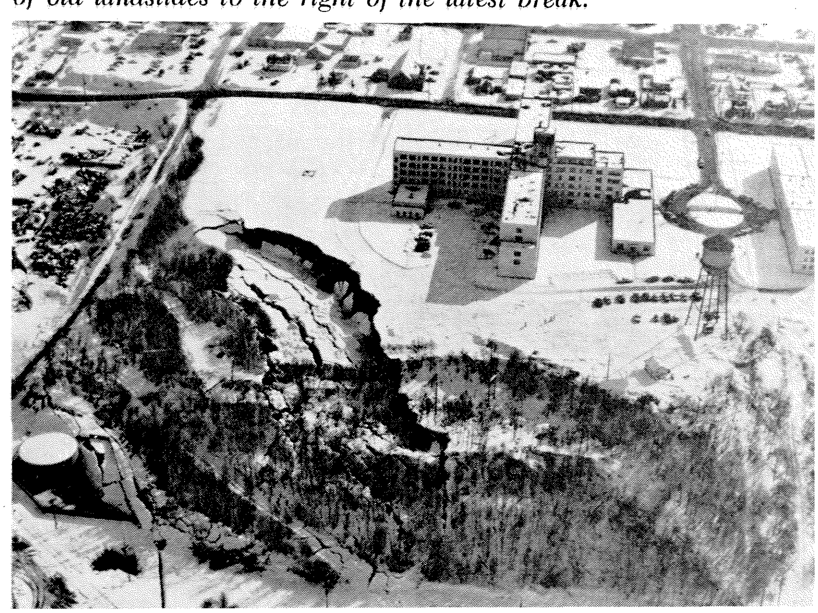
A second kind of foundation disturbance was shown in Niigata [Japan] where whole buildings tilted as though they were rolling in a heavy sea. One large multi-story apartment house rotated through an angle of 80 degrees in foundation soil that was "liquefied" by the earthquake shaking. Even though this concrete building finished up on its side, little structural damage occurred.

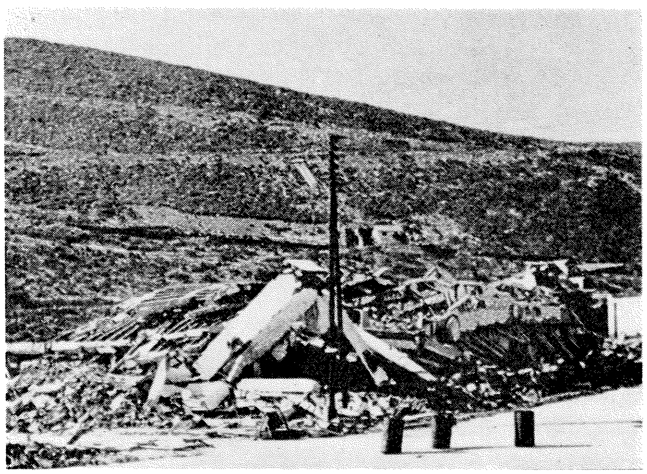
The type of damage that is most susceptible to analysis occurs when buildings on firm ground are shaken by an earthquake. Before-and-after photographs of a multi-story office building in Agadir show what happened during the 1960 earthquake. Although the building disintegrated because of the shaking of the solid ground, telephone poles remained firmly planted in the ground.

Measurement of destructive ground motion

It might be expected that information about the shaking of the ground during destructive earthquakes would be obtained from the instruments in seismological laboratories. However, those instruments are for the most part sensitive devices designed to record distant earthquakes giving rise to extremely small ground motions. If a strong earthquake should occur near the station, the instruments would read off-scale, or might even, as in Tokyo in 1923, be thrown off their bases onto the

Even if a structure is well built, a poorly chosen site can lead to disaster in an earthquake, as almost happened at this hospital in Anchorage. Note the scars of old landslides to the right of the latest break.





This building in Agadir, Morocco, collapsed during an earthquake, although the ground remained firm. Another "structure," the telephone pole, was unharmed.

floor. Earthquake engineers must thus design and install their own rugged instruments specifically for the purpose of recording big earthquakes.

Recording strong ground motion

A special strong-motion accelerograph has been designed for recording three components of the ground acceleration versus time during strong earthquakes. Because the recording paper must move fairly rapidly to permit the analysis required by the engineer, it is not feasible to run the paper continuously as in seismological instruments. The instrument must be triggered by the earthquake which is to be recorded. This is done by a starting pendulum, which at the beginning of the ground motion makes an electric contact to start the photographic paper and turn on the recording light.

One of the biggest deficiencies of the present engineering studies of earthquakes is the lack of a sufficient number of such instruments. In order to give a usable record, the device must be located within 20 to 30 miles of a large earthquake. The area to be covered is immense, and thousands of instruments are needed where only hundreds exist at present.

Because of this lack of instruments, for only one recent, destructive earthquake—Niigata—has a record of the strong ground motion occurring in the region of damage been obtained. Of course this lack of basic data hampers studies of what happened, since in examining ruins one is often not sure whether the damage was caused by a heavy ground motion or by an especially weak structure.

The U.S. Coast and Geodetic Survey maintains a network of recording instruments, which includes 15 accelerographs in Alaska installed since 1964. Unfortunately, there were no instruments in Alaska to measure the destructive ground motions of the 1964 earthquake. Because of the limited area of coverage of each instrument and the small probability of occurrence of a strong earthquake sufficiently near any particular instrument, such networks must be operated for many years to accumulate useful data. There is a concentration of instruments in San Francisco and Los Angeles where there are many important structures on various foundation conditions. In addition, several buildings in San Francisco and Los Angeles have instruments in upper-story positions to record the behavior of the building during earthquakes. Such simultaneous measurements of ground motion and building response make it possible to consider a strong earthquake as a full-scale, dynamic test of the structure, from which significant dynamic properties can be computed.

In spite of the small number of instruments, a number of excellent records of strong ground motion have been obtained. One, the El Centro 1940 earthquake record, has become in a sense a standard earthquake for all workers in the field. A technical paper on the subject from any seismic country (such as Japan, Russia, Chile) will probably refer to it.

The El Centro earthquake had a maximum horizontal acceleration of about one-third the acceleration of gravity. George Housner, Caltech professor of civil engineering and applied mechanics, has made a special study of the maximum horizontal acceleration that might be expected close to a fault on firm alluvium during an earthquake, and he has concluded that it is of the order of one-half the acceleration of gravity. There are reasons for supposing that the properties of the earth's crust are such

continued on page 24

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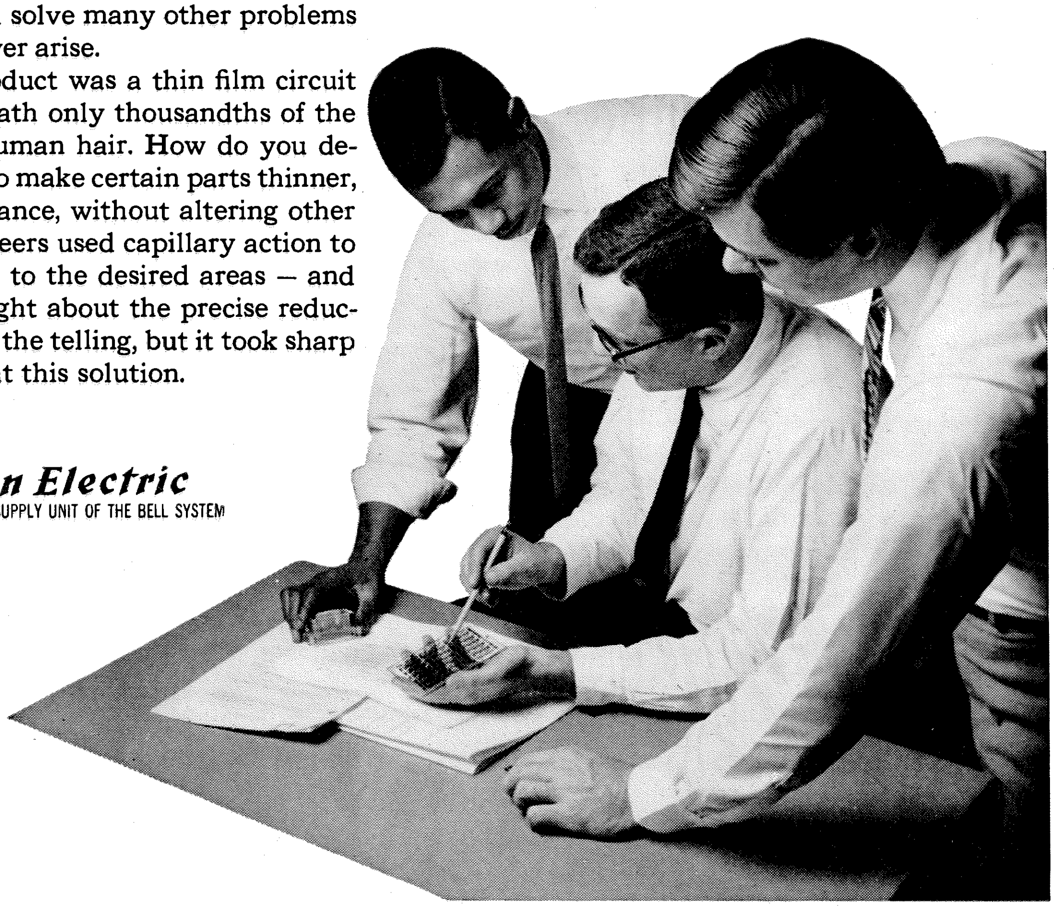

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that more destructive shaking is unlikely or even impossible. Similarly, the maximum time duration of strong shaking is of the order of 45 seconds, although the shaking may be felt for a longer period.

Designing for Safety

A typical building, in the absence of earthquakes or wind, supports its own weight and contents as vertical loads. The effect of an earthquake is mainly to apply horizontal loads to the building. As a first approximation, these horizontal forces are proportional to the weights of the floors, and also to the ground acceleration. A secondary effect is a modification of the vertical loads because of vertical accelerations, but this is not usually as important a factor as the horizontal force.

To illustrate the potentially destructive nature of a horizontal force, consider a simple structure formed by placing a beam on top of two columns without connections. Such a structure might adequately support a vertical load, but could easily be toppled by a horizontal load. A simple way to cure this difficulty would be to connect the members together so that when a horizontal force acts, the structure perhaps bends, but does not collapse. This illustrates one of the most important principles of earthquake-resistant design—that the structure should be firmly connected together so that it acts as a unit. This may seem to be such an obvious consideration that it hardly needs to be mentioned. Nevertheless, failure to remember it is the basic cause of much earthquake damage, as was illustrated by a number of instances of complete collapse during the Alaska earthquake.

A second simple type of difficulty may exist when two different buildings are close together. Being different, the two buildings are likely to vibrate in a different way during an earthquake, one zigging while the other zags. The consequent pounding of the two buildings can do severe local damage, and this has often been noted in past earthquakes. One cure, of course, is to provide a sufficient clearance between the structures to prevent contact.

A rather more complicated difficulty can be illustrated by an L-shaped asymmetrical building, where one part of the building is much stiffer than the other. Differences in the way in which the two sections vibrate may set up a damaging condition at the juncture of the two sections. This does not mean that asymmetrical buildings should not be built, but special provisions should be made to strengthen them at critical sections.

Much earthquake damage can be traced to a relatively few basic design errors such as those just mentioned. The cure for such difficulties is more widespread dissemination of information among architects and engineers.

Among the steps taken to ensure safe structures, perhaps the most important is the establishment of building codes or regulations containing directions for earthquake-resistant design and construction. A properly formulated building code embodying current knowledge in the field, backed up by legally enforced inspection and control, can go a long way toward assuring public safety during earthquakes. Such building codes are not as common or as comprehensive as is often supposed.

The most widely used building code in the west is the Uniform Building Code of the Pacific Coast Building Officials Conference. This code, which covers all aspects of construction, is issued in a standard form that can be legally adopted by various municipalities and government agencies. At present some 650 such agencies have officially adopted it. However, the existence of the standard code does not mean that all cities have officially adopted it, or that, if adopted, it is effectively enforced. The universal experience of all countries has been that an earthquake code itself without a vigorous and continuous inspection and enforcement policy is of little use. In any given region, therefore, the question to ask is not whether an earthquake code exists, but whether or not there is an active local group backing it.

The first effective earthquake-resistant building code in California appeared in 1927 in the first published edition of the Uniform Building Code. Since then the code has been revised every few years to keep up with the increasing knowledge. The Long Beach earthquake of 1933 was the real breakthrough in the development of regulation and control. As a direct consequence of the great damage to school buildings in the Long Beach earthquake, the Legislature of the State of California, through the Field Act, assigned to the State Division of Architecture the authority and responsibility, under the police power of the state, to approve or reject plans and specifications and to supervise construction of all public school buildings. The State Division of Architecture has carried this assignment out with great effectiveness, and all California school buildings built since 1933 have been

continued on page 26

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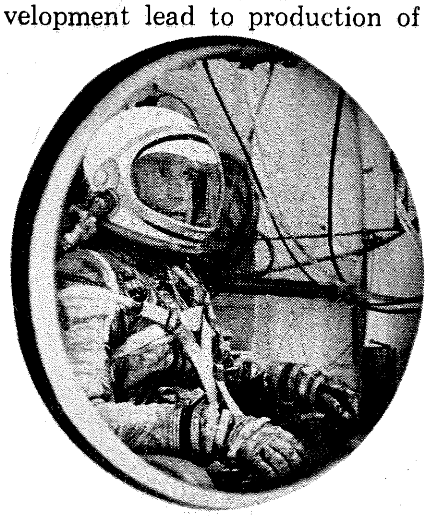

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designed and constructed under careful supervision with respect to earthquake forces.

For many years both San Francisco and Los Angeles operated under building codes different from each other and from the Uniform Building Code. In 1960 a special Seismology Committee of the Structural Engineers Association of California developed a standard earthquake code which now has almost universal acceptance, so that Los Angeles, San Francisco, and the Uniform Building Code all have virtually the same earthquake provisions.

It is not to be supposed that an earthquake code is a comprehensive treatise on earthquake-resistant design. The complete earthquake section of the Uniform Building Code runs to only a dozen or so pages; it is only a guide for a trained and experienced designer. Such building codes must always presuppose the existence of a high-level professional activity in the area.

Earthquake engineering research at Caltech

For many years basic problems of the behavior of structures subjected to earthquake forces have been studied at Caltech. One type of problem which has been solved involves a simple one-story structure consisting of a mass mounted on horizontally flexible columns. It is supposed that the ground has the acceleration of a measured past earthquake, and a calculation of the maximum deflection of the building with respect to the ground is made. This maximum deflection is plotted against the ratio of mass to stiffness, so that for any given structure an idea of the deformation caused by the earthquake can be worked out. Whether or not the calculated deformation is dangerous for the structure must of course be further examined. Analyses have been made for all of the past strong earthquakes for which good ground acceleration records are available. By a comparison of the results of such calculations, it has been possible to express certain average properties of past strong earthquakes in a form that is useful for design purposes.

A second research field in which the Caltech group has been active is that of the dynamic testing of full-scale structures. Because of the difficulty and expense of making tests of large structures, there are many gaps in the basic knowledge of the dynamic characteristics of such things as multi-story buildings, bridges, and dams. To learn more about such problems, a special system of vibration generators has been developed at Caltech under the sponsorship of the California State Division of Architecture. A test program was carried out in cooperation with the Los Angeles Department of Water and Power in which a set of four vibration generators was mounted at the crest of an earth-filled dam. With this system, a sinusoidally varying horizontal force of 20,000-pound amplitude can be produced over a range of accurately determined frequencies. By measuring the motion of the dam at various frequencies, one can calculate the dynamic physical properties of the dam in the as-constructed condition. Similar tests have been made in several multi-story buildings and in various special structures, such as large rocket test stands, and a considerable clarification of the dynamic properties of structures has resulted.

Current design philosophy does not attempt to avoid all damage, but does intend to prevent the kind of complete collapse that would lead to injury or loss of life. Once this has been accomplished, the designer hopes to balance repair costs against the increased initial building costs that would have been necessary to prevent damage completely. This is clearly a statistical problem which requires for its satisfactory solution improvements in knowledge of the probability of occurrence of earthquakes in a particular region and of the true dynamic behavior of structures.

If all existing knowledge can be employed and good construction techniques and high-quality materials can be ensured, there is no reason why structures cannot be made safe in the above sense against the most violent earthquakes. The principal danger in the world today comes from the millions of old structures that were built either before present knowledge existed, or under economic conditions that for various reasons did not permit suitable quality construction. Unfortunately, a large fraction of the world's population must live in houses that would inevitably collapse in even a small earthquake. This is a problem that is being investigated by several UNESCO committees, but as yet no satisfactory solution to this immediate practical problem seems to be in sight.

Although there are a number of such pressing practical problems remaining to be solved, it may be said that the basic knowledge of the effects of earthquakes on structures is at present extensive and is steadily advancing. It may thus be expected that, with the proper effort, the world will ultimately be relatively free of serious earthquake hazards.

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If you're looking for the same rewards that appealed to Mr. Weisz in his new career, write a personal letter to: Charles H. Schaaff, President, Mass Mutual, Springfield, Massachusetts. He's always interested in hearing from a good man!

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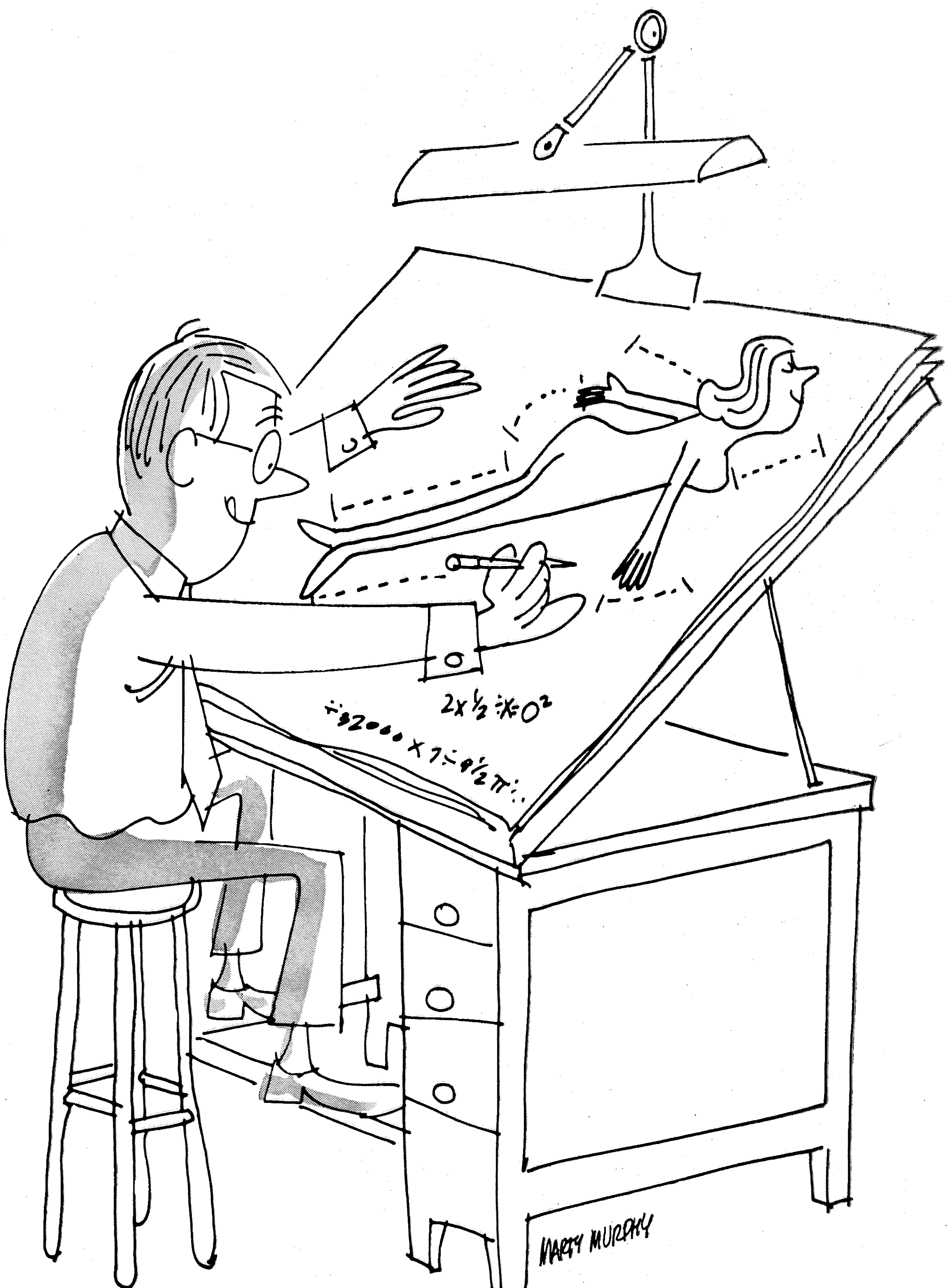

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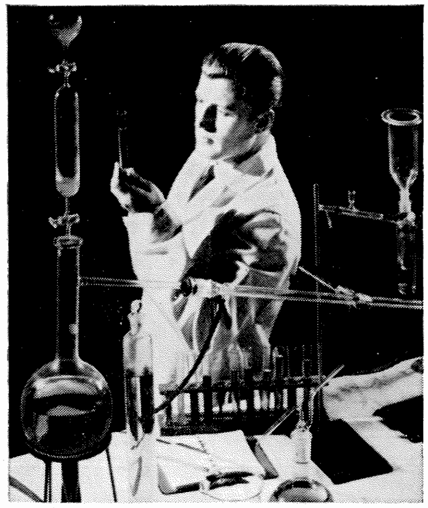

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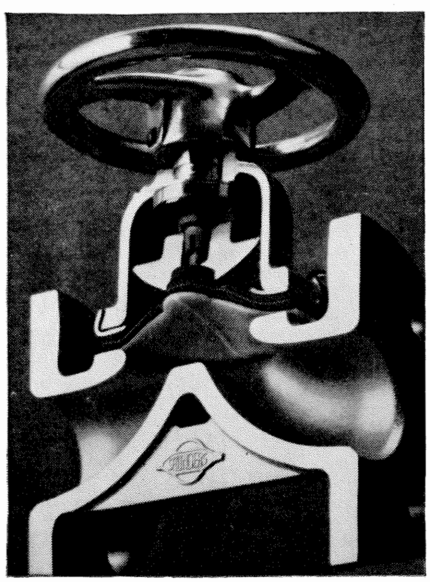

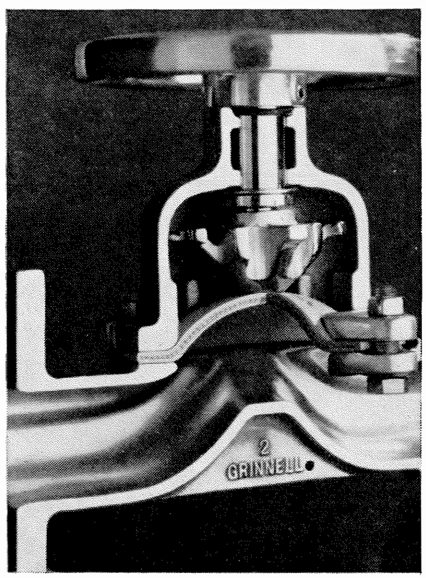

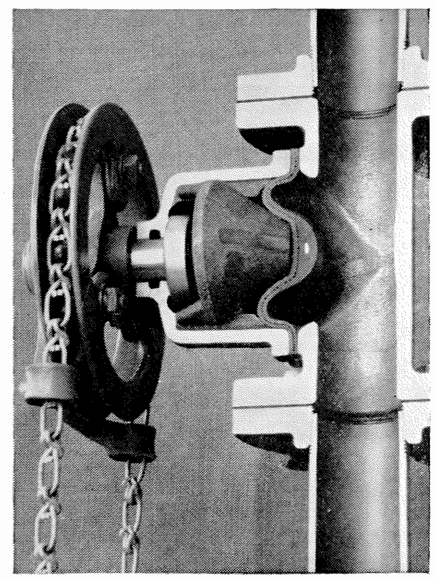

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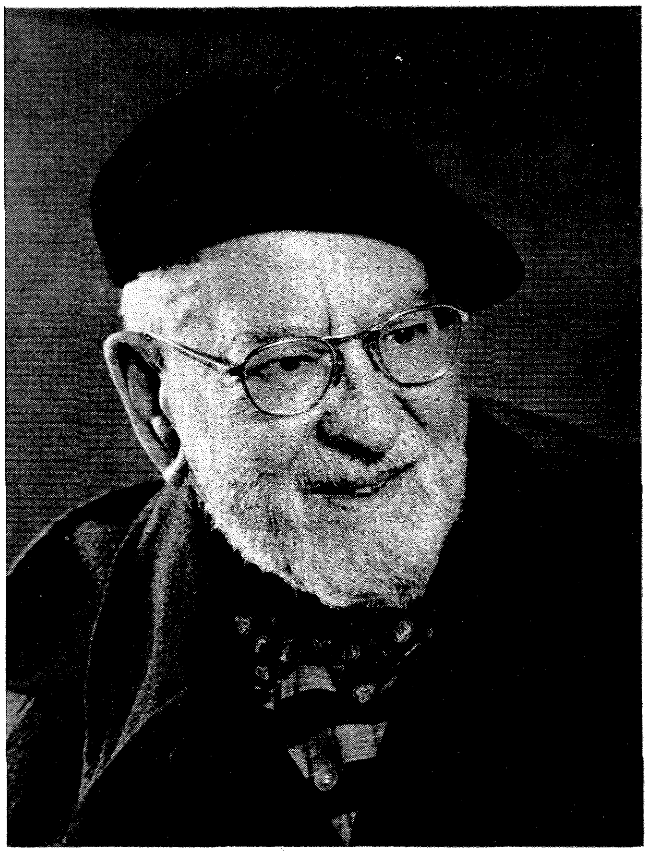

PAUL S. EPSTEIN

(1883-1966)

Paul Sophus Epstein, professor emeritus of theoretical physics, died at his home in Pasadena on February 8. He was 83 years old.

"The death of Professor Epstein marks the ending of an era at the California Institute," said President Lee A. DuBridge. "A distinguished theoretical physicist, he played an influential part in the foundation of the present physics division. From his arrival in 1921 until his retirement as professor emeritus in 1953, several generations of Caltech students were guided and inspired by his warm and vital interest in his field and in their lives. He occupies a special place in the history and progress of the Institute."

Paul Epstein was born in 1883 in Warsaw. He was graduated from the Imperial University of Moscow in 1906, and in 1909 got the equivalent of a PhD, becoming assistant professor of physics there. A year later he went to Munich, where he studied the theory of electromagnetic waves, in particular the theory of diffraction, with Arnold Sommerfeld. In 1919 he went to Zurich University where he submitted a paper on the theory of the Stark effect as his thesis for an appointment as assistant professor of physics. He was at Leyden University as assistant to H. A. Lorentz when he met R. A. Millikan, who was scouting for Caltech personnel, and in 1921 he came to Caltech. Epstein's work from about 1910 to 1920 in the development of quantum mechanics, with that of Sommerfeld and Niels Bohr, was an important contribution to the development of atomic theory.

At Caltech he began by teaching all phases of theoretical physics, but eventually confined his teaching to thermodynamics and statistical mechanics. His work led him to areas of applied theoretical physics, which occupied most of his Caltech career. Among his later contributions were studies of electromagnetic waves around the earth, the stability of air bubbles in water, and the theory of absorption and scattering of sound waves in the atmosphere. During the war he studied the absorption and scattering of sonar waves in the ocean.

Dr. Epstein was a member of the National Research Council from 1928-30, a member of the National Academy of Sciences, a fellow of the American Physical Society, of the American Association for the Advancement of Science, and of the Societé Francaise de Physique. His broad interests ranged over the fields of art, music, history, and psychoanalysis, and his friends included such men as the artists Paul Klee, Vassily Kandinsky, and Franz Marc. He was also a friend of the distinguished psychiatrist Sigmund Freud. He was a trustee of the Psychoanalytic Institute of Los Angeles, a board member of the Psychoanalytic Study Group of Los Angeles, and he had been a member of the Coleman Chamber Music Association of Pasadena since 1921.

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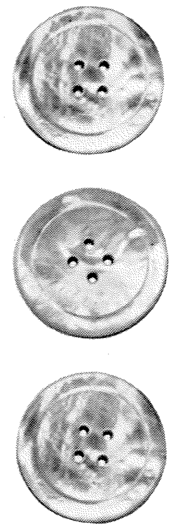

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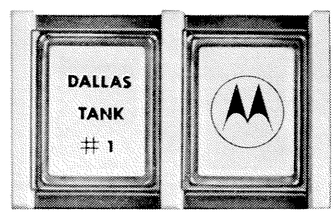

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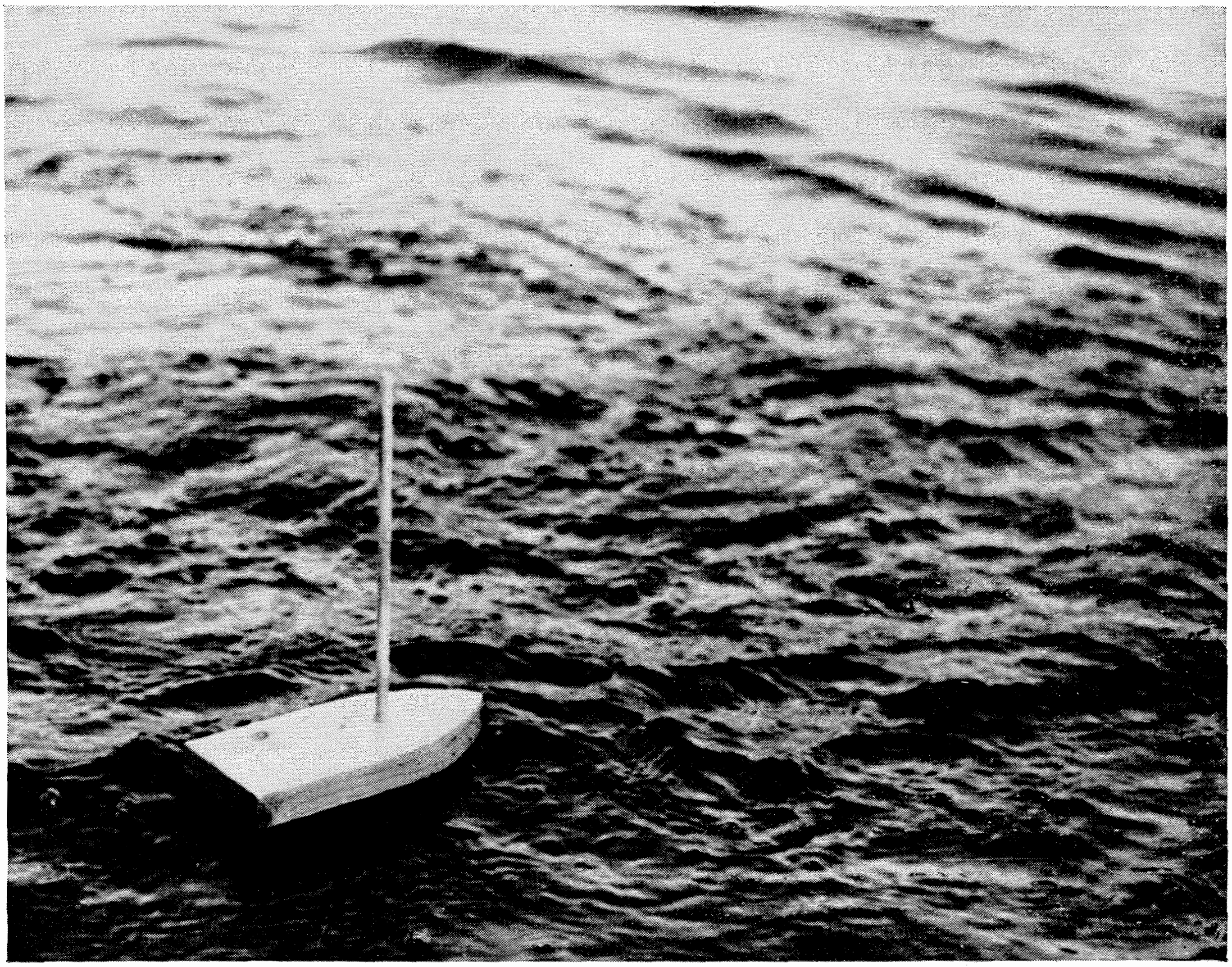

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Personals

1923

BERNARD G. EVANS, who has been in the real estate field for more than 40 years, is currently doing valuation work for the proposed Malibu nuclear power plant site and for the expansion of the Los Angeles International Airport. He plans to retire in June but will continue to do consulting.

1925

FRANK CLAYTON writes from Ft. Worth, Texas, that he is still chief plant engineer for the General Dynamics Corp. division there, involved in building F-111 fighter-bombers. He is also a national director of the National Society of Professional Engineers.

1928

SYDNEY B. INGRAM, PhD, recently celebrated his 35th year of service with the Bell Telephone Laboratories. He is director of the company's technical employment center in Murray Hill, N.J. Before 1960 he was director of education and training, in charge of graduate and undergraduate educational programs administered by Bell.

1929

DUANE E. ROLLER, PhD, professor emeritus of physics at Harvey Mudd College in Claremont, died on December 24 at the age of 71. A member of the initial group of seven faculty members when the college opened in 1957, Roller had been retired since 1964 from his position as head of the department of physics. Earlier in his career, Roller taught at the University of Oklahoma in Norman, at Hunter College in New York, and at Wabash College in Crawfordsville, Ind., and was the first editor of the American Journal of Physics from 1933 to 1949. He was also assistant director of the Hughes Aircraft research and development lab and on the senior technical staff of Ramo-Wooldridge Corp. He leaves his wife, Doris, and a son, Duane, of Norman, Oklahoma.

1931

CAPT. PERRY M. BOOTHE, USN, MS '32, has been assigned to Saigon for duty in construction planning for U.S. troops in Vietnam. Boothe recently spent 27 months in London as director of the European division of the Bureau of Yards and Docks, a job involving all Navy construction and facility maintenance from Ethiopia to Northern Ireland. His family will remain in Arlington, Va., during his Vietnam assignment.

1934

NICK T. UGRIN, vice president of industrial relations of the Union Oil Company of California, has been elected president of the Unemployment Insurance Association for 1966.

1936

JOHN Y. BEACH, PhD, supervisor of the analytical and physical measurements section of the Chevron Research Co. in Richmond, Calif., is now chairman of the American Chemical Society's California section.

1943

ARTHUR V. CARLSON, MS, a meteorologist at the U.S. Army Electronic Proving Ground in Ft. Huachuca, Ariz., recently received special recognition from the Department of Defense for his role in a value engineering study on radiosondes. The five-man group with which he worked was credited with a potential annual saving to the government of four million dollars. The project involved devising a new parachute system for balloon-borne radiosonde equipment used by meteorology technicians to measure atmospheric conditions. Carlson has been at Ft. Huachuca since 1954. He and his wife have three children: Gayle 16, Gregory 12, and Kirk 9.

JOHN ELDRIDGE CUSHING JR., PhD, professor of immunology at the University of California at Santa Barbara, was married on December 18 to Anne Hyde Greet. She is assistant professor of French at the university.

1946

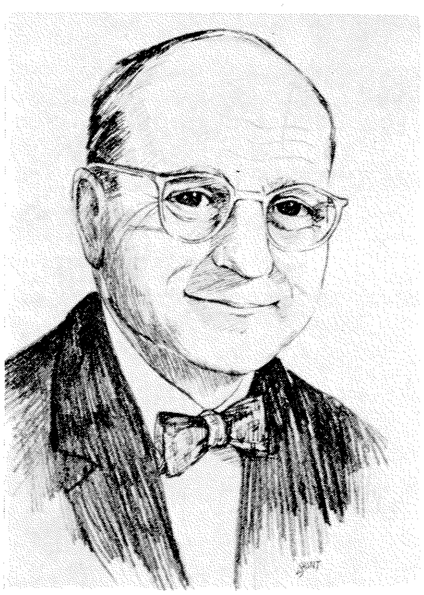
FRANK S. GATES, who is chief engineer at the El Paso refinery of the Chevron Oil Company, writes that he and his family (five children) have recently moved into a new home. Gates has been in El Paso since 1964.

1949

DON E. HIBBARD, his wife, and four children, recently returned to the U.S. after eight years in South America. He writes that "Caracas had the most enjoyable weather – like southern California before smog – Maracaibo had the most oil, and Bogota, the most beautiful green countryside and mountains." The Hibbards are now in Miami, Fla., where Don works in a new Caribbean-Central American petroleum evaluation group of the International Petroleum Co.

1951

JOHN R. FEE, a civil engineer with the James Montgomery firm of consulting engineers in Pasadena, is also Major John Fee, executive officer of the 6159th R & D chapter of the United States Army Reserves. This special research and development unit, made up of top ranking men in science and engineering from southern California, studies and tests scientific innovations developed in the services and reports on whether or not the developments would be applicable to military purposes.



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1952

JOHN C. THOMPSON, MS, has been appointed vice president of the Peerless Manufacturing Co. of Dallas.

DAVID L. HANNA, an associate with Booz, Allen & Hamilton International, Inc., in Lahore, West Pakistan, writes: "My family was evacuated from Lahore to Beirut during the India-Pakistan border war which we could see and hear from our house. Happily, the dependents were allowed to return on Dec. 10, so we all enjoyed a thankful Christmas together."

1955

JOSEPH D. BENNETT, MS, a senior structures engineer with General Dynamics Corp. in Ft. Worth, recently joined the flight flutter test section of the F-111 dynamics group and will be moving to Edwards AFB in California to take part in testing the new fighter plane.

1959

BERNARD C. REARDON, MS, PhD '64, and his wife, Iliana, are living in Cork, Ireland, where Bernard was born and spent his boyhood. The Reardons were married last December 27 in Pasadena.

GEORGE LOGEMANN is an assistant

NORMAN ZABUSKY, PhD, '59 supervisor of the plasma physics research group at the Bell Telephone Laboratories, Inc., Whippany, N.J., is co-director of the International School of Nonlinear Mathematics and Physics to be held from June 27 to August 5, 1966, at the Max Planck Institute of Physics and Astrophysics in Munich, Germany. The school, sponsored by the Advanced Study Institute Programme of NATO, will present a broad look at natural nonlinear phenomena and attempt to abstract unifying concepts and methods. Courses will be divided into two, separate, three-week sessions, the first dealing with physics and the second with mathematics. Enrollment is open to individuals currently doing research in nonlinear mathematics or physics, who have completed the equivalent of course requirements for a PhD. Tuition is $225 for each session; scholarships and assistantships will be awarded to selected individuals from academic institutions. Deadline for applications is March 1.

Write: Dr. N. J. Zabusky, Nonlinear School, Bell Telephone Laboratories, Inc., Whippany, N.J.

York University, where he is helping prepare a computer sciences graduate program. He also is developing computer systems for the university's Institute for Computer Research in the Humanities.

1961

CAPT. WARREN L. SIMMONS, USAF, MS, who is an instructor in physics and assistant varsity golf coach at the Air Force Academy in Colorado Springs, won first place in the Air Force World-Wide Golf Tournament held at Maxwell AFB in Alabama last August. As winner, he went on to represent the Air Force against the Army, Navy, and Marines at the Interservice Golf Tournament at Cherry Point, N.C., in September, and captured another first place title. Simmons won by 11 strokes – 6 under par for 72 holes.

1962

ROBERT E. CARTER, PhD, is lecturer in organic chemistry at the University of Goteborg in Sweden. He also acts as part-time consultant for a drug company there.

KIP S. THORNE is a National Science Foundation postdoctoral fellow at Princeton University's Palmer Physical Laboratory. His article, "Gravitational Collapse and the Death of a Star," appeared in

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