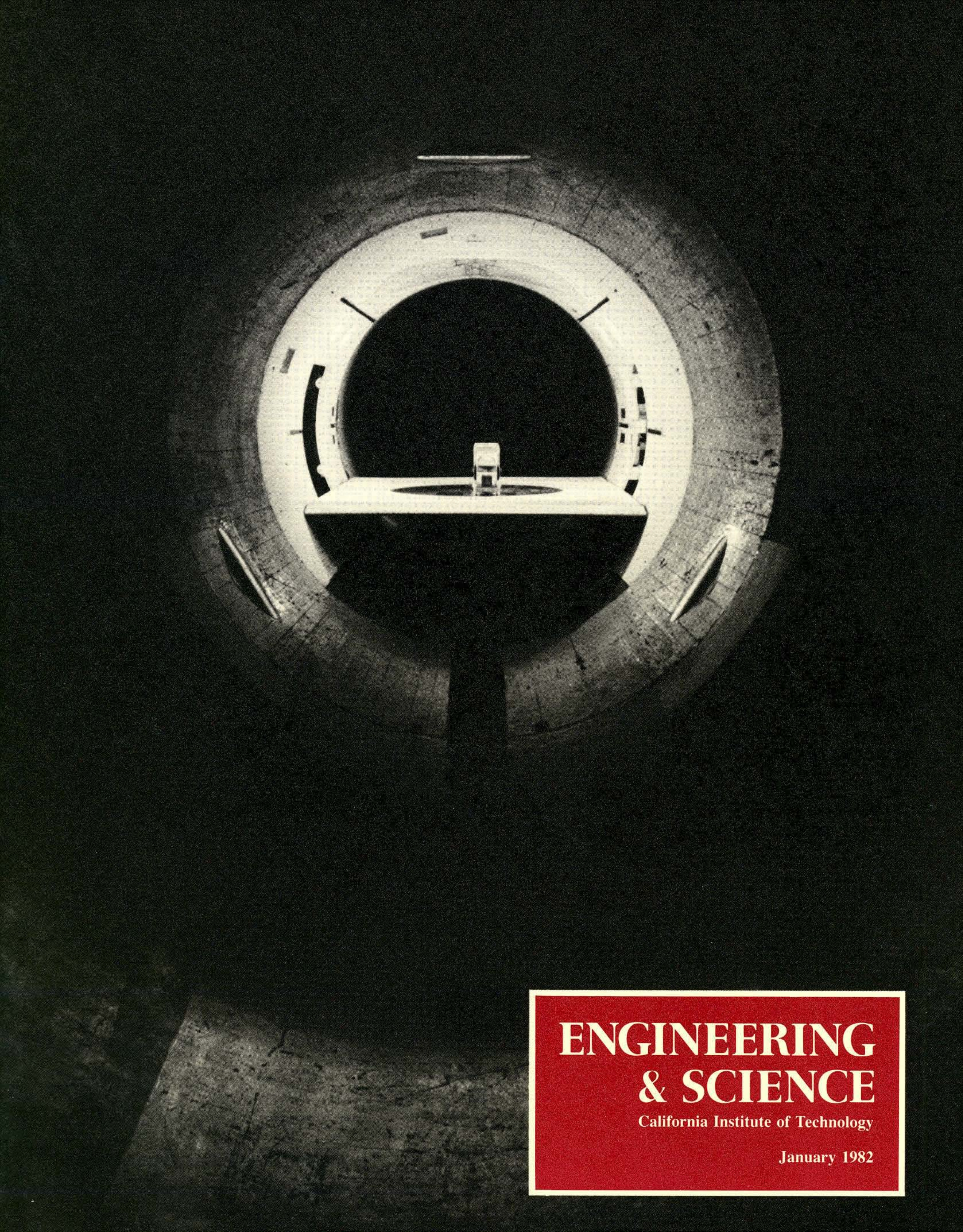
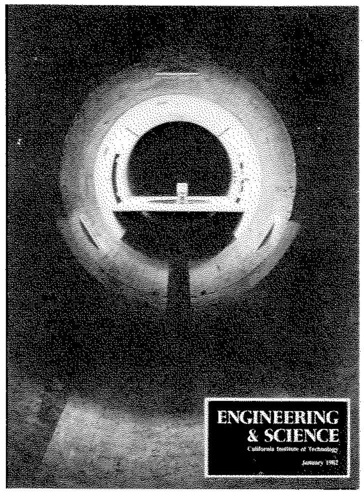


ENGINEERING & SCIENCE

California Institute of Technology

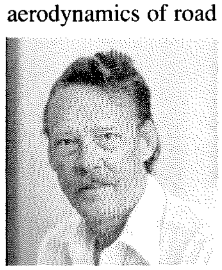
January 1982

In This Issue



Tunnel Vision

On the cover — a truck model undergoes aerodynamic testing in the 10-foot wind tunnel. Originally designed and built over 50 years ago for research with aircraft, the wind tunnel has also been used for more than 20 years to study the aerodynamics of road vehicles.



The person responsible for bringing cars and trucks into Caltech's wind tunnel was William H. Bettes. He first came here in 1956 as a consultant with the Southern California Cooperative Wind Tunnel, which was managed by Caltech. He began to work part time for the Institute in 1958 and full time in 1960. (He also earned his MS in aeronautics from Caltech in 1963.) By the time he came here, however, Bettes was getting "bored with airplanes," and, since he had "always been interested in cars," the wind tunnel found a new application.

Designers of cars built for speed have long known the advantages of wind tunnel research (for example, the land speed record car *Goldenrod,* whose 1965 record still stands, was tested in the Caltech tunnel), but it has been only recently that the major automobile manufacturers have begun to look at aerodynamic design as a way to cut fuel consumption. Overcoming aerodynamic drag accounts for half of the fuel consumption in highway driving.

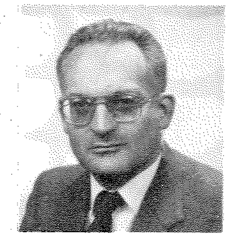
So it was quite a timely topic that Bettes, who is now director of experimental facilities and manager of GALCIT, presented in his October Watson lecture. An article adapted from that talk, with some of the technical data omitted, "The Aerodynamic Drag of Road Vehicles — Past, Present, and Future," begins on page 4.

Cosmic Connection

Research on cosmic rays — atomic nuclei stripped of their electrons bouncing around our galaxy at speeds almost up to the speed of light — has a long history at Caltech. Even before he came here, Robert A. Millikan had begun his studies of this "penetrating radiation," which he later proved came from the cosmos and named "cosmic rays." Although he mistakenly believed they were photons rather than charged particles, Millikan's initial work spawned research that began to reveal the characteristics of these and other particles.

Caltech scientists are still among the leaders in catching cosmic rays and deciphering the messages they carry about the universe and its formation. Since the atmosphere stops most cosmic rays, sophisticated detectors are being packed off into space — still on balloons as in Millikan's day, but also on satellites and other spacecraft. Voyager 1 is now on its way out of the solar system to send back the first data on low-energy galactic cosmic rays. In "Star Stuff," beginning on page 15, News Bureau Director Dennis Meredith describes some of these current experiments and the mysteries they are solving, as well as some of the new riddles they are posing.

Castles in France



Last spring a conference on "Family and Property in Traditional Europe," sponsored by the Division of the Humanities and Social Sciences with the support of the Weingart Foundation, brought together historians from the U.S., Canada, and Europe at Caltech and the Huntington Library. The five-day program included, in addition to the scholarly seminars, public lectures by some of the visiting scholars.

One of these lectures concerned a new slant on the political role of the earliest French castles, presented by Michel Bur, professor of medieval history at France's University of Nancy II. An article adapted from it, "The Motte and Bailey Castle: Instrument of a Revolution," appears on page 11.

Bur is an archaeologist as well as a historian, and when he found insufficient information in written records, he set out to find more evidence in the ground. And the remains of the 10th- and 11th-century castles are quite literally only ground, little hills barely distinguishable from the ones put there by nature. As the pioneer of this archaeological approach to French history, he currently heads a national research team compiling a catalog of fortified dwellings in France.

He is also writing a book describing the history of a medieval family through the changes in its castle or residence, and he is working with John Benton, professor of history at Caltech, on an edition of the charters of the counts of Champagne.

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PICTURE CREDITS: Cover, 21, 25-28 — Chris Tschoegl/15, 18 — Andrew Buffington.

Engineering & Science (ISSN 0013-7812) is published five times a year, September, November, January, March, and May, at the California Institute of Technology, 1201 East California Boulevard, Pasadena, California 91125. Annual subscription $7.50 domestic, $15.00 foreign, $20.00 foreign air mail, single copies $1.50. Controlled Circulation postage paid at Pasadena, California. Published by the California Institute of Technology and the Alumni Association. Postmaster: Send change of address to Caltech, 1-71, Pasadena, CA 91125.

ENGINEERING & SCIENCE

CALIFORNIA INSTITUTE OF TECHNOLOGY | JANUARY 1982 — VOLUME XLV, NUMBER 3

ALUMNI FLIGHTS ABROAD

This program of tours, originally planned for alumni of Harvard, Yale, Princeton, and M.I.T., is now open to alumni of California Institute of Technology as well as certain other distinguished colleges and universities. Begun in 1965 and now in its sixteenth year, it is designed for educated and intelligent travelers and planned for persons who might normally prefer to travel independently, visiting distant lands and regions where it is advantageous to travel as a group.

The program offers a wide choice of journeys to some of the most interesting and unusual parts of the world, including Japan and the Far East; Central Asia, from the Khyber Pass to the Taj Mahal and the Himalayas of Nepal; the surprising world of South India; the islands of the East, from Java and Sumatra to Borneo and Ceylon; the treasures of ancient Egypt, the world of antiquity in Greece and Asia Minor; East Africa and Islands of the Seychelles; New Guinea; the South Pacific; the Galapagos and South America; and more.

REALMS OF ANTIQUITY: A newly- expanded program of itineraries, ranging from 15 to 35 days, offers an even wider range of the archaeological treasures of classical antiquity in Greece, Asia Minor and the Aegean, as well as the ancient Greek cities on the island of Sicily, the ruins of Carthage and Roman cities of North Africa, and a comprehensive and authoritative survey of the civilization of ancient Egypt, along the Nile Valley from Cairo and Meidum as far as Abu Simbel near the border of the Sudan. This is one of the most complete and far-ranging programs ever offered to the civilizations and cities of the ancient world, including sites such as Aphrodisias, Didyma, Aspendos, Miletus and the Hittite citadel of Hattusas, as well as Athens, Troy, Mycenae, Pergamum, Crete and a host of other cities and islands of classical antiquity. The programs in Egypt offer an unusually comprehensive and perceptive view of the civilization of ancient Egypt and the antiquities of the Nile Valley, and include as well a visit to the collection of Egyptian antiquities in the British Museum in London, with the Rosetta Stone.

SOUTH AMERICA and THE GALAPAGOS: A choice of itineraries of from 12 to 29 days, including a cruise among the islands of the Galapagos, the jungle of the Amazon, the Nazca Lines and the desert of southern Peru, the ancient civilizations of the Andes from Machu Picchu to Tiahuanaco near Lake Titicaca, the great colonial cities of the conquistadores, the futuristic city of Brasilia, Iguassu Falls, the snow-capped peaks of the Andes and other sights of unusual interest.

EAST AFRICA—KENYA, TANZANIA AND THE SEYCHELLES: A distinctive program of 5 outstanding safaris, ranging in length from 16 to 32 days, to the great wilderness areas of Kenya and Tanzania and to the beautiful islands of the Seychelles. The safari programs are carefully planned and comprehensive and are led by experts on East African wildlife, offering an exceptional opportunity to see and photograph the wildlife of Africa.

THE SOUTH PACIFIC and NEW GUINEA: A primitive and beautiful land unfolds in the 22-day EXPEDITION TO NEW GUINEA, a rare glimpse into a vanishing world of Stone Age tribes and customs. Includes the famous Highlands of New Guinea, with Sing Sings and tribal cultures and customs, and an exploration of the remote tribal villages of the Sepik and Karawari Rivers and the vast Sepik Plain, as well as the North Coast at Madang and Wewak and the beautiful volcanic island of New Britain with the Baining Fire Dancers. To the south, the island continent of Australia and the islands of New Zealand are covered by the SOUTH PACIFIC, 28 days, unfolding a world of Maori villages, boiling geysers, fiords and snow-capped mountains, ski plane flights over glacier snows, jet boat rides, sheep ranches, penguins, the Australian "outback," historic convict settlements from the days of Charles Dickens, and the Great Barrier Reef. Optional visits can also be made to other islands of the southern Pacific, such as Fiji and Tahiti.

CENTRAL ASIA and THE HIMALAYAS: An expanded program of three itineraries, from 24 to 29 days, explores north and central India and the romantic world of the Moghul Empire, the interesting and surprising world of south India, the remote mountain kingdom of Nepal, and the untamed Northwest Frontier at Peshawar and the Punjab in Pakistan. Includes the Khyber Pass, towering Moghul forts, intricately sculptured temples, lavish palaces, historic gardens, the teeming banks of the Ganges, holy cities and picturesque villages, and the splendor of the Taj Mahal, as well as tropical lagoons and canals, ancient Portuguese churches, the snow-capped peaks of the Himalayas along the roof of the world, and hotels which once were palaces of maharajas.

THE FAR EAST: Itineraries which offer a penetrating insight into the lands and islands of the East. THE ORIENT, 30 days, surveys the treasures of ancient and modern Japan, with Kyoto, Nara, Ise-Shima, Kamakura, Nikko, the Fuji-Hakone National Park, and Tokyo. Also included are the important cities of Southeast Asia, from Singapore and Hong Kong to the temples of Bangkok and the island of Bali. A different and unusual perspective is offered in BEYOND THE JAVA SEA, 34 days, a journey through the tropics of the Far East from Manila and the island fortress of Corregidor to headhunter villages in the jungle of Borneo, the ancient civilizations of Ceylon, Batak tribal villages in Sumatra, the tropical island of Penang, and ancient temples in Java and Bali.

Prices range from $2,350 to $4,500 from U.S. points of departure. Air travel is on regularly scheduled flights of major airlines, utilizing reduced fares which save up to $600.00 and more over normal fares. Fully descriptive brochures are available, giving itineraries in detail and listing departure dates, hotels, individual tour rates and other information. For full details contact:

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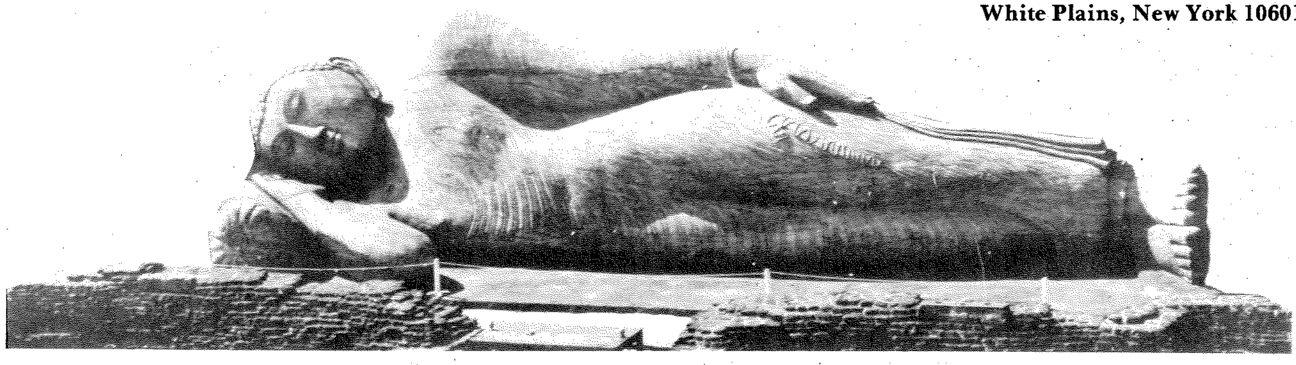


SCIENCE/SCOPE

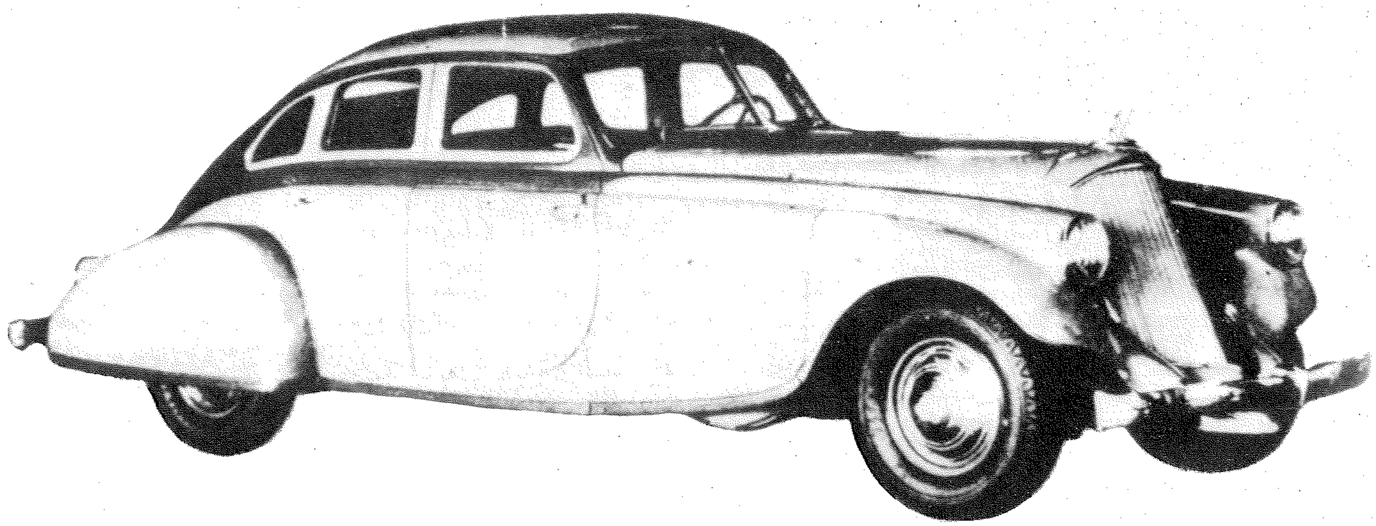
A new all-optical logic device could make many electronics systems immune to effects of natural or man-made "noise," including lightning strikes and radio interference. Hughes scientists have fabricated a high-speed optical device that uses no electronic signals. It is made of discrete components, including four reflecting surfaces and a slab of non-linear material (gallium arsenide). The device has shown optical bistability (flip-flop behavior) with switching times of 3 nanoseconds and switch energies under 100 microjoules. Although propagation delays have kept the device's speed under the theoretical limit up to 10 gigahertz, the speed will be increased by further miniaturizing of the device on an integrated optic chip. The device could be used in fault-tolerance computers, flight control systems, and ultra high-speed signal processors.

A structural and thermal test model of NASA's Galileo Probe is undergoing a series of tests simulating every environment that the Hughes-built probe will experience from launch through descent into the Jovian atmosphere in the late 1980s. The model recently passed a descent simulation with temperatures ranging from -260°F through 240°F and pressures ranging from a vacuum through 235 pounds per square inch -- all in a span of 48 minutes. The Probe contains six instruments that will measure atmosphere characteristics to a depth corresponding to at least 10 times the pressure of air at sea level of Earth. This will be the first sampling of the Jovian atmosphere in an attempt to learn its composition.

Pilots soon may get navigational information from a TV display instead of paper maps. Hughes, under a U.S. Air Force contract, is developing a system that will use a computer to electronically generate and display realistic pictures of terrain and man-made features. The new map will be coupled to an aircraft's navigation system to help the pilot fly fast and low despite bad weather, darkness, and radar jamming. Ultimately, production models of the map could be tailored to meet different mission requirements. One mission, for example, may require roads and highways as navigational checkpoints, whereas another would require navigation with reference to terrain features. The prototype will store 250,000 square miles and use more than 1,500 bits of data to encode each square mile.

Hughes needs graduates with degrees in EE, computer science, physics, ME, and math. To find out how you can become involved in any one of 1,500 high-technology projects, ranging from submicron microelectronics to advanced large-scale electronic systems, contact: College Placement Office, Hughes Aircraft Company, P.O. Box 90515, 100/445/SS, Los Angeles, CA 90009. Equal opportunity employer.

A 100-kilovolt hydrogen ion source will play a vital role in fusion energy studies in the Tokamak Test Reactor at Princeton University. The source will create a 65-ampere beam of deuterium ions that subsequently will be neutralized by charge exchange to produce a beam of fast neutral particles. This neutral beam can cross the intense magnetic field lines that contain the plasma in the reactor. It will fuel and heat the plasma to the point where self-sustained fusion can take place. The reactor, when completed, will use 12 such ion sources. Hughes built the device under contract to the U.S. Department of Energy.



The 1933 Pierce Silver Arrow had many of the aerodynamic features usually credited to the 1934 Chrysler Airflow.

The Aerodynamic Drag of Road Vehicles

Past, Present, and Future

by William H. Bettes

AERODYNAMIC drag is the force opposite to the direction of motion that acts on a body moving through air — say an automobile or a truck — and retards its movement. The engine power, which can be read as fuel consumption, needed to overcome aerodynamic drag makes the aerodynamic design of road vehicles a very timely issue and one that must be considered.

Drag is only one of the aerodynamic forces acting on vehicles; the others are the lift force and the side force. Since these forces and the moments associated with their axes (rolling, yawing, and pitching) are dependent on the square of the velocity of the vehicle relative to the airstream and on some geometric aspects of the vehicle itself, it is useful to describe these forces in terms of nondimensional coefficients that apply over a wide velocity range. While only aerodynamic drag will be discussed here, the other forces and moments should not be neglected in the design stages. For example, the combination of the lift coefficient and the pitching moment coefficient describes how a vehicle will behave on wet roads with respect to hydroplaning. And a combination of the yawing and rolling moment coefficients is used to determine how a car will behave in a crosswind.

The drag coefficient (C_D) is a measure of the vehicle's aerodynamic efficiency. (Aerodynamic drag $= (\rho/2)\, C_D \bullet A \bullet V^2$, where ρ is air density, A is the projected frontal area of the body, and V is velocity.) Even though aerodynamic drag is critically dependent on the velocity, it is only the product C_D times A that the designer can control. The reason aerodynamic losses are so important relative to engine power is that the power required to overcome these losses is a function of the *cube* of the velocity. In most of my discussion I will be considering highway driving, because, at highway speeds, overcoming aerodynamic drag is responsible for more than 50 percent of fuel consumption. In city driving, that is, stop-and-start driving below 20 mph, it is primarily vehicle weight that contributes to fuel consumption; beyond that, in the stage between city and highway (called the urban driving cycle), overcoming aerodynamic drag accounts for approximately 25 percent of fuel consumption.

Wind tunnels have played an important role in determining the aerodynamic drag of road vehicles. Caltech's low-speed wind tunnel with a 10-foot-diameter test section, located in the Graduate Aeronautical Laboratories (GALCIT), was built 51 years ago and has been operating continuously ever since. Essentially all of the early work in this wind tunnel was restricted to aircraft-related research and development, but for the past 24 years it has also been used as a design tool in the development of area lighting, buildings and other structures, wind turbines, oil drilling rigs, life rafts, ships and boats, and ground-proximity vehicles (including hovercraft, trains, trucks, automobiles and motorcycles). The technical material, most of it from our wind tunnel tests, that supports the statements and conclusions in this article was not able to be included here.

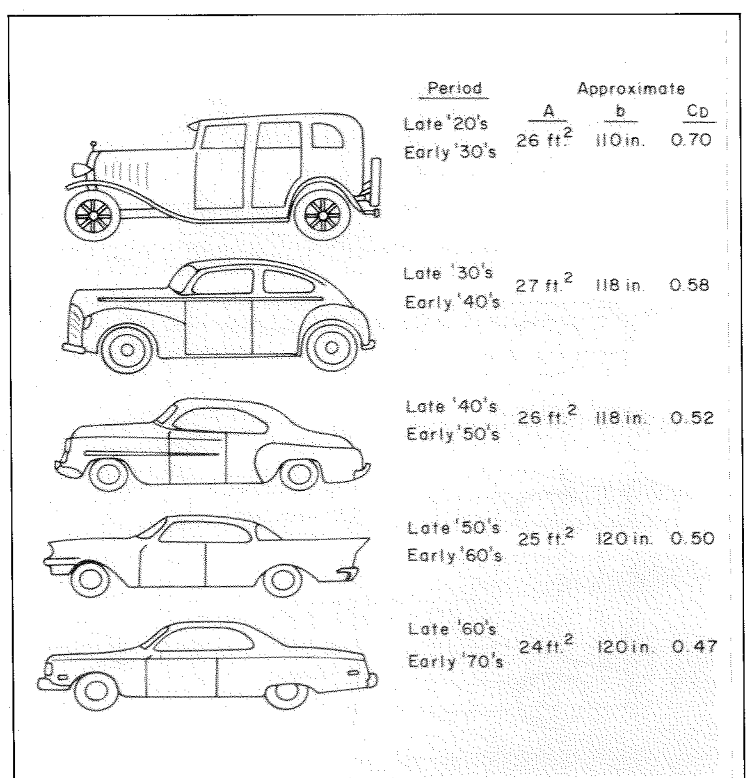
Road vehicles, which are bluff bodies that exhibit substantially separated flows (where the airstream no longer holds onto the body but pulls away) over complex geometries, can only be treated experimentally, since even the most sophisticated analytical means fail to predict the location of flow separation and reattachment. In the design of aircraft, for example, every effort is made to eliminate flow separations over the body, since these separations lead to increased drag. Automobiles, on the other hand, have to be blunt front and rear in order to provide sufficient interior space for seating and still be able to maneuver tight turns and parking. The airflow over an automobile separates in regions of abrupt geometric transitions in front as well as over the large rear area.

Between the time of the earliest automobiles and the late 1920s or early 1930s, automobile design didn't change much. Cars were still a series of boxes, that is, a box for passengers and driver and a box for the engine, with everything else added on — fenders, headlights, spare tire, sunscreen, and so forth. During the late 1920s and early 1930s the better of these cars had a drag coefficient of about 0.7 and a frontal area of about 26 square feet. Ten years later the frontal area had actually increased slightly, due to the blending of the fenders with the body. This blending more than offset the small increase in frontal area, and the aerodynamic drag was on the decrease. By the early 1950s fender and body blending had gone still further, and the front end had grown more rounded. Cars were beginning to get a little lower, the frontal area was beginning to drop a bit, and drag coefficients were still on their way down.

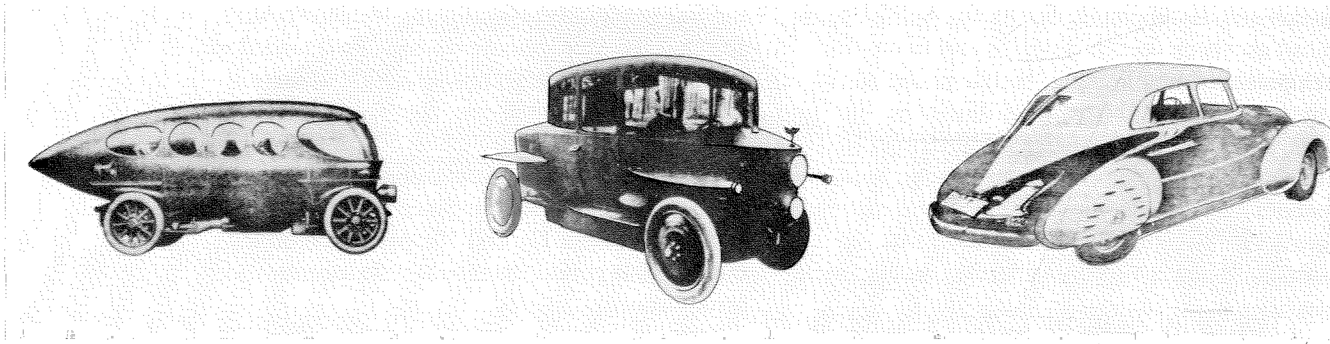
By the early 1960s the blending of bodies, fenders, headlights, and other add-ons was complete, although for styling reasons in the majority of the cars of this period the front edges were sharpened up, causing flow separations in these areas. Still the drag coefficients were on their way down. By the early 1970s the best aerodynamic production cars had drag coefficients as low as 0.47. Because the cars were getting lower, the frontal area was still decreasing. Rounding had come back on the front end, windshields were designed better, and the trailing edges (on the back end) tended to be hard lines, forcing flow separation at these lines. Even though the drag coefficient and the frontal areas steadily decreased between the 1920s and the 1970s, these changes came strictly through styling evolution. Since the price of gasoline was between 11¢ and 30¢ per gallon during much of this period, there was little incentive for aerodynamic efficiency.

There is, however, a particular class of ground vehicles in which a premium *is* placed on low aerodynamic drag — land speed record cars. Automobile racing was a natural activity as soon as two cars appeared on the same road. The first land speed record was set at 39.2 mph by a Belgian car on a road outside Paris in 1898. By 1904 the 100-mph barrier had already been broken. There was considerable activity in land speed record racing around the turn of the century, as the electric cars, the gasoline-powered cars, and the steam-powered cars all vied for supremacy. Since racing sold automobiles, the manufacturers supported this activity.

The 1906 Stanley Steamer, which set the record at a little over 127 mph that year, benefited from good aerodynamic styling of that day. The application of aircraft technology (aircraft engines, lightweight materials, the use of wind tunnels as design tools) to land speed record car design began substantially in the 1920s. But the



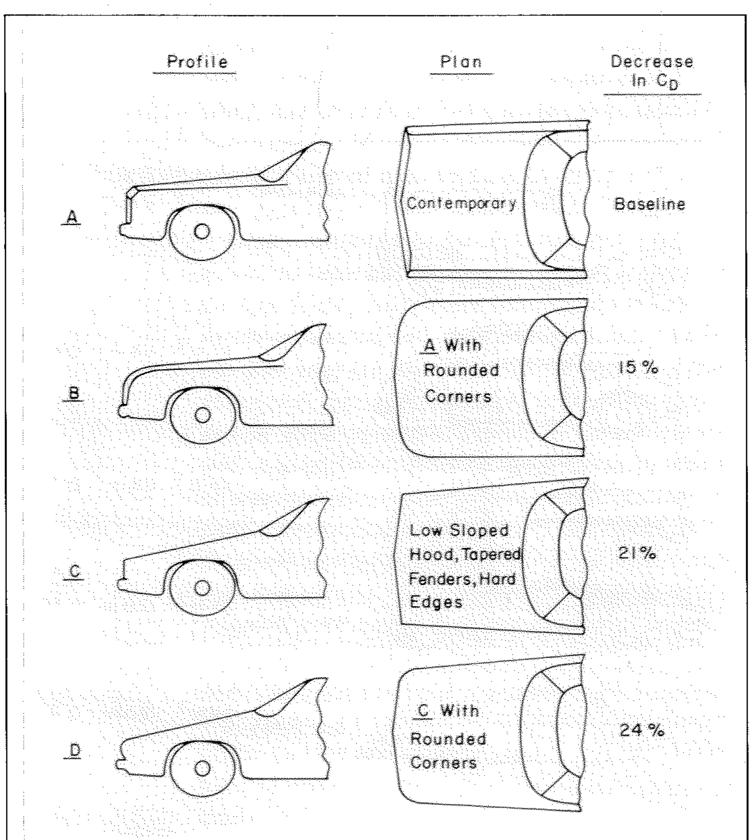
Air drag of typical American full-sized cars. A = frontal area, b = wheelbase, C_D = drag coefficient.



Some examples of early aerodynamic design include (from left) the 1914 Ricotti by Castagno, the 1921 Rumpler, the 1930 Jaray, and the 1913 Bi-Autogo two-wheeler by Booth.

1928 White Triplex is an example of only a limited application of aircraft technology. It used three Liberty aircraft engines with a total horsepower of over 1400 and set a speed record of 207.55 mph in 1928. But no wind tunnel was used during its design, and the aerodynamic work on the car was poor indeed.

In the following year the British Irving car with a single Napier aircraft engine of 925 horsepower brought the record up to over 231 mph. This car did use a wind tunnel in its design program. The current record of 409.28 mph was set in 1965 by the American car *Goldenrod,* and all attempts to break that record in the past 16 years have been unsuccessful. The aerodynamic grooming on the *Goldenrod* was done in the GALCIT 10-foot wind tunnel here on campus.

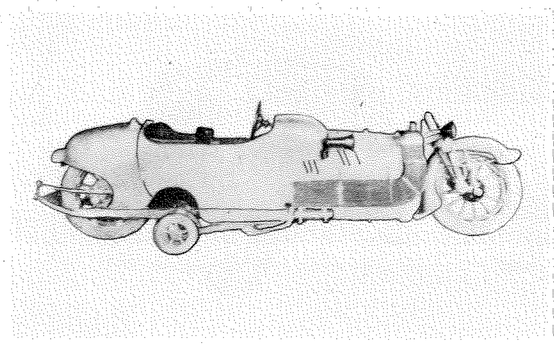


Effects of front-end geometry on drag coefficient.

Since good aerodynamic design is so essential for these land record cars, there is an obvious lesson for designers of passenger automobiles about the importance of aerodynamic drag on the engine power required. At speeds below 45 mph the rolling losses associated with the tires and the weight of the vehicle predominate in the power required for a full-size car. At speeds of 45 mph and above, however, aerodynamic drag consumes by far the most power. For an intermediate-size car, for example, 52 percent of the power required goes toward overcoming aerodynamic drag on the highway (at 55 mph), and 24 percent during urban driving. Tires consume 36 percent of the power in highway driving and 40 percent in the urban driving cycle; the remainder goes into mechanical losses. For a subcompact, 56 percent of the power is needed to overcome aerodynamic drag on the highway (as opposed to 32 percent to tire losses), and 27 percent for drag (38 percent for tires) in urban driving. Again the remainder is due to mechanical losses. A standard transmission was used for these data, and reasonable mechanical losses were assumed. This is not an area in which to expect any major breakthroughs.

There are a few things that could be done with tires to reduce the rolling losses, for example, larger diameter tires, harder compounds in the rubber, or higher inflation pressures. The latter two, however, also reduce the traction, and this is already near the limit with existing materials. It still seems that the best method of reducing rolling losses is the one the manufacturers have been tackling — trying to reduce the weight of the vehicle. But they've already come a long way in that area. A lot of plastic has been used already, and any further substantial weight reductions in automobiles will probably have to come from more exotic aircraft-type materials, such as titanium, magnesium, and aluminum. These are very expensive compared to steel and require different machine and design techniques than are now used in the auto industry.

If we compare the tradeoffs between weight reduction and aerodynamic drag, a 10 percent re-



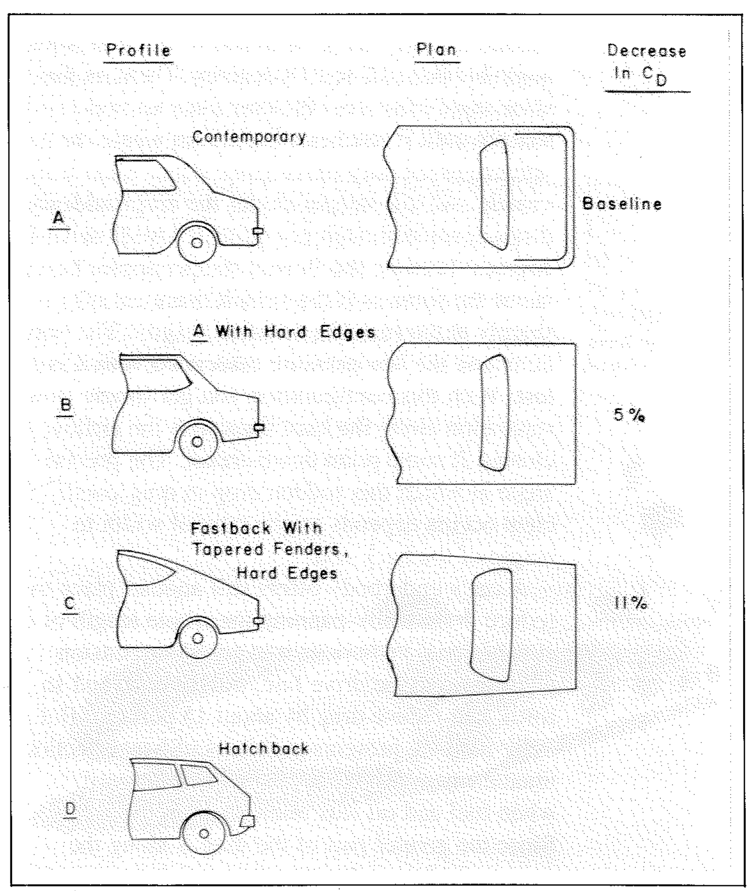
duction in the drag coefficient (with no change in frontal area) would yield approximately a 5 percent fuel economy improvement in a subcompact on the highway. This same improvement would require a 16 percent weight reduction, which is substantial. The same 10 percent drag reduction in an intermediate car would require a reduction of 22 percent in weight for equal fuel economy improvement.

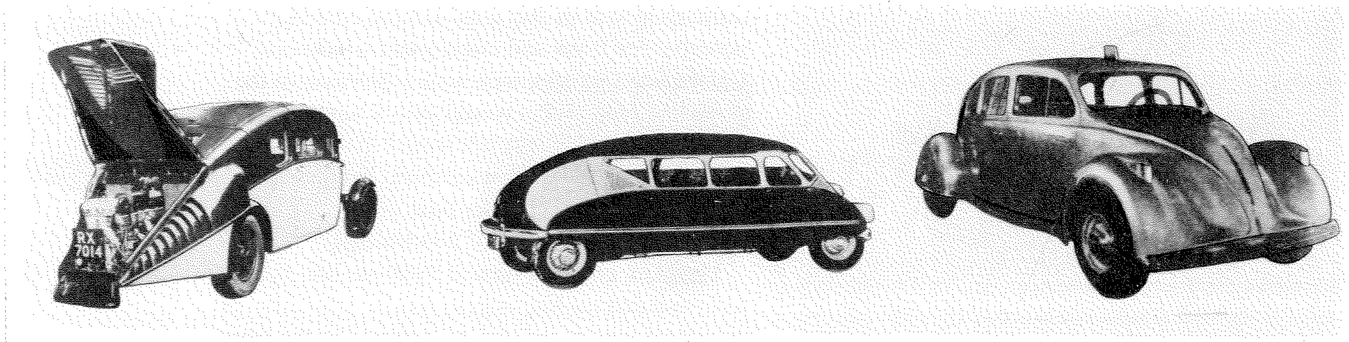
While further weight reduction on autos as we now know them will be difficult, there are a number of ways to achieve easily that 10 percent drag reduction and much more by aerodynamic design. In the 10-foot wind tunnel here at Caltech we have worked on the various areas of the automobile that contribute to its aerodynamic drag. Based on data from the wind tunnel, the largest drag coefficient reductions can be gained by altering the geometry of the front end. We can use as a baseline a 1980 car characterized by the hard lines on its front end and slab sides that the stylists chose to use to give it its character. Simply by rounding the corners of the front end, both in plan and profile (elevation) views, you could reduce the drag of that baseline car by about 15 percent. If it were necessary to retain the hard lines, sloping the front end both in elevation and plan would reduce the drag over the baseline configuration by 21 percent. This is because the favorable pressure gradients along the sides and over the hood would make separation caused by those hard lines reattach very quickly, and the positive pressures built up on the fronts would be much less than they are on the baseline vehicle. By combining the two approaches — rounding and sloping — we could reduce the drag of a typical 1980 automobile by about 24 percent.

The windshield also offers room for improvement, although there are problems associated with changes here. Eliminating the partitions (A-pillars) between windshield and side window and rounding it into one surface at the corners and top would pick up about 3 percent in the drag coefficient. This would probably necessitate a fixed side window, or at least its forward portion. It's difficult to seal in this area without creating a potential for leaks and consequent wind noise. Combining this approach with a decrease in the slope and plan radius would gain a 6 percent reduction in drag. The result would look like a sleek GT car. A larger windshield brings the problem of increased solar heat inside, but no law dictates the slope angle of windshields.

The back end of a typical 1980 car had fairly well-rounded trailing edges, which, ironically, is the wrong way to go here as opposed to the front end. Rounded trailing edges, by allowing the separation lines to fluctuate, produce a mean wake that is larger than one that would result if you fixed the separating streamlines at the lowest point. If hard edges are properly placed so as to minimize the size of the wake and prevent the fluctuation of the separation lines that occurs with rounded edges, the overall drag of the car would be reduced by about 5 percent. Tapering the back end could improve the typical contemporary automobile by 11 percent in aerodynamic drag. A "fastback" design works fine but is not necessary if the corners at the rear window header and the trailing edges of the trunk are correctly placed. The "hatchback" configuration, however, which is so popular on the subcompacts, is a bit more complicated.

Effects of rear-end geometry on drag coefficient.





Three rear-engine cars (which allowed more freedom for aerodynamic design of the front end) of the 1930s: (from left) the R-100 built by a British airplane designer in 1930, a 1935 design by Stout, an experimental Briggs car by Tjaarda (1935); and a front-engine car, the 1938 French Delahaye.

Two types of flow separation are possible with a hatchback, depending on the steepness of the slant. When the slant angle is very gentle, not much steeper than a fastback, flow separation along the side edges is accompanied by a fairly strong shed vortex along each outboard edge, which creates low pressures on the back of these edges that tend to pull the car back and add to its drag. But at the same time this vorticity also creates a low-pressure field that tends to entrain flow from over the roof and hold it attached. By proper design some pressure recovery can be obtained over the central portion of the back end. By balancing these tradeoffs of high and low pressures we can actually end up with a lower drag coefficient than with a steeper slant that has no vorticity.

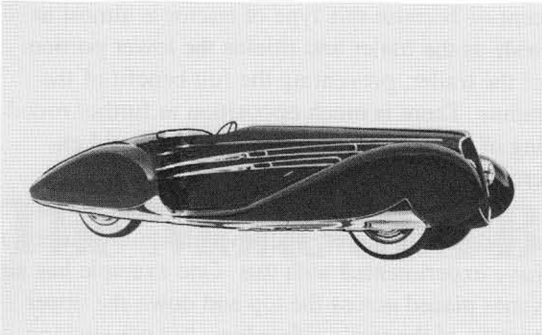
Data collected at the wind tunnel indicate that a minimum drag can be achieved with a base slant angle between 12 and 18 degrees. Then, as the slant angle increases, the drag goes up very sharply until it reaches a maximum where the vortices essentially envelop the entire back of the vehicle. At still steeper angles the drag suddenly drops again (although not quite as low as at 12-18 degrees) because the flow at steeper angles behaves the same as if the vehicle were cut off sharply at the rear like a station wagon. The vorticity and the low pressure associated with it is lost. With this configuration you get simple flow separation along the hard lines with the airflow closing at some point downstream. The precise angle at which this sudden drop in drag coefficient occurs depends on the ratio of width to height of the back end.

A car's underbody offers still another place to reduce drag. Belly-panning the whole length of a conventional vehicle with exposed suspension elements, engine drive line, differential, and so forth, can reduce drag by about 15 percent. But belly-panning presents problems of heat rejection, maintenance, and even creates a fire hazard, when fuel and oil leak and collect in the pan. Since the greater part of the drag is along the front end of the vehicle with the higher velocities associated under the front axle, you can pick up about 9 percent just by belly-panning back to that axle. This still makes for maintenance problems. One solution is the use of an additional section of sheet metal extending downward below the front valance panel with a free lower edge (often called an airdam or spoiler). If placed correctly, this dam will force the separating streamline to go along the same line as a belly-pan and offer the same reduction in drag without preventing access for maintenance.

Not all of the factors affecting drag are outside the car. In the cooling system of a front-engine car, air is taken in across the heat exchanger and then left to its own devices to get out of the engine compartment. But high-pressure buildup on the firewall is just as much a drag item as if it were acting on the front end, typically accounting for about 5 percent of the total aerodynamic drag. Getting rid of this air in an aerodynamically efficient manner could cut that down quite a bit.

Ventilation of the passenger compartment also plays a role, and the penalty in at least some larger cars when driving at highway speeds with the windows open is about 5 percent of the total drag coefficient. There is one case in England where some interesting pressure patterns were measured — positive pressures on the back end were achieved with the windows open and negative pressures with them closed. It might be profitable to look into this and see whether perhaps something could be done with the flow by placing small devices on the side to get the pressures up on the back end of vehicles.

There are other, more general, factors that could affect vehicle drag. One is the fineness ratio — the ratio of the vehicle's length to its maximum diameter. Although there is little conclusive evidence on the optimum fineness ratio for road vehicles, our wind tunnel data on these vehicles indicate that they could be compared to the behavior of a streamlined body in free air. Aircraft-type bodies do have optimum fineness ratio values (for which drag is a minimum), and our data suggest that road vehicles do also —



probably somewhere between 2.8 and 3.6.

Another factor that could affect vehicle drag is aspect ratio — whether a vehicle is low and wide or tall and narrow for the same frontal area. Of the two vehicles with the lowest drag coefficients that I know of, however, there is an example of each: One is low and wide and the other tall and narrow. Both were tested in the 10-foot wind tunnel, so I can attest to the accuracy of the data. The low, wide one is the *Goldenrod,* the car mentioned earlier that has held the land speed record for wheel-driven vehicles since 1965. Built by the Summers brothers, it had a frontal area of 8½ square feet and a length of 33 feet. The length wasn't based on an optimum fineness ratio; rather it was the length necessary to accommodate four Chrysler engines, one behind the other, the water supply for cooling, fuel, driver, parachute pack, and so on. The tall, narrow vehicle is the Van Leeuwen electric car, basically an airfoil, where the frontal area was minimized by placing one of its two seats behind the other.

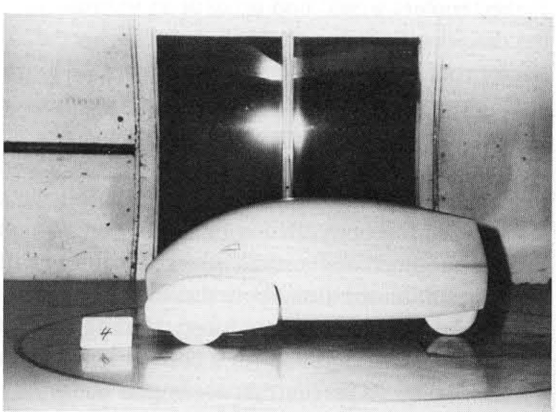
It will be helpful in comparing these cars with others to define a drag coefficient that takes the effects of side winds into account — the wind averaged drag coefficient ($\overline{C_D}$). It is this value rather than the zero-angle drag coefficient that would most accurately represent the performance of a vehicle over a long period of driving. Its formula is:

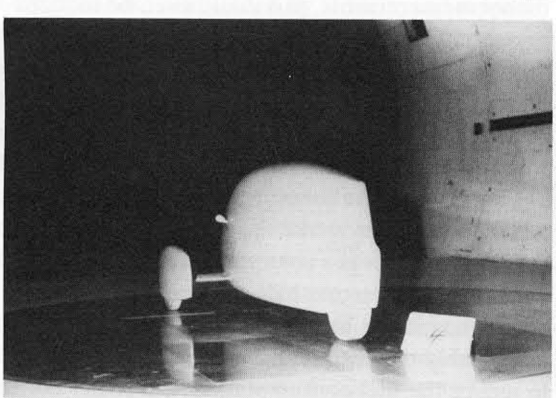
$$\overline{C_D} = \frac{\overline{D}}{\frac{\rho}{2} V_V{}^2 A} = \frac{1}{\pi}\int_0^{\pi} C_D(\psi)\left[1 + \left(\frac{V_W}{V_V}\right)^2 + 2\left(\frac{V_W}{V_V}\right)\operatorname{Cos}\psi\right] d\psi$$

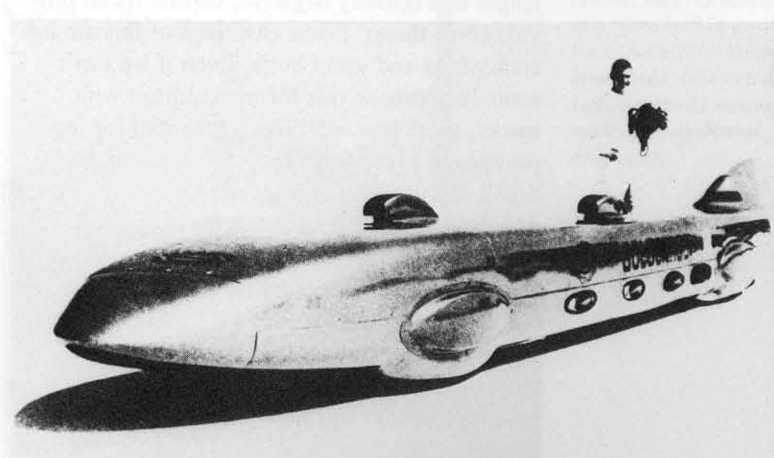
where V_W = mean wind velocity and V_V = vehicle velocity, with $C_D(\psi)$ obtained from wind tunnel data. Basically this means that the wind averaged drag coefficient is a function of the behavior of the drag coefficient with wind angle and of the ratio of wind velocity to vehicle velocity. The integral from 0 to π indicates that there is an equal probability over a period of time of experiencing a wind from any direction between a pure headwind and a pure tailwind.

Using the product of this coefficient times the frontal area as a comparative measure of the vehicles' aerodynamic drag, we get 1.02 square feet for the *Goldenrod* and 1.20 square feet for the Van Leeuwen electric car. A typical full-size contemporary car has a product value of 10 square feet, a subcompact of 9 square feet. (This doesn't mean that a subcompact is more aerodynamically efficient; it just has less frontal area.) This comparison offers a striking example of what can be gained through aerodynamic design.

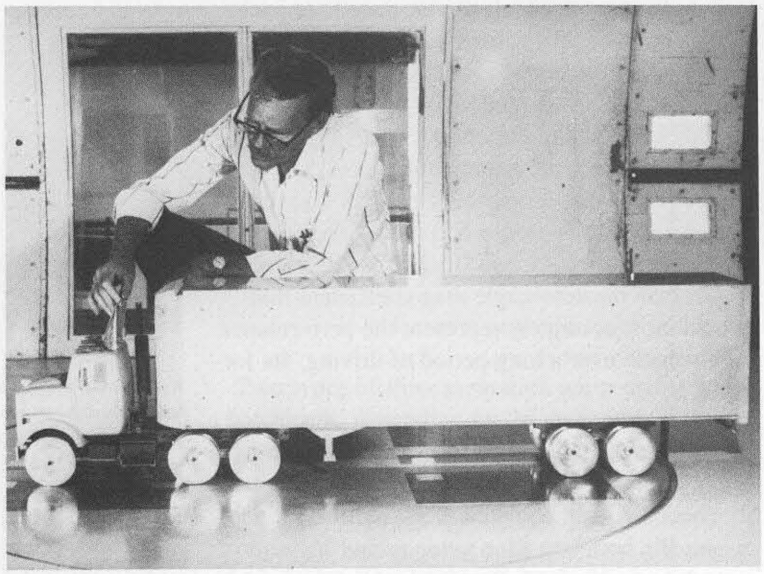
The behavior of the drag coefficient with wind angle is different for different road vehicle geometries. For trucks, for example, the drag







Left, a wind-tunnel model of the tall, narrow Van Leeuwen electric car; right, the low, wide Goldenrod, *holder of the land speed record. Both have extremely low drag coefficients.*



In the wind tunnel Bill Bettes adjusts an air deflector on the tractor roof. Its purpose is to separate the airflow over the top edges and sides, to reattach along the top leading edge of the trailer.

coefficient increases with wind angle much faster than for automobiles. Trucks, which have also been of interest to us in the wind tunnel, have various areas that contribute to their very large aerodynamic drag. The base drag, that is, the drag due to the suction pressure on the back end of the trailer, is responsible for about 19 percent of the total. The underbody accounts for only about 2 percent, not because the underbodies are so aerodynamically clean, but because the overall drag is so large. The skin friction coefficient is the drag due to the friction of the air rubbing along the sides of the truck and trailer, and this is responsible for about 12 percent. This adds up to a third of the total aerodynamic drag. The remaining two-thirds of the aerodynamic drag of these large vehicles comes from the frontal area and from cooling.

It is interesting to note that the theoretical lower limit for forebody drag in potential flow is zero for a semi-infinite body, and for a body of finite length it is actually negative; that is, it can provide some thrust. Some examples of this are aircraft wings and yacht hulls. Even if we can't actually approach this theoretical limit with trucks, there is at least much potential for improvement in the front end of these vehicles. Small changes on the front edge of the trailer can make dramatic differences in the drag coefficient. On a straight truck, one with the van body attached to the cab, rounding the edges of the van with a 1-inch radius makes a difference in drag of almost 3 percent over one with sharp edges. Rounding the vertical edges with a 10-inch radius on a typical trailer pulled by a conventional tractor lowers the drag by almost 17 percent. With a cab-over-engine tractor, it's less — about 12 percent — because this type of tractor is almost as wide as the trailer and shields the lower portion of the trailer, preventing the full benefit of the radius. There is much opposition to further rounding of the trailer's edges because it would encroach on the trailer volume.

Another option is to mount something on the outside of the trailer, and several manufacturers have experimented with this. One example has air vanes placed across the top and down the upper portion of the van's side edges, but not sticking out beyond the sides. The air vanes guide the flow around the turn and eliminate the separation, thereby alleviating the high pressure on the face of the vehicle and actually providing a suction on the corners. The decrease in drag due to the presence of air vanes is about 13 percent.

An air deflector mounted on the tractor roof serves the same purpose as the air vanes — keeping the high positive pressure off the face of the trailer. It does this by guiding the flow from the edges of the deflector to the top and sides of the trailer. The height of these devices compared to the height of the trailer is quite critical, and so is the separation between the air deflector and the trailer. If the geometry of the deflector is not properly adapted to the trailer in use, the wind averaged drag can actually be greater with the deflector than without it, even though the drag at zero wind angle may be lower. Most tankers and flatbed trailers would end up with an increase in the drag coefficient with an air deflector on the tractor roof.

Of course, one can imagine doing much more to streamline the front end of these large trucks. In a test case in one of our smaller wind tunnels in the aeronautics department, we used a fully streamlined forebody, that is, a tractor that was fully streamlined and a standard trailer with turning vanes mounted along both the vertical edges and on the top edge. This reduced the drag coefficient to 0.565 from 0.935 for a conventional rig, a reduction of 40 percent. According to our wind tunnel measurements, this could even be reduced to over 50 percent by fully integrating the tractor with the trailer in a streamlined fashion. There are problems with this in maintaining the articulation between the two and in engine heat rejection, but it is not impossible.

Looking into the future I can find no valid technical reason why the drag coefficients of trucks and passenger automobiles can't be reduced to less than one-half of today's values. Aerodynamic design is finally being explored as probably the easiest and most economical way to reduce the fuel consumption of our road vehicles. □

The Motte and Bailey Castle:

Instrument of a Revolution

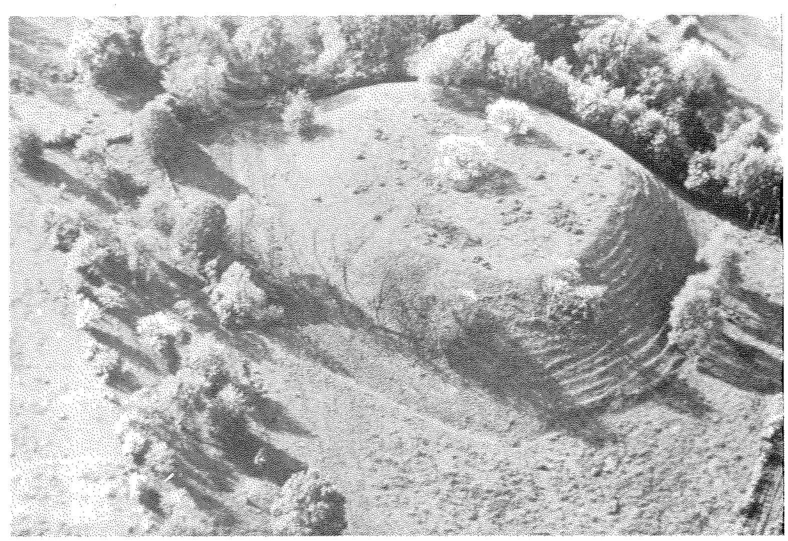
by Michel Bur

SCATTERED across the European countryside are a number of what appear to be insignificant mounds of dirt. As a medievalist and archaeologist trying to reconstruct the European landscape of the 10th to 15th centuries, I have become interested in these little artificial hills, because for several generations in the 10th and 11th centuries they constituted a weapon for the widespread seizure of power and were at the root of the most important social and political revolution of the medieval world — the beginning of feudalism.

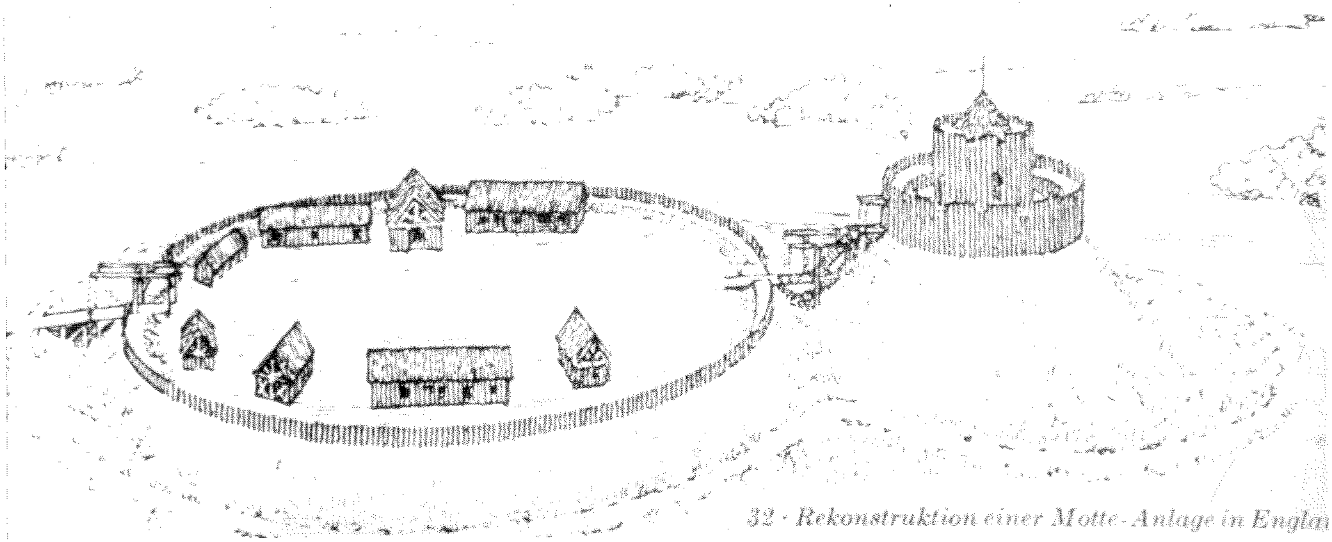
So far no one knows exactly how many of these mounds there are or their geographical distribution. It is hard to say whether they formed a pattern or were independent units. It is certain that they are neither tombs in the style of the Egyptian pyramids or Celtic tumuli, nor temples similar to the ones the Aztecs built on this side of the Atlantic. They are mottes — the first fortified castles.

A motte was made partially or completely by human hands, surrounded by a ditch, and topped by a wooden tower. A trenched annex was attached to the foot of this mound, forming the lower yard or bailey where the service buildings were assembled. The remains of mottes and baileys are still found today all over the European countryside, and their preservation over the intervening centuries has probably been due to the fear or respect that surrounds a leader's dwelling.

The mottes began to appear toward the end of the 10th century, first in low and swampy areas but then also on hills and rocky spurs, during a period of the disintegration of central power — the cracking of the unity of the Carolingian



Above, the present-day remains of a motte built in a valley (Le Vieil-Dampierre: Marne, Sainte-Menehould, Givry-en-Argonne). Left, a motte 21 meters high made of chalk (Rethel: Ardennes).



Reconstruction of a motte and bailey castle. Reprinted from Burgen des Abendlandes, *A Tuulse, Verlag Anton Schroll & Co., Munich, 1958.*

empire. Consequently this was the period of the rise of feudalism and the formation of local power. For warriors seeking to subvert the king's authority, to appropriate hereditary rights of command and justice, and to expand their power over a territory, a motte constituted a powerful weapon. It enabled its possessor to hold out against attacks on territory he already controlled and to spread out in all directions. The mottes were the physical expression of a challenge to the incompetence of the central power. As the force behind the law over the neighboring population, they established the supremacy of the strong over the weak, of the dominant over the dependent. The motte was the symbol of a new feudal society.

Historians have wondered for a long time where lords acquired their powers of justice and command. Some have argued that these powers were inherent in landowning and that the owner of a large domain was naturally inclined to give orders and to police the population within the limits of his estate. But this theory of the landowning origin of lordship has now been abandoned. The social and political transformations that occurred in the 10th and 11th centuries could not be explained by such a simple hypothesis. Undoubtedly, important landowners benefited from these changes, but they could not have created them.

Others have seen the origin of seignorial power in the *droit de ban* — the right to command, coerce, and punish originally delegated by the king to his officers and then increasingly appropriated by them. Such power was fairly widely distributed, but to exercise it during civil wars, a lord had to have control not only of human resources but also of some kind of material means. Current research leads us to think that without the instrument represented by the motte and bailey castle, the final appropriation of the *droit de ban* by the king's officers or the usurpation of this power by the wealthiest landowners would never have taken place. The motte accelerated the tipping of the balance of power toward the seignory. The crucial power we must consider is not that of lordship based on ownership of land (even though this type of power had always existed at a very modest level), nor the lordship of command (as this alone does not account for the means used by the possessors of power of command to establish their position and hold out against attack). The most important factor was the lordship inherent in possession of a castle; the motte and bailey castle crystallized power and in some cases even created it.

Who, then, built the mottes? The most obvious are the legal holders of power — the founders of principalities (dukes and counts) who, after having power delegated to them on a revocable basis, then claimed it for themselves by hereditary right. Because the right to a fortress was one of the rights held by kings and therefore subject to their delegation, these individuals were in the best position to actually erect them. Formal laws existed for building castles, and the counts were eager to preserve this monopoly of fortification. But, as the power of the delegating central authority crumbled, it was not always possible to maintain this monopoly. In some areas, anarchy spread very fast and very far down the social scale. Motte and bailey castles multiplied all the more easily because the materials needed for their construction — dirt and wood — were readily available, very inexpensive, and did not require specialized tools or skilled workers.

A similar phenomenon of "illegal" castle building occurred in times of crisis such as succession or wardship, particularly around the middle of the 11th century in territories that were otherwise well under control. When the ruler recovered his power, he usually preferred to formalize the status quo rather than start a war with the new castle owners who had appeared during the crisis. In the long run, however, even these illegal castles usually ended up acquiring legality by agreement between parties. Those that stayed totally independent were very rare.

Since it was a weapon in the competition among the powerful and at the same time their dwelling and that of their entourage (a setting for knightly life), the castle was fixed within a set of values and institutions completely foreign to the rest of the rural world. Basically the castle and its institutions ignored the peasant. The only connection with the tillers of the soil was one of domination, exploitation, and even outright pillage. The castle was, in effect, the camp of an occupying army in a conquered country.

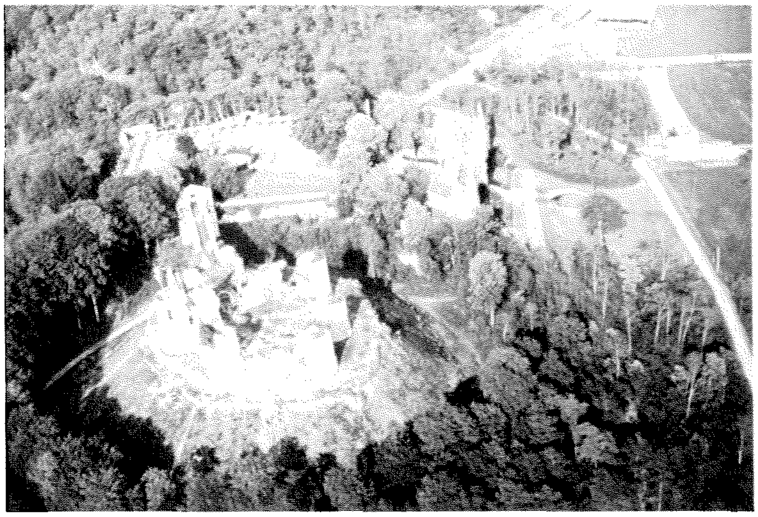
We must therefore erase once and for all the image of the medieval castle providing a shelter for the neighboring population in case of invasion or other danger. It is an obsolete image dating back to a much earlier era when the Frankish kings, concerned about the welfare of their warrior subjects, maintained large fortresses for collective defense. In fact, at the time of Charlemagne and his immediate successors, such fortresses were unnecessary because the empire was at peace. Later, in the late 9th and 10th centuries, kings and bishops tried to build ramparts for protection against the Scandinavian invaders, but this peril provided an opportunity for private rivalries for power to be unleashed. Because of competition for the crown, this soon led to civil war. The seditious lords, motivated by a brutal drive for power and supported by client vassals and bands of outlaws, were not interested in the common good. The advent of feudalism is to be equated with the triumph of private interests, at least temporarily, for power always seeks to legitimate itself.

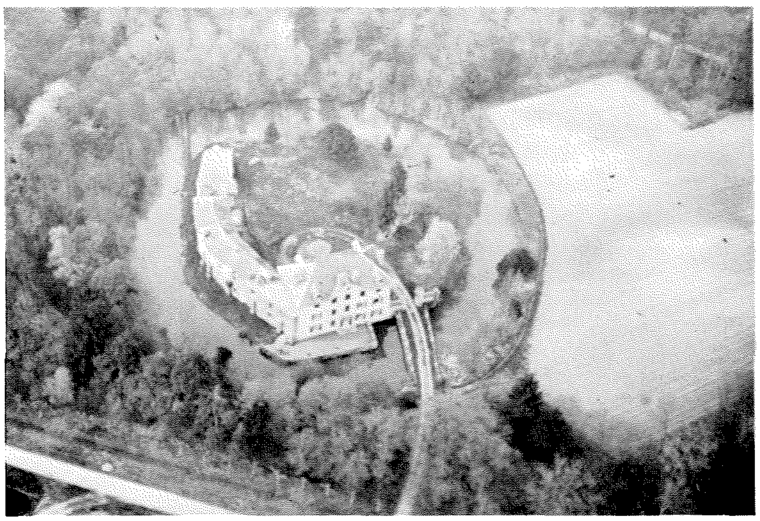
Thus the castle is not linked organically with the spread of population. Since their main mission was not to protect the weak but to allow the strong to survive and dominate, castles were implanted anywhere, but primarily at strategic points and traditional locations for the exercise of power. Castles controlled the main thoroughfares; they usurped the property of the royal treasury and the wealth of the church. The castle holders' aims were to confiscate agricultural produce, income from trade, and the symbols of authority for their own advantage.

Consequently, castles were not attractive to the rest of the population as places to settle. A network of mottes was imposed on an already partially shaped countryside without introducing large changes in population patterns. Sometimes castles coincided with older settlements, and sometimes they stood alone. Their formidable outlines were enough to dissuade anyone from approaching, except, of course, those spoiling for a fight. The burgs, or nascent towns, that formed in their immediate vicinity were usually modest groups of craftsmen or administrators in charge of the master's supplies and the execution of his orders. Many such burgs disappeared when the fortified system did. Those that survived and grew owe it less to the privileges that they were occasionally granted by the castle than to more determining factors such as rich soil or location on well-traveled routes.

There are, however, a few exceptions — cases in which the castle did support population according to a carefully elaborated plan. This phenomenon can be observed in the Norman settlements on the borders of their duchy and in Great Britain. As foreigners trying to establish themselves among a hostile population, the Norman lords, monks, and merchants felt the need to live together and support one another. So they combined the establishments necessary for their respective activities — the castle, the priory, and the burg. More generally, in areas of colonization, a true convergence of interests induced lords and peasants to combine their efforts and to bring their dwellings together within a common defensive system that included the village and the castle. Psychologists are well aware of the effects of enclosure in reinforcing collective feelings. Earthworks still visible on the soil attest today to the original solidarity of the teams that cleared the forest.

At center left the circular outline of a motte can be seen. Directly behind it is the lower yard, or bailey, while still further behind (shaped like a grand piano) is the outline of the former village compound, or burg. The tree-lined rectangle in the foreground, below the road, is the site of a priory. (Vanault-le-Châtel: Marne, Vitry-le-François, Heiltz-le-Maurupt.)





Top, a "motte," mostly natural, bears the remains of a 13th-century stone castle (Fère-en-Tardenois: Aisne, Château-Thierry). Below, a later "maison," whose moat has since been filled in (La Cense-Bizet: Marne, Châlons, Vertus).

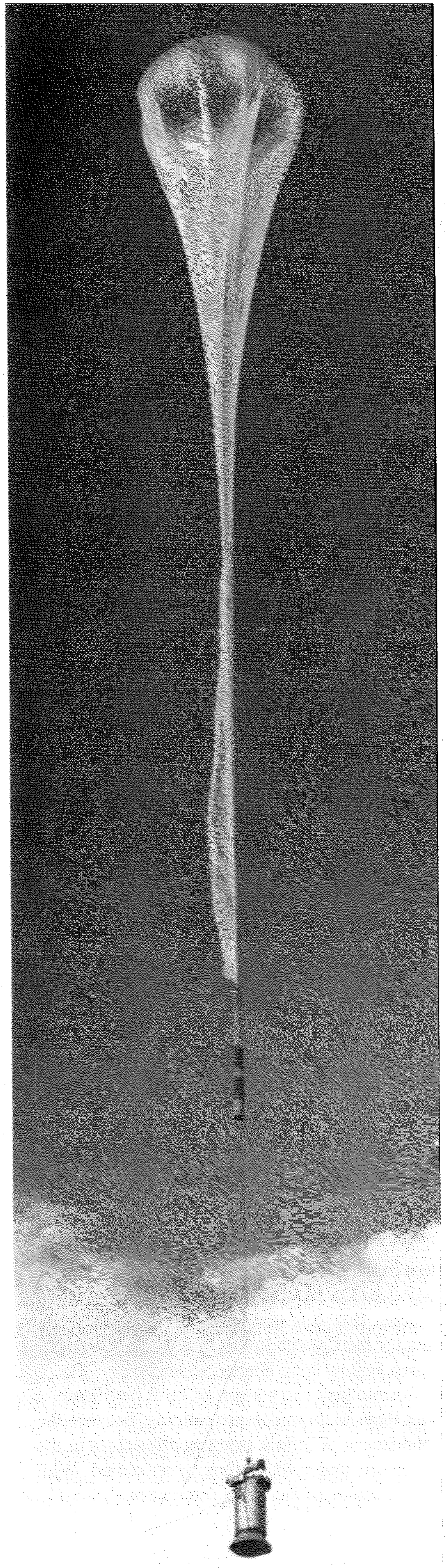
Variety and size of the seignories were also factors in the need for supporting population. A great prince descended from Carolingian noblemen could hold a large region without modifying its structures, riding from one place to another without really settling down. On the other hand, a minor lord, isolated among his rivals, probably felt the need to rally as many of his men around him as possible. In all likelihood the medieval countryside was shaped more by the minor lords than by the great territorial princes.

Although it was a decisive weapon in the battles for influence and the distribution of power in the 10th and 11th centuries, the motte and bailey castle, like any other weapon, grew obsolete. As siege methods improved, the stone castle proved a much more efficient fortress. But, while wood and dirt are inexpensive materials and easy for peasants to work, hewn stone is an expensive material requiring skilled workers. Therefore the new castles could be built only by the wealthiest lords while the lesser ones struggled to modernize their more and more obsolete dwellings. Selection worked in favor of the strongest powers with the king at the top.

If the dissemination of authority during the 10th and 11th centuries was due to the multiplication of earthen castles, the relative concentration of authority in the 12th and 13th centuries can be explained to a great extent by the cost of stone fortifications. But, while the former was a truly revolutionary occurrence, the latter followed in slower, more evolutionary stages. A last step, also evolutionary, in the central concentration of power was taken at the end of the 15th century, when kings were able to destroy any castle with their superior field artillery.

After about 1250, castles of earth and wood were no longer built, and this kind of fortified dwelling was abandoned. The lords who could not afford a stone castle began building a new kind of dwelling — a "maison." Laws limited the size of these houses to modest dimensions. These early country houses were built on a foundation that was generally rectangular in shape and surrounded by a ditch. Adjoining houses and service buildings were surrounded by a hedge or palisade with a wood or stone gate. Some houses were fortified, that is, surrounded by a blind wall without projections. In response to circumstances, especially during the Hundred Years War, some fortified houses acquired crenellation, corner towers, and drawbridges. They turned into real little castles, and the foundations on which they stood were improperly called mottes. Sometimes fortified houses were replaced by a kind of small rustic donjon, a dwelling tower. Because of the minor importance of these buildings, they did not leave a clear mark on the countryside or affect the distribution of population. Though a village might contain several fortified houses, no fortified house ever gave birth to a village.

Much is being done today in France to study earthenwork fortifications before they disappear in the modernization of the countryside. It is important to inventory them to learn how many there are and their distribution and density. An investigation is currently being conducted to establish a series of classifications based on carefully measured diagrams prepared by surveyors and presented on a standardized scale. This has already begun for the province of Champagne and is being planned for eastern France, eventually to extend to all of continental France. At the same time, archival research is yielding historical information about each site — dates, names, and the titles of the inhabitants. This investigation, supported by the National Center for Scientific Research, will undoubtedly lead to a better understanding of feudal society. □



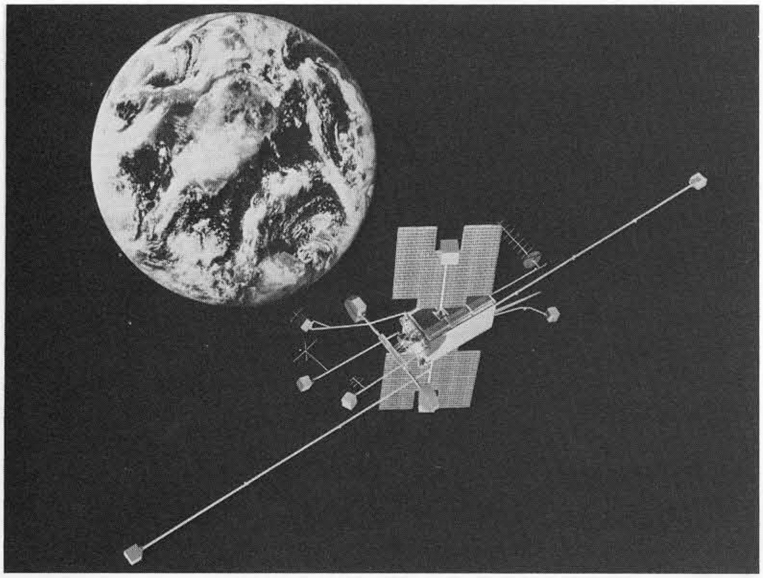
Star Stuff

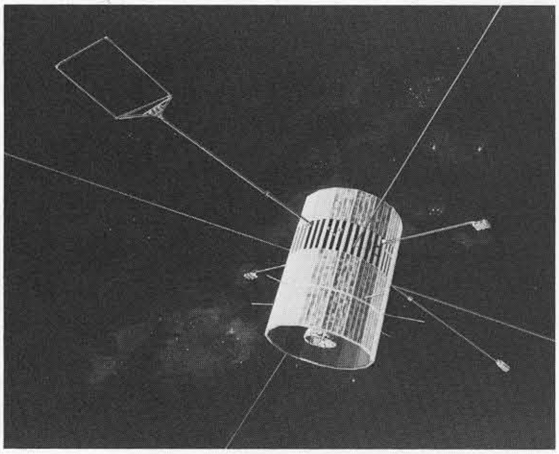
by Dennis Meredith

WHILE we humans may never reach the stars — at least not in this millennium — in a very real sense the stars have already reached us. Careening about our Milky Way like chaotic flights of cosmic bullets are swarms of high-energy charged particles. They have been blown out of exploding stars or launched into flight by the shock waves from such explosions. For millions of years they have ricocheted about the galaxy, their paths altered by collisions with other particles and the deflection by galactic magnetic fields. These particles are known as cosmic rays, and they bombard the solar system from all directions. They are mainly the nuclei of atoms stripped of their electrons and accelerated to a wide range of velocities, from a few percent to more than 99 percent of the speed of light. Like bullets, they come in a wide variety of calibers, from the BBs of hydrogen nuclei to the howitzer shells of uranium. And each atomic nucleus also comes in a number of different isotopes.

The sun answers back with its own flux of solar energetic particles. These particles flow outward in billowing gusts along the warped magnetic field lines of the rotating sun. During the immense explosions called solar flares, the intensity of such particles can jump to one million times normal in an hour. The sun also emits waves of very low energy particles, called the solar wind, which act as a barrier against galactic cosmic rays, so that only the higher energy galactic rays make it all the way upstream into the interior of the solar system. Another source of energetic charged particles in space is the magnetospheres of the planets, which both accelerate and trap particles, sometimes squirting them out into interplanetary space.

Cosmic rays carry memories of their birth and travels in their charge, mass, energies, and streaming patterns. By using balloons, rockets, satellites, and space probes, physicists have managed to loft particle detectors above the atmo-





Top, OGO-6 (Orbiting Geophysical Observatory), launched in 1969, carried Vogt's and Stone's first Caltech-built cosmic ray detector into space. Right, IMP-8 (Interplanetary Monitoring Platform) launched in 1973 provided one of the first long looks at high-energy particles from the sun, the galaxy, and the earth's magnetic field.

sphere (necessary because the atmosphere stops almost all extraterrestrial cosmic rays) to capture glimpses of the particle stream. It has been a highly successful effort, and over just the last few years, sophisticated new detectors have allowed the knowledge of cosmic rays and their solar, planetary, and galactic sources to grow enormously.

Scientists at Caltech's Space Radiation Laboratory, led by Professors of Physics Edward Stone and Rochus Vogt have been among the leaders in these studies. Their research group, a team of physicists, students, engineers and other essential staff members, as well as collaborators at other institutions, have built and flown detectors aboard satellites with an alphabet soup of names — OGO, IMP, ISEE, and HEAO — as well as aboard balloon flights and the two Voyager spacecraft, now speeding into the outer reaches of the solar system.

The scientists are continuing a long tradition of pioneering cosmic ray research at Caltech. The many cosmic ray studies at the Institute included those of Robert A. Millikan, whose research did much to characterize these particles, and who in fact dubbed them "cosmic rays." One of Millikan's students, Carl Anderson, who is now Board of Trustees Professor of Physics Emeritus, was awarded the Nobel Prize in 1936 for his discovery of the positron using cosmic rays as a source, and his cosmic ray studies yielded evidence of some of nature's fundamental particles. Another Millikan student, H. Victor Neher, who is also now an emeritus professor of physics, continued and enlarged Millikan's studies for several decades. And still another who worked as a student with Millikan on cosmic ray research is William Pickering, professor of electrical engineering emeritus.

The current era of cosmic ray research at Caltech was marked by the launching of NASA's Orbiting Geophysical Observatory (OGO-6) in 1969. It carried Vogt's and Stone's first Caltech-built cosmic ray instrument into space. OGO was soon followed by two "IMPs" — Interplanetary Monitoring Platforms 7 and 8 — launched by NASA in 1972 and 1973. They carried a new generation of silicon charged-particle detectors designed by Stone and Vogt, with electronics built under the supervision of William Althouse. These satellites, orbiting midway between the earth and the moon, gave scientists one of the first continuous, long-term looks at the swarms of high-energy particles from the sun, the galaxy, and the earth's magnetic field. Among many other discoveries, the IMP spacecraft yielded evidence showing that the planet Jupiter acted as a powerful particle accelerator, flinging dense waves of high-energy electrons at least 200 million miles into space. These Jovian electrons — with energies of several million electron volts (MeV) — often totally dominate the flux of cosmic ray electrons surrounding earth.

The IMPs also revealed how the charged particles trapped in the earth's magnetic field behave. For example, they found that surrounding the "tail" of the earth's magnetosphere, which is swept back by the blowing solar wind, is a layer of high-speed electrons. This 15,000-mile-thick layer is apparently accelerated by the earth's magnetic field. The IMP satellites proved more than capable; they were extraordinary. While IMP-7 had to be turned off in 1978 for budgetary reasons, IMP-8 is still sending back streams of data for the Caltech group, including Senior Research Fellow John Bieber, to analyze.

Cosmic rays carry a sort of birth certificate with them in their isotopic patterns, because the abundances of certain isotopes offer clues to the conditions under which they were formed. With the launching of the Third International Sun-Earth

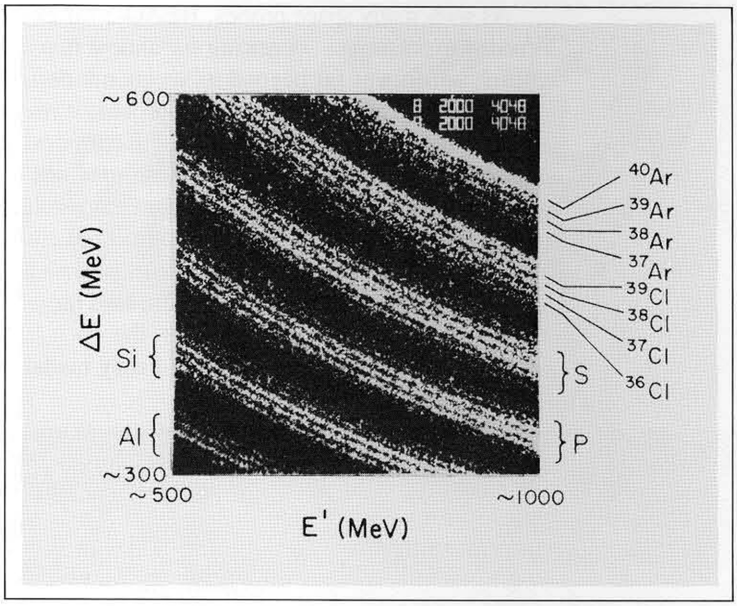
Explorer (ISEE-3) in 1978, Stone, Vogt, and their colleagues provided the first instrument that could read this birth certificate with high resolution. Senior Scientist Alan Cummings oversaw the production of the unique silicon detectors that made this possible. The spacecraft was also unique because it orbited the sun at the "libration point" over one million kilometers from earth — the point at which the gravitational pull of the sun and earth neatly balance one another.

The Caltech-built instrument on board ISEE was called a cosmic ray isotope spectrometer, and it yielded several surprises. For one thing, it made the first high-resolution measurements of heavy nuclei accelerated during a solar flare — a magnetic explosion on the sun that can release the energy of a million hydrogen bombs. The Caltech scientists used the ISEE instrument to measure the isotopic patterns of carbon, oxygen, neon, and magnesium as they spewed out of flares.

Surprisingly, the ISEE experiment represented one of the first times scientists had ever directly measured the isotopic composition of the sun. Despite the fact that the sun is by far the dominant object in the solar system, there is very little direct information about its composition. Most of our information about solar system compositions comes from studies of terrestrial and meteoritic material.

ISEE also provided the first hints that our solar system may be made of distinctly different stuff from that in nearby regions of the galaxy. The ISEE instruments revealed that galactic cosmic rays possess a distinctly different isotopic composition from solar cosmic rays. The Caltech scientists confirmed earlier measurements showing that, compared with the common isotope of neon ^{20}Ne, there is more than three times more of the heavier ^{22}Ne in galactic cosmic rays than in solar cosmic rays. They subsequently found that the heavy isotopes of manganese ^{25}Mn and ^{26}Mn are also more abundant in galactic cosmic rays.

Many astrophysicists have concluded that these differences are not isolated; in five cases in which the cosmic ray isotopic composition has been precisely determined, the galactic material is different from the solar material. Thus, we may have been cooked up using a different recipe from the rest of the galaxy. Perhaps, say the scientists, because our solar system condensed out of cosmic dust almost five billion years ago, we represent a sample of the galaxy frozen in time, while the rest of the galaxy continued to percolate along, evolving without us. ISEE is still active, and the Caltech scientists, including Senior Research Associate Richard Mewaldt and graduate student John Spalding, expect further insights from the



This on-line display of raw isotope data was acquired with the Caltech Heavy Isotope Spectrometer Telescope (HIST) during a calibration at the Bevalac. The experiment involved a ^{40}Ar beam incident on a polyethelene target, where many of the ^{40}Ar ions break up into lighter nuclei. The instrument measured the particles, each plotted here as an individual point, emerging from the target. The broad bands are due to the elements aluminum to argon, and each broad band consists of narrower parallel "tracks" corresponding to individual isotopes. These data provided the first experimental proof that cosmic ray instruments composed of silicon detectors could identify individual isotopes of heavy elements with high resolution. HIST was carried into orbit on ISEE-3 in 1978.

long series of scientific questions they will ask of ISEE's rich trove of data.

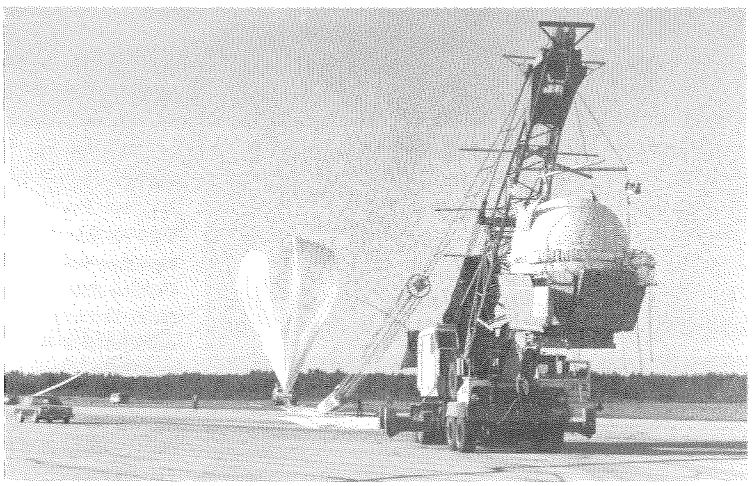
While ISEE was able to capture and measure elements as heavy as iron, beyond iron in the periodic table of the elements lies additional important information about how cosmic ray nuclei are formed in stars. The elements heavier than iron, ranging up to uranium, require special conditions to create because, unlike lighter elements, they absorb energy during their formation rather than releasing it. Certain of their isotopes are believed to be formed by "rapid" neutron capture, possibly when a violent supernova or its remnant pulsar slams neutrons into the nucleus in a process taking only a few seconds. Other heavy isotopes are formed by "slow" neutron capture, in which neutrons are added one at a time in the thermonuclear fires of stars that evolve more slowly.

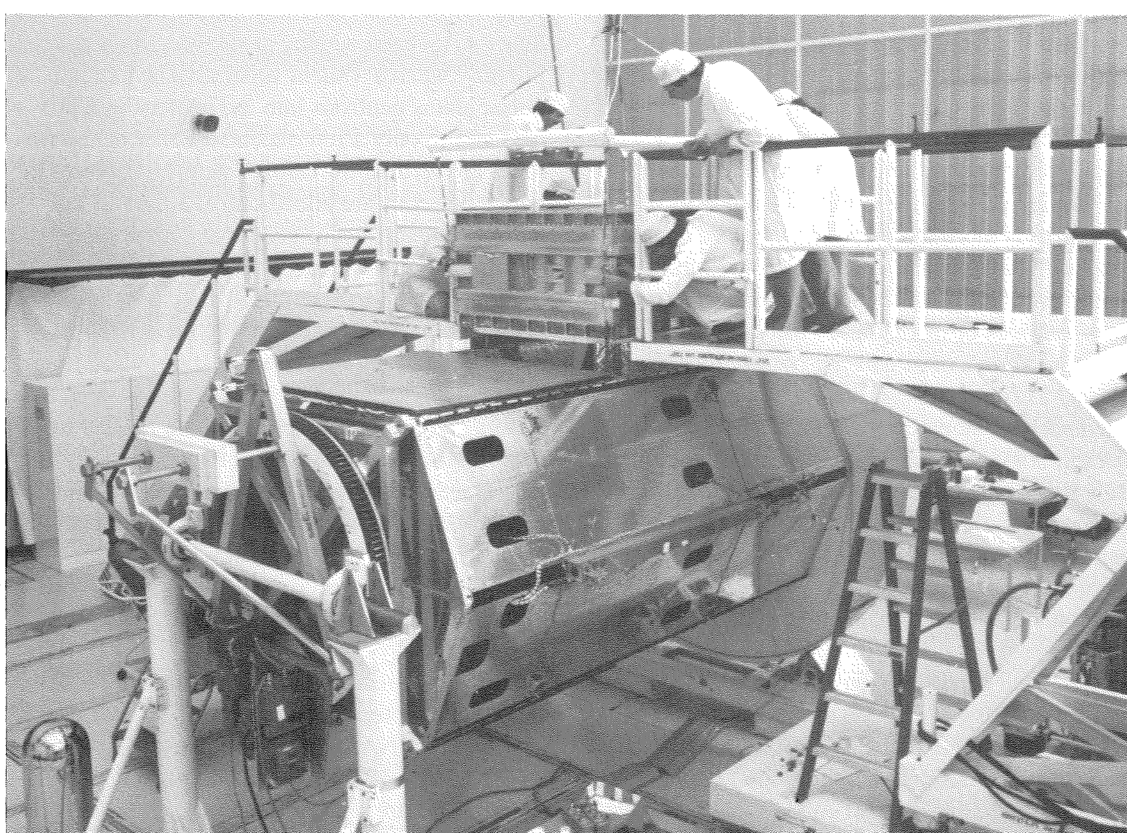
As valuable as these ultra-heavy cosmic ray nuclei are to science, collecting them is no easy matter, because they are up to 100 million times scarcer than their lighter cousins. Large-area detectors and long exposure times are needed to detect significant numbers of them. But, working with researchers from the University of Minnesota and Washington University (the team leader is Martin H. Israel, professor of physics at Washington University, Caltech PhD '69), the Caltech scientists were able to build the largest area cosmic ray detector yet used in space. It included two ionization chambers, each measuring two square meters in area. In 1979, it was carried into space on NASA's High-Energy Astronomical Observatory (HEAO-3). Among the nuclei detected so far are zinc, selenium, krypton, molybdenum, xenon, and barium.

As with many space probes, HEAO-3 far exceeded expectations, operating for almost two years, which was far beyond its six-month design lifetime. And as with many space probes, it revealed to the researchers a fascinating complexity in cosmic ray nuclei formation. Some previous experiments had suggested that ultra-heavy galactic cosmic ray nuclei were formed almost exclusively by rapid neutron capture in supernova explosions, and the HEAO-3 group did find these nuclei, such as selenium. However, the experimenters also found many ultra-heavy nuclei, such as strontium, that were formed by the gentler slow neutron capture process.

The confounding question then became how these slow-cooked nuclei could have been launched to near light speeds if they were not formed in a violent explosion. According to a recent model proposed by Caltech Professor of Theoretical Astrophysics Roger Blandford in collaboration with Jeremiah P. Ostriker of Princeton, the shock wave from a supernova sweeping through space might accelerate such non-supernova material. The HEAO-3 team, including Senior Scientist Tom Garrard, is continuing its analysis of the satellite's data, sorting out more and more of the ultra-heavy elements. Eventually, they hope to have sorted out the elements all the way to uranium.

Continuing the Caltech group's effort to measure cosmic ray isotopes, Senior Research Associate Andrew Buffington and Senior Scientist Stephen Schindler are currently leading a collaborative effort with the Danish Space Research Institute to complete a new instrument capable of high resolution in detecting rare cosmic ray isotopes with energies above a billion electron volts. The detector, weighing several thousand pounds, will be launched by balloon next fall and should provide the Caltech scientists still another valuable chance to capture material from the stars.





Top, an instrument designed to search for cosmic ray antiprotons and antihelium nuclei is readied for balloon launch at The Pas, Saskatchewan, in 1980. Right, half of the cosmic ray instrument (the other half goes into the opposite side) is lowered into the HEAO-3 satellite at the TRW Inc. plant. HEAO-3 was launched in 1978.

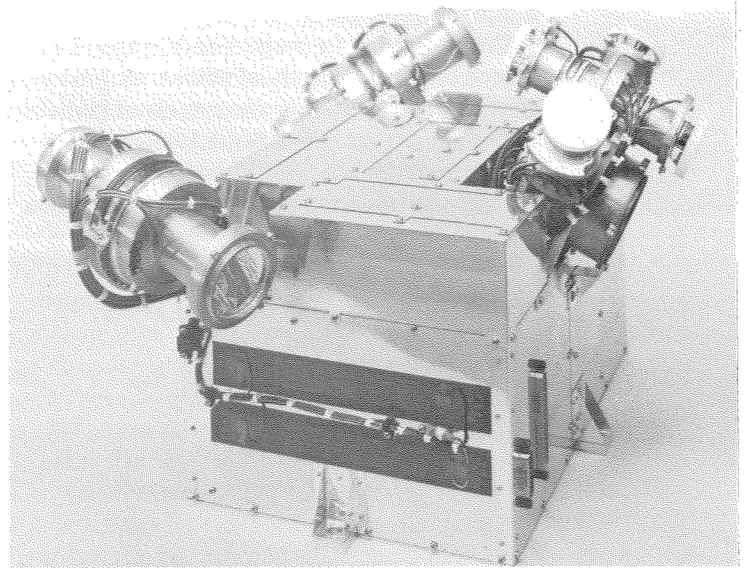
The scientists hope the new detector will yield insights into the age of cosmic rays and the material they have encountered in their travels. The abundances of certain isotopes of cobalt, nickel, and iron, for instance, can give scientists a measure of the time between birth and acceleration, because these isotopes decay only as atoms with orbital electrons, and not as stripped nuclei traveling at high speeds. Still other radioactive isotopes of aluminum, chlorine, calcium, manganese, or iron can function as cosmic ray "clocks" to measure how long cosmic rays have been rattling about the galaxy.

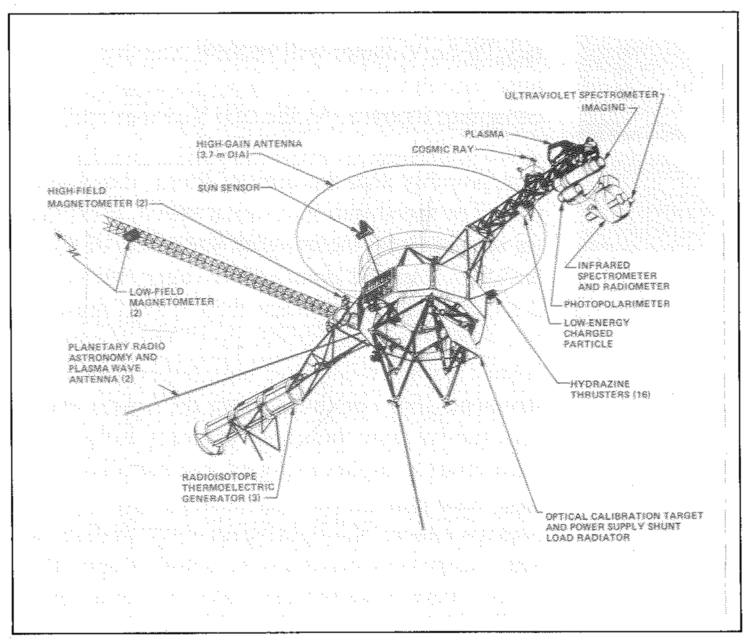
In 1980 Buffington and Schindler also flew a balloon-borne experiment to search for cosmic ray antiprotons and antihelium nuclei. While earlier high-energy studies had shown a few antiprotons among cosmic ray protons, most scientists believe these didn't come from any large antimatter source in the galaxy, but were merely the result of ordinary cosmic ray protons striking atoms in interstellar gas. Physicists have succeeded in producing similar small numbers of antiprotons on earth by colliding particles in high-energy accelerators.

Since such antiprotons were far less likely to be produced at low energies, Buffington and Schindler studied cosmic rays with energies one-tenth as high as in the earlier studies, expecting to see less than one-tenth as many antiprotons in their experiment. But surprisingly, they found just as many as the high-energy experiments had revealed. The "Mystery of the Too Many Antiprotons" remains to be solved. Is it the first hint of an exotic region of antimatter somewhere in the universe? Or is it a strange quirk of ordinary cosmic rays that scientists still do not understand?

While Stone, Vogt, and their colleagues were developing better and better detectors for their balloon and satellite experiments, they were also helping send detectors far beyond the local environment of the earth. Working with scientists from Goddard Space Flight Center, University of Arizona, and University of New Hampshire, the Caltech researchers are participating in the cosmic ray experiment aboard the two Voyager spacecraft. Vogt is principal investigator for the cosmic ray investigation, and Stone is a co-investigator as well as the Project Scientist for the overall Voyager mission.

The small 16-pound Voyager cosmic ray package is located about halfway out on the instrument booms of the two probes. The task of the silicon detectors is to measure the energy spectrum of electrons and cosmic ray nuclei — ranging from one to 500 MeV, as well as the abundances of atomic nuclei from hydrogen through





The cosmic ray instruments aboard Voyager 1 and 2 each consist of seven telescopes – two double-ended ones (left) for high-energy cosmic rays and a quartet of telescopes (right) for low-energy particles. Beneath the latter is a telescope designed to measure cosmic ray electrons. The instrument is located half way out on one of Voyager's booms, as shown in the diagram.

iron. The scientists' targets have also included the radiation belts of Jupiter and Saturn and the particles erupting from solar flares. Just as the cameras of the two Voyager spacecraft have returned stunning pictures of Jupiter and Saturn, so the cosmic ray packages have also performed brilliantly.

Among many other discoveries the scientists found that, compared to common solar system material, Jupiter's trapped radiation belts are heavily enriched with high-energy oxygen, sodium, and sulfur nuclei, zipping through space at up to 10 percent of the speed of light. The sulfur probably originated from the famous volcanic eruptions on Io and the sodium from surface deposits on that moon. Graduate student Neil Gehrels studied the flow and fate of this material within the immense Jovian magnetosphere.

The cosmic ray instrument on Voyager 2 even yielded evidence recently of still another moon around Saturn. Studying the patterns of particle absorption around the planet, Research Fellow David Chenette detected a "shadow" indicating that the particles were blocked by a small moon sharing the orbit of Mimas.

In analyzing Voyager cosmic ray data from solar flares, graduate student Walter Cook found that abundances of some elements in flares indicated that they sampled material from the sun's corona — the hot, low-density region above the sun that produces the solar wind — rather than from the underlying photosphere, which is the sun's glowing "surface." The mechanism by which the sun apparently filters photospheric material to produce the coronal composition is not yet understood.

Sometime during the next two decades Planetary Probe Voyager will become Starship Voyager, and the cosmic ray experiment will really come into its own. As the two Voyager craft reach a distance of several billion miles from the sun, possibly near the orbit of Pluto, they are expected to speed into interstellar space, escaping for the first time the constant streaming of the solar wind. Past this point the Voyager cosmic ray detectors will give humans their first glimpse of low-energy galactic cosmic rays. The Voyager cosmic ray scientists have high hopes for their instruments. For one thing, since the lowest energy rays survive only thousands of years, rather than millions as at higher energies, the particles must have been emitted recently from nearby objects, perhaps a mere 500 light-years away. In fact, the low-energy rays may even be non-isotropic; that is, they may come preferentially from one direction. Since there have been few violent cosmic-ray-producing events in our galactic neighborhood recently, the researchers hope to use the Voyager instruments to associate cosmic rays for the first time with a specific astronomical object.

While Stone, Vogt, and their fellow scientists look forward with excitement to the future Voyager explorations, they have also faced disappointment in their other major exploratory project; the American half of the Solar-Polar mission was canceled in the recent round of federal budget cuts. The joint European-American program was to have consisted of twin probes vaulted out of the plane of the ecliptic to orbit over the sun's poles. Aboard the American craft was to have been a large high-resolution cosmic ray instrument built by the Caltech group and its collaborators. Had the probe flown above the sun's poles, the physicists would have explored a region of the solar system possibly as strange as any alien planet. For one thing, the craft might have sailed through a sort of polar doldrum in the solar wind, where low-energy galactic cosmic rays may come streaming into the solar system, carrying with them information about the rest of the galaxy. The detector system for the canceled mission, however, is already largely completed, and the Caltech scientists hope eventually at least to fly it aboard an earth-orbiting satellite.

While cosmic ray research has taken great strides in the last few years, volumes of tantalizing questions about the universe still remain — many of which this group of Caltech researchers feel they could answer by sifting through data on star stuff, the fascinating storm of particles that swirl about us as cosmic rays. □

How to Catch

CAPTURING a cosmic ray is not as difficult as it might seem, because the energetic particles leave considerable evidence of their passing. They ionize gases, damage solids, and create electrical disturbances in crystals, and all of these phenomena have been used as bases for cosmic ray detectors. However, sorting out the cosmic ray nuclei from one another is another business entirely.

In fact, the first primitive device used to study cosmic rays — the ionization chamber — told little more about the rays than that they existed. The ionization chamber is basically a gas-filled insulated chamber into which a pair of electrodes is inserted. When a charged particle passes through the chamber, it ionizes the gas in the chamber, creating a current. Physicists using these devices quickly discovered that some mysterious source of ionizing radiation tended to produce signals in the chambers, even when radioactive materials were not present. It was eventually discovered by launching ionization chambers on balloons that this radiation came from outer space.

Still later an improved, high-voltage version of the ionization chamber, called the Geiger-Mueller counter, came into wide use. This counter produced an electrical signal each time a charged particle passed through the gas in the high-voltage chamber.

An advanced version of the ionization chamber served as the basis for the cosmic ray detector aboard the satellite HEAO-3. In this detector, cosmic ray particles traversed a complex stack of ionization chambers in which the size of the signal caused by each particle was precisely measured. The result was that scientists could characterize the particle by how much energy it lost traversing the series of detectors. In addition, HEAO contained more than 1,000 smaller ionization chambers in an X-Y grid pattern that were individually

a Cosmic Ray

instrumented to determine the position and angle of incident particles.

To yield still more information about the cosmic rays, the HEAO-3 detector also featured a Cerenkov detector. This device is based on the fact that a form of light called Cerenkov radiation is produced when charged particles pass through certain materials at very high velocities. The particles produce a sort of electrical shock wave in the material, resulting in a flash of light along the particle's "wake." In Cerenkov detectors, photomultiplier tubes are used to detect the flashes from cosmic rays.

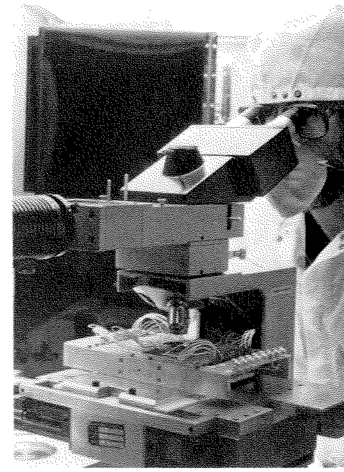
When cosmic rays pass through certain plastic or inorganic materials and excite the molecules in them, the recombination of ions in the particles' wake also produces a flash of light. This phenomenon has become the basis for scintillation counters used as cosmic ray detectors.

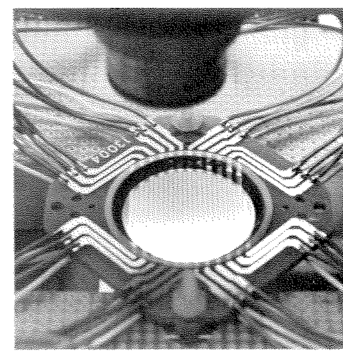
The detector being developed for the balloon-borne isotope spectrometer is a form of scintillation counter. It consists of stacked discs of highly polished sodium iodide crystals about half a meter in diameter. These plates are surrounded by a series of photomultipliers that can track the particle through the detector. By comparing the signals from several discs, each viewed by six photomultipliers, scientists can determine, not only the particles' charge and mass, but also the precise angle and position at which the particles traversed the detectors, and thus can correct for the variations in thickness of material seen by particles entering at different angles. Signals from Cerenkov detectors above and below the detector array can be compared to find the velocities of the particles.

Of all cosmic ray instruments in use today, solid-state silicon detectors yield the most accurate measurement of energy deposition by energetic particles. Silicon detectors are basically thin wafers of silicon crystal with gold and aluminum electrodes attached. A cosmic ray striking the detector produces a tiny electrical signal that is linearly proportional to the energy lost by the particle. By measuring electrical signals in a stack of such wafers, scientists determine a particle's energy and charge. The ISEE instrument could resolve cosmic ray isotopes (mass), where earlier instruments could identify only elements (charge), because of the development of two-dimensional, position-sensitive solid-state detectors that can track the particle through the detector stack, allowing precise corrections for the detectors' position and angular response. The electrodes on these position-sensitive detectors are a criss-crossed grid, so that each cosmic ray impact is precisely located.

Silicon detectors have been the basis of instruments on board OGO, IMP, ISEE, and Voyager, and were to be launched on the canceled Solar-Polar mission. The Solar-Polar instrument was to have included far superior silicon detectors 30 square centimeters in area, versus 9 square centimeters for the ISEE and Voyager detectors, and 3 square centimeters for the IMP detectors. In addition, the Solar-Polar position-sensitive detectors were to be four times larger than on ISEE. Such increased detector area is important because it increases the number of cosmic ray events detected per unit of time.

Regardless of whether they are silicon detectors, scintillation counters, Cerenkov detectors, or ionization chambers, modern space-borne cosmic ray detectors are remarkable scientific instruments — among the most sensitive and stable devices launched by man to study the universe. They are manufactured with painstaking care and carefully calibrated by bombarding them with precise beams of particles from high-energy accelerators, such as the tandem Van de Graaff in Caltech's Kellogg Laboratory and UC Berkeley's Bevalac accelerator. All this ingenuity pays off; modern detectors operate for many years with variations of less than hundredths of a percent to measure with extreme precision the infinitesimal impacts of cosmic ray nuclei.





Through a microscope Richard Mewaldt examines a position-sensitive, solid-state detector. The silicon detector, seen below in a laboratory test set-up, has deposited on its surface an array of parallel gold stripes (each .8 millimeters wide) that are used to determine the position of incident particles.

Members of the Space Radiation Laboratory Voyager team, led by Rochus Vogt (dark shirt) get the first look at real-time data from their cosmic ray instrument during Voyager 1 launch operations at JPL.

Research in Progress

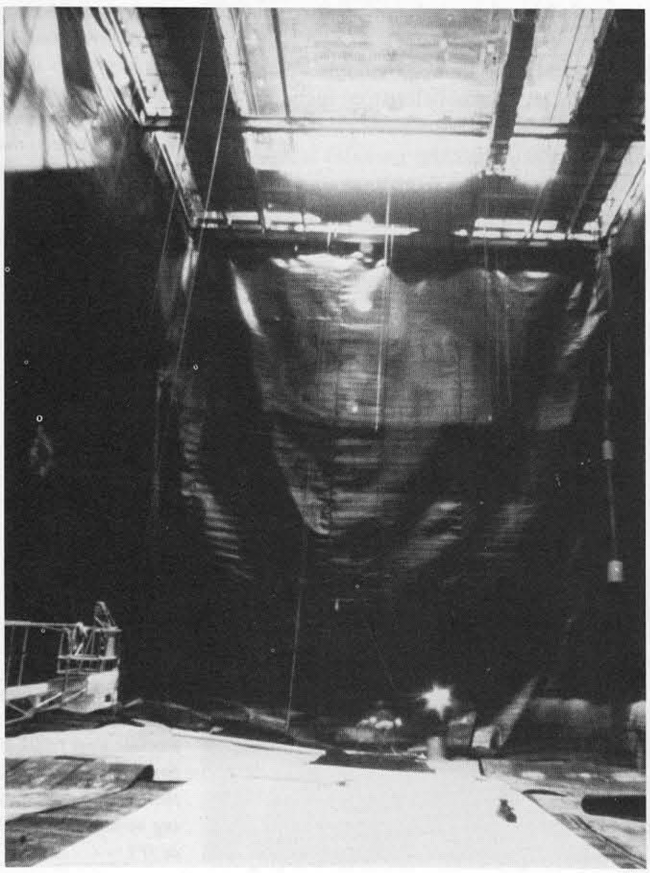
Proton Pool

A TANK of water the size of Millikan Library can't help but inspire visions of the ultimate water prank. And it also inspires a few jokes among the physicists who dreamed up the giant pool holding thousands of tons of water (which is not drowning the stacks in Millikan but is located 2000 feet underground in an Ohio salt mine). John LoSecco, assistant professor of physics at Caltech, refers to the plastic-lined pit as "the world's largest underground water bed" and proposes to throw in a lot of Jello if it should start to leak. Even Woody Allen commented on the project in his film *Stardust Memories,* expressing great dismay on reading of the attempt to prove that all matter will eventually disintegrate.

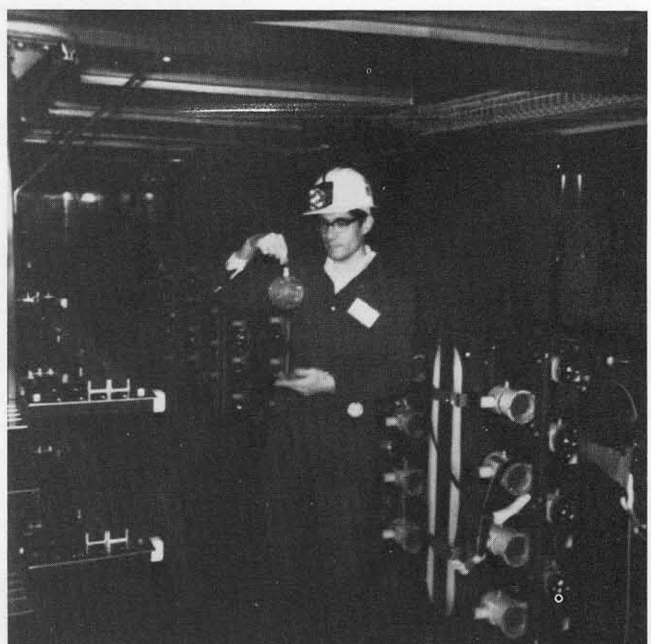
The giant pool is a proton-decay detector (and if protons decay, so does everything else). The $4-million project in the Fairport mine of Morton Norwich Products Inc. was initiated in 1979 by UC Irvine, the University of Michigan, and Brookhaven National Laboratories (hence IMB) and funded largely by the Department of Energy. Caltech's link to the undertaking is LoSecco, who came here this year but is also still working in the salt mine on the world's largest such detector.

Why does it have to be so large? The water serves two functions — it's the detector, and it also contains the protons themselves — the more water, the more protons. Protons are very stable particles and were thought to exist forever; if they decay at all, it is very, very slowly. Their lifetime has been derived theoretically to be at least 10^{30} years, or 10^{20} times the age of the universe, so Woody Allen need not be too alarmed. Since you can't sit around watching one for that long, the only other way to catch one in the act of decaying is to observe an enormous number of protons. Since the 8000 tons of water in the detector contain about 4½ times 10^{33} protons, the IMB group hopes to see four or five hundred decay events in a year.

If researchers do observe a proton decaying, many pieces of the puzzle of mod-



At left, the proton detector pit, 60' x 80' x 70' and 2000' underground, is lined with thick black plastic before being filled with water. Below, John LoSecco displays one of the 2048 photomultiplier tubes (others are lined up behind him) that will pick up the signals of decaying protons.



ern physics will fall into place. Since the understanding in recent decades of the weak and strong forces holding the nucleus of an atom together, the holy grail of physicists has been to link these two to electromagnetism and gravity and show that all four of the fundamental forces of nature were once part of the same process. Mathematical tools such as gauge theories permitted the integration of the weak force and electromagnetism in 1967 (the 1979 Nobel Prize in physics was awarded for this work); this theory predicted the existence of a new interaction — the weak neutral current — which was duly observed experimentally a few years later. Although gravity is still a holdout, a grand unification theory combining under one gauge group both the weak and strong forces and electromagnetism was proposed in 1975. This theory, however, also predicts another leftover piece of the puzzle — an as yet unobserved interaction, the decay of the proton. The proton-decay experiment is therefore a test of grand unification models, and physicists around the world are now watching protons in detectors that range in size from 100 tons to 8000 tons.

If you're going to use 8000 tons of something, it had better be cheap, says LoSecco, explaining why water was chosen as the detector medium. Purified water from Lake Erie was funneled into the hollowed-out pit 2000 feet below the lake; the depth is necessary to block out background noise from cosmic rays, which occur three orders of magnitude less often at that depth than at the earth's surface.

A decaying proton would produce very energetic charged particles that would travel through the water faster than the speed of light. (The speed of light in water is 30 percent lower than in a vacuum.) This action creates Cerenkov radiation, a shock wave similar to the sonic boom from an aircraft flying faster than the speed of sound. The rigid structure of Cerenkov light enables the experimenters, when they pick it up, to trace exactly what produced it.

In the IMB project, 2048 photomultiplier tubes positioned around all six sides of the tank are poised to pick up Cerenkov light. These photomultipliers in turn are linked up to three serially operating computers, arranged in a decisionmaking hierarchy, which quickly record information of all events in the detector, then process and discriminate among the data to decide what is worth keeping for further analysis by the human scientists. Caltech's LoSecco, whose background is actually in theoretical physics, was involved in the sophisticated electronics that make up this system, specifically in the design of the digital data readout system. Even at California's considerable distance from the salt mine he will be analyzing printouts of the proton watch.

For conclusive results the IMB group will probably continue to watch protons for a few years. In the meantime (or subsequently) the biggest detector in the world can also, with a few modifications, be used to study other phenomena, for example, neutrinos and their possible mass and the origin of cosmic rays (the cosmic rays that do reach the detector are high-energy ones that aren't bent much and so remember where they came from). LoSecco is also interested in some of the "crazier" proposals for the huge pool — looking for signals of the sun's missing neutrinos and of collapsing stars at the center of our galaxy. □ – *J.D.*

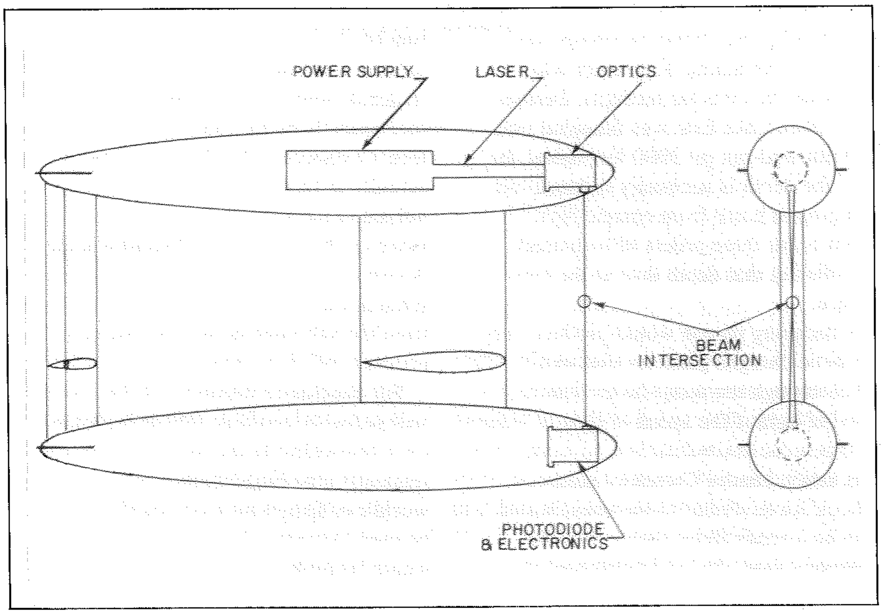
Ocean Motion

DUMPED into southern California's coastal waters every year are 288,000 metric tons of particulate matter carried by rain runoff and treated waste water. Among these tiny particles, which account for 75-90 percent of coastal pollutants, are hundreds of tons of chlorinated hydrocarbons and such toxic metals as chromium, lead, cadmium, and arsenic.

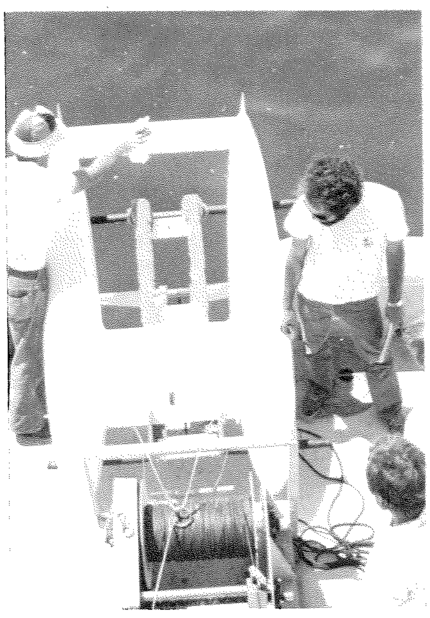
The fate of these particles has important implications for this area both in the reduced intensity of the sunlight reaching the giant kelp beds because of the particles and in the possible accumulation of toxic wastes near shore. It has been assumed that these particles were carried out to the ocean where their concentrations would be insignificant. But this is not known.

To try to find out what happens to them, a six-foot-long submarine equipped with lasers has been developed to observe these particles in the act of whatever they do down there. Conceived in the Keck Laboratories of Hydraulics and Water Resources by E. John List, professor of environmental engineering science, and built by research fellow Gregory Gartrell, Jr., the little submarine — a twin-hulled "fish" — is part of a larger project investigating the chemistry and physics of particulate matter in seawater. Much of the research, with postdoc Henry Pearson and graduate student Iraklis Valioulis, has involved computer simulation to construct mathematical models of the physical processes involved. The little catamaran, with its laser and sophisticated electronics, will be towed behind a larger boat to gather data in the field, that is, under the water, to complement some of these simulations.

The ultimate destination of the particles depends on whether they are deposited as sediment or remain in suspension, eventually to be transported far out in the ocean. Two basic physical mechanisms affect what happens: ocean turbulence and the particle coagulation rate. If the particles collide with each other and coagulate into bigger and bigger particles, they will fall to the bottom. How often they collide is a function of Brownian motion, of differential sedimentation (if some particles fall faster than others, they will catch up and collide), and of the relative velocities of the particles induced by turbulence.



To determine the speed of suspended particles in seawater, a laser is generated in one hull of the catamaran submarine and passed through a beam splitter. Where the two beams intersect between the hulls, particles will create an interference pattern, which is received by the photodiode and transmitted back to the towing vessel.



The "fish" is readied for a test run from the research boat Osprey.

Since turbulence is the major determinant of coagulation of particles between 1 and 100 micrometers (the size of treated wastewater particles), List and his colleagues believe this must be the controlling process in the size distribution of the particles. It is this process that the submarine will investigate.

A key element in the description of turbulence-induced particle coagulation is the rate of dissipation of turbulent kinetic energy, and this can be affected by density stratification. The coastal waters consist of layers of different temperatures. Between the top warm layer, stirred by wind and waves, and the colder, also turbulent, depths below, lies a sharply defined zone, the thermocline, which is somewhat static. The role of the thermocline in damping the dissipation of turbulent kinetic energy is of interest to List, who believes this role has been underestimated. Although the nonturbulent zone would retard mixing with the wider ocean waters, it would also slow down the coagulation rate, maintaining the smaller size particles that would remain in suspension and not settle out.

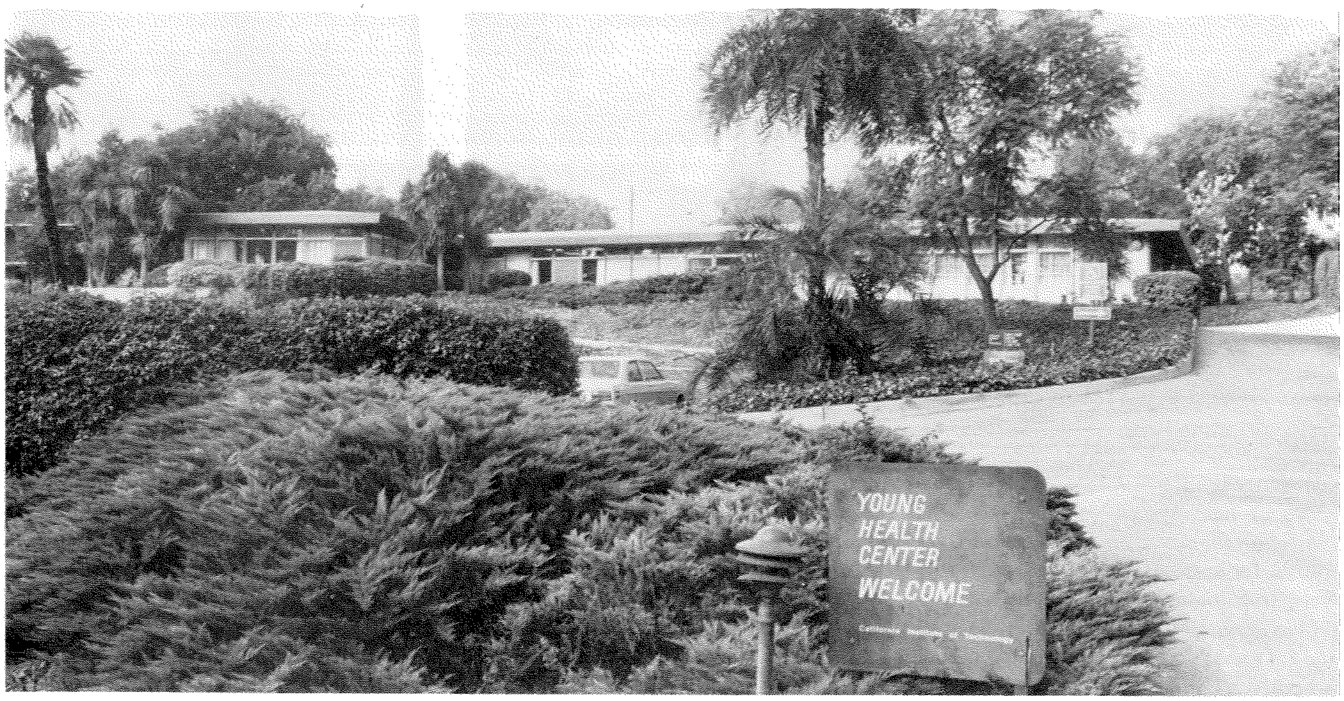
The submarine fish houses a laser-Doppler velocimeter, an instrument that has already revolutionized velocity data measurement in the laboratory. The laser beam is generated in one hull of the catamaran and passed through a beam splitter. The resulting two beams (eventually there will be three) intersect at a point midway between the hulls, and any particle in the intersection (200-300 per second) will create an interference pattern of flashes, which are picked up by a photodiode in the opposite hull. Measurement of the time between flashes gives the speed of the particle. From this speed the rate of dissipation of turbulent kinetic energy can be determined.

As the fish is towed behind a boat, "porpoising" up and down across the stratifications up to 100 meters below the surface, its signals are transmitted to an onboard data storage system through an electrical support cable. Caltech's 32-foot research vessel *Osprey* has been used in testing the submarine, which will soon be ready for its maiden research voyage. Fieldwork is being conducted out of the Kerckhoff Marine Biological Laboratory at Corona del Mar.

The research is funded by the Office of Marine Pollution Assessment and Sea Grant, both of the National Oceanic and Atmospheric Administration, by the National Science Foundation, and by part of a Mellon Foundation grant to Caltech to study the fate of hazardous substances. James J. Morgan, professor of environmental engineering, is co-investigator with List on the project, studying the chemical aspects of coagulation. The hull of the fish was designed by Carl Gibson, associate professor at UC San Diego, originally for temperature and salinity measurements; and James Hunt, now assistant professor at UC Berkeley, developed the coagulation hypothesis for his Caltech doctoral thesis. Graduate student Panayiotis Papanicolaou is also involved in laboratory work associated with the project. □ – *J.D.*

Statement of ownership, management and circulation (required by 39 U.S.C. 3685). 1. Title of publication: Engineering & Science. A. Publication no.: 00137812. 2. Date of filing: November 3, 1981. 3. Frequency of issue: 5 times a year. A. No. of issues published annually: 5. B. Annual subscription price: $7.50. 4 Complete mailing address of known office of publication: 1201 East California Blvd., Pasadena, Los Angeles County, California 91125. 5. Complete mailing address of the headquarters or general business offices of the publishers: Same as above, Public Relations Building. 6. Full names and complete mailing address of publisher, editor, and managing editor: Publisher, Alumni Association, California Institute of Technology, Pasadena, CA 91125; Editor, Jacquelyn Bonner, California Institute of Technology, Pasadena, CA 91125; Managing Editor, none. 7. Owner: Alumni Association, California Institute of Technology, 1201 East California Blvd., Pasadena, CA 91125. 8. Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages or other securities: none. 9. The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes has not changed during the preceding 12 months. 10. Extent and nature of circulation: A. Total no. of copies printed: average during preceding 12 months, 12,720; actual number of latest issue, 13,000. B. Paid circulation: 1. sales through dealers and carriers, street vendors and counter sales: average during preceding 12 months, 10; actual number of latest issue, 10. 2. Mail subscription: average during preceding 12 months, 6368; actual number of latest issue, 6320. C. Total paid circulation: average during preceding 12 months, 6378; actual number of latest issue, 6330. D. Free distribution by mail, carrier or other means, samples, complimentary, and other free copies: average during preceding 12 months, 5811; actual number of latest issue, 6605. E. Total distribution: average during preceding 12 months, 12,189; actual number of latest issue, 12, 935. F. Copies not distributed: 1. Office use, left over, unaccounted, spoiled after printing: average during preceding 12 months, 531; actual number of latest issue, 165. 2. Returns from news agents, none. G. Total: average of preceding 12 months, 12,720; actual number of latest issue, 13,000. 11. I certify that the statements made by me above are correct and complete. Jacquelyn D. Bonner.

On Campus



Healthful Change

THE floor-to-ceiling black plastic curtains that hung at either end of the main hall of the Health Center this last summer were anything but handsome. Handsome is as handsome does, however, and they were effective at screening out the even less handsome clutter that went with the major remodeling project going on behind them. The purpose of the project was to realign some of the building's geometry to accommodate the changes in the nature of student health care that have taken place since the Health Center was built in 1957.

Even at that time the design of the building represented a conservative approach to medical practice. Emphasis was on providing for treatment of the physical problems of patients, and much less attention was given to the need for helping them with emotional problems. Many aspects of that kind of philosophy have now changed, and recognition of this fact dictated this summer's reconstruction, which makes way for an enlarged staff of counselors without displacing medical personnel or services.

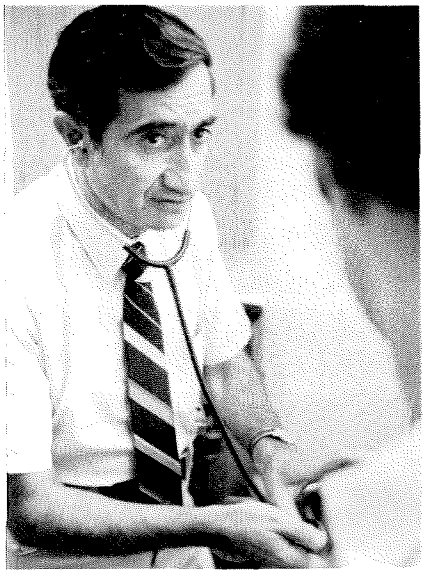
The Archibald Young Health Center was the gift of Mrs. Editha Young in memory of her husband, a Pasadena attorney and philanthropist and a member of The Associates for over 25 years. At a cost of $200,000 a building was erected that had a 10-bed infirmary (two 4-bed wards and two isolation rooms), three physicians' offices, and three treatment rooms, plus X-ray, physiotherapy, and waiting rooms. There was also a convalescent room, a kitchen, and a lounge that could be converted to a 6-bed ward in case of need.

The staff in those days consisted of three part-time physicians, and consultants in radiology and psychiatry. A nursing supervisor managed a white-uniform-clad staff of RNs who worked with the doctors in the general medical office care of patients and the minor surgery performed in one of the treatment rooms. The nurses also did some laboratory tests and operated the infirmary 24 hours a day, 7 days a week throughout the academic year. There was a faculty committee on student health that served in an advisory capacity on matters of policy and administered the Emergency Health Fund, the only available source of funds to help students defray the cost of illness or injury.

The faculty committee still keeps in touch with Health Center activities, but the Emergency Health Fund has been replaced by health insurance, and there have been some basic changes in the way doctors deal with many illnesses. "The whole philosophy of medicine used to be to put patients to bed, keep them warm, give them a rest," says Dr. Gregory Ketabgian, director of health services. "Sometimes, of course, we couldn't do much else for them, but these days we have many effective treatments — like antibiotics, for instance — that get patients on their feet pretty rapidly. Also, we've learned that most of our student patients will recover from their illnesses in about the same period of time whether or not they go to bed. If a student is seriously ill, we may put him to bed here for a day or two, but we try to get him back to his room and his classes as soon as possible."

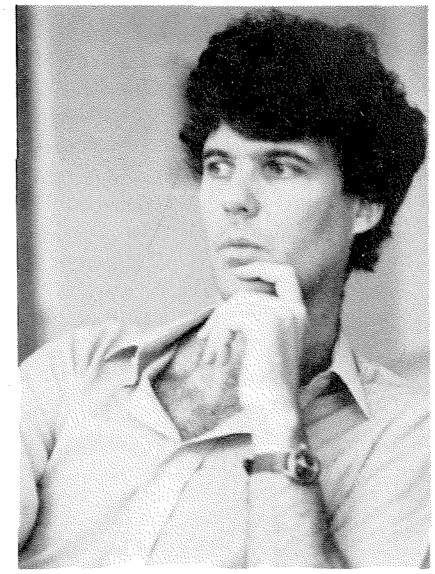
The result of this attitude is that though the stream of patients through the Health Center remains about the same in numbers year after year, the infirmary section of the building and all of its supporting facilities are largely unused. Out of a total of about 5,500 patient visits per year, only about 40 are actually admitted to the infirmary because of illness.

There are some other changes in medical attitudes too. The staff looks more in-



Dr. Gregory Ketabgian

NP Rhonda Campbell



Dr. Bruce Kahl

formal, for instance, because they don't wear white uniforms any more; and the professional relationship between MDs and RNs seems to have changed too. That is mostly because nurse practitioners (NPs) have replaced registered nurses (RNs) on most of the shifts. NPs have all the training in standard nursing procedures that RNs have, but they have additional training and supervised experience that enables them to take an expanded role in patient care. The Caltech NPs see the patients first in many cases, make assessments of their condition, and decide whether an NP is capable of handling the situation or whether it should be passed on to a physician. As a result the NPs actually see more patients than the MDs, a procedure that frees the doctor to spend more time on the cases that need his attention.

This may sound a little free-wheeling, but there's nothing haphazard about it. The NPs act within the framework of written "protocols," which describe in detail the procedures for each of the major problems they are likely to encounter, specifying what they may and may not do and in what circumstances. If there is any doubt at all, the patient is sent on to the physician. Incidentally, this procedure is explained to each new patient, and he or she makes the choice of going along with the NP or seeing the doctor.

Another kind of safeguard is an "internal audit" procedure in which a staff committee makes a monthly review of a random selection of the charts that are kept on all patients. If the chart fails to meet the standards for completeness, clarity, and other criteria, it is sent back to the person responsible, and that may be (and has been on occasion) a physician. This assures adequate charting, which is important in a situation where a different staff member may see the patient at different times, and it is also educational for everyone concerned. Education is a big project at the Health Center; in fact, one of the items that is supposed to be found on each chart is that the patient has been "educated." The medical and nursing staffs try to make sure the patients understand the nature of their illnesses, what complications might arise, and when they should call the doctor or come to the Health Center.

One of the strong proponents of more emphasis on health education for the students is Rhonda Campbell, who is supervisor of nursing services. A ten-year veteran of the Health Center, she is enthusiastic about the changed and changing approach to patient care and about student participation in bringing about the changes. One of the groups she has worked with is the Student Health Advisory Committee (SHAC), a group of student volunteers interested in health. Over the last year or so they have conducted a survey of health-related questions among students and organized a seminar on crisis intervention, and they are preparing a booklet on health. This year most of the staff will also be participating in a year-long training program for a group of students who hope to become volunteer paraprofessionals able to provide peer health services and counseling.

One of the most popular student/Health Center interfaces has taken place on the pages of the student newspaper, *The California Tech*. Under the leadership — and some prodding — of NP Lynnette Wilmoth, a weekly column discussing some aspect of health problems and care appears as "The Body Shop." Some 20 columns were written last year by five different members of the staff on such topics as tanning, warts, acne, jogging, sleep, flu, hiccups, mononucleosis, colds, contraception, poison oak, stress, diet, acid burns, appendicitis, exercise, and longevity.

All of these activities — and more — are covered by the Health Center medical staff of four part-time physicians. In addition to the director of health services, Dr. Ketabgian, there are Drs. Judson James, Marlene Coleman, and Haig Manjikian, attending physicians. Dr. James is a surgeon who takes care of most of the athletic injuries and is an enthusiastic spectator at a lot of the athletic events, and Dr. Coleman acts as a counselor for students interested in pre-medical academic work. There are three NPs on regular duty — Campbell, Wilmoth, and Leila Costa — and two or three RNs give part-time service. Barbara Montgomery is the one who usually handles the middle-of-the-night problems. Secretary Anita Duran directs patient traffic during clinic hours, types charts, and deals with insurance.

This adds up to very little growth in the numbers of medical staff over the past 25 years. The situation is quite different in the case of the counseling staff. From one part-time consulting psychiatrist, that has grown to the equivalent of 2½ full-time professionals. Dr. Bruce Kahl is a psychiatrist who spends half time as director of counseling services. He is joined by two part-time clinical psychologists, Drs. Barbara Fass and Robert Drezner, and psychiatric social worker Jenny Fuss.

In the course of this growth, the accommodations found for the counselors have tended to be makeshift, inconvenient, and carved out with some loss to the medical people. Finally, last spring the decision was made to convert the west end of the infirmary wing to counseling use. The counselors now have four offices, a separate entrance (from the parking area on the west side of the building), and their own clients' waiting room. This leaves the old infirmary wing with five beds (in three rooms) and the lounge, and all other medical activities (including a new staff conference room and enlarged lab space) are consolidated in the north end of the main wing.

Everybody seems happy with the new arrangements, including troubled students who appreciate the privacy made possible by the new counseling setup. The lower visibility for those waiting to see a counselor because they don't have to share a waiting room with a fellow student waiting to get an allergy shot is important. The separation from both the idea and the reality of illness is also important.

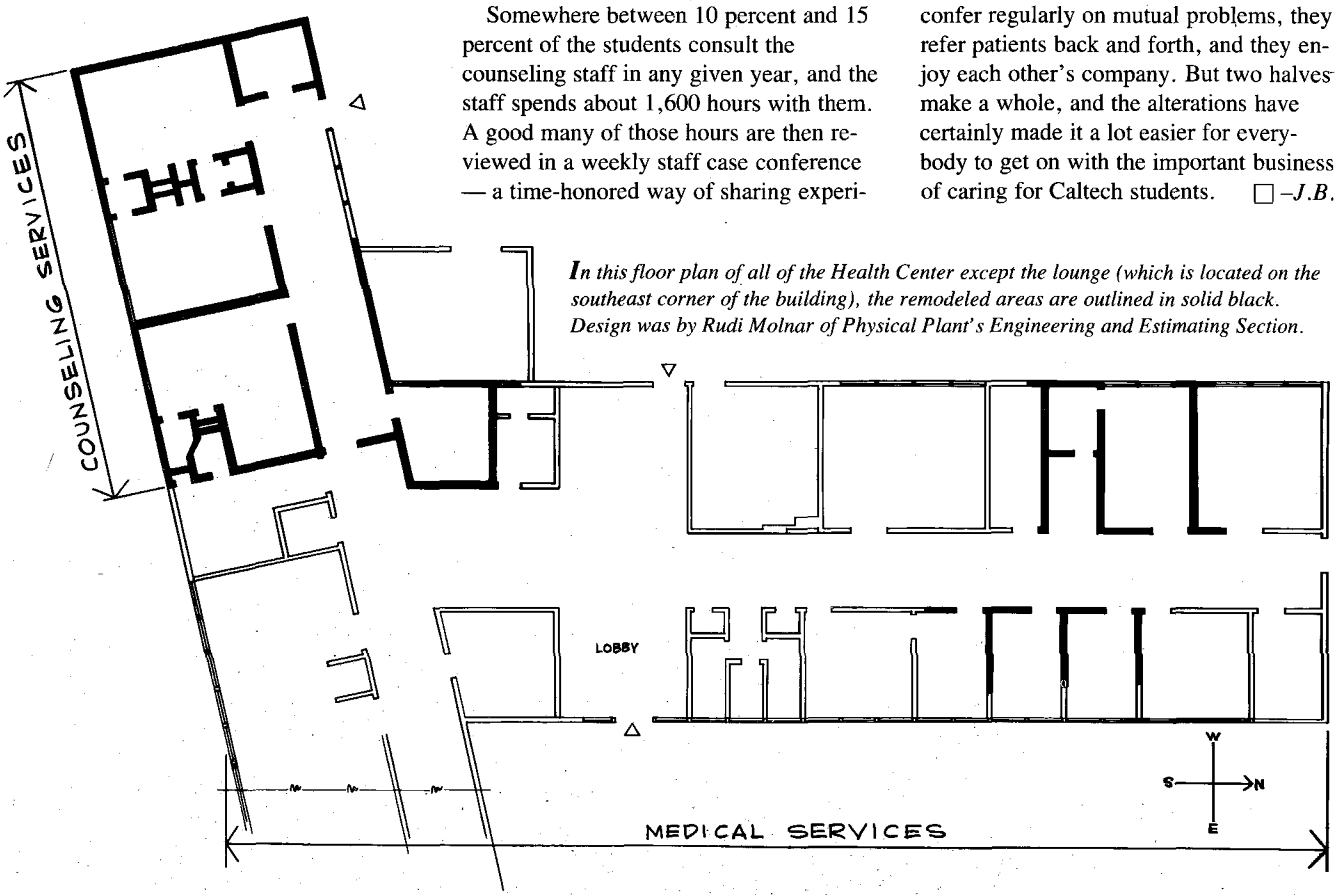
The counseling staff tries to emphasize that they are not in the business of treating illnesses but rather of helping people solve problems — and everybody has problems. A lot of the ones the Caltech counselors encounter grow out of the fact that Caltech students are quite young and very bright. Many of them are trying to establish their own identities in terms of their concept of themselves and their vocational choices. There are students who are depressed, many because of transferring from the security of a predictable home and academic environment to a dormitory and new academic and social pressures. They have study problems and relationship problems and questions about the rightness and wrongness of their decisions — and a host of other problems quite natural to high achievers in their age group.

What the counselors try to do in their sessions with these students is to help them come to understand why they do what they do (or don't do) or feel the way they feel (or don't feel). Most of the sessions are one-to-one, and most of the therapy is fairly short term. Some people come in just to get clarification on a particular issue and/or validation for their point of view, and that doesn't usually take many meetings. The majority see the counselors from 5 to 15 times. For a few, longer term therapy is indicated, and occasionally there are serious crises, statistically less often, interestingly enough, than in the general population. Occasionally, as a last resort, a student must be hospitalized, though none was in the academic year 1980-81.

Somewhere between 10 percent and 15 percent of the students consult the counseling staff in any given year, and the staff spends about 1,600 hours with them. A good many of those hours are then reviewed in a weekly staff case conference — a time-honored way of sharing experience, problems, and ideas. Occasionally outside experts are brought in to make presentations, and local psychiatrists are available as consultants.

Not all the activities of the counselors are directly involved in therapy. Along with their medical colleagues, they are also dedicated to trying to educate their constituency. One approach is through a peer counseling program with undergraduate students — about 10 or 20 a year — who are not in the program to learn to do any sophisticated counseling but to spot potential problems among their peers, to talk with those who need someone to talk to, to suggest going for help to some, and to alert the appropriate people — counselors, RAs, and deans, for example — if they suspect major difficulties in the offing. Career counseling seminars have been conducted by the staff, and some have taught academic psychology courses for the Division of the Humanities and Social Sciences. Right now they are working on ways of increasing communication with graduate students and with the RAs and on establishing closer ties with the Dean's Office and the Master of Student Houses.

The black plastic curtains are long gone now, and the new paint already has a scratch or so, but the two halves of Caltech's student health services are comfortably settled into their separate areas in the Young Health Center. This doesn't mean in any way that they are divided; they confer regularly on mutual problems, they refer patients back and forth, and they enjoy each other's company. But two halves make a whole, and the alterations have certainly made it a lot easier for everybody to get on with the important business of caring for Caltech students. □ *—J.B.*



In this floor plan of all of the Health Center except the lounge (which is located on the southeast corner of the building), the remodeled areas are outlined in solid black. Design was by Rudi Molnar of Physical Plant's Engineering and Estimating Section.

Random Walk

Keeping the Block Rolling

In this photo by Linda Glick, Caltech alumnus John D. Bush (between the ropes) is demonstrating his theory that the ancient Egyptians could have built the pyramids by lashing segment-shaped cradles around blocks of stone and then parbuckling them up a ramp.

FOUR years ago *E&S* published an account by alumnus John D. Bush (BS '55) of his theory about how the Egyptians built the pyramids ("The Rolling Stones," October 1977). Not, he said, by 100,000 or so slaves being driven by whip-cracking overseers to haul the massive stones, inch by inch, up a pyramid's 8-degree incline. The Egyptians were probably a lot smarter than that, and, besides, they didn't have that large a labor force. Bush thinks they might have done the job using wooden cradles (which they knew about), lashing four of them around blocks of stone to make a cylinder. Such a device could have been parbuckled up an inclined plane by a relatively modest number of workers. He calculates that this technique would have enabled as few as a thousand men to raise all the blocks in the Great Pyramid in 20 years. No hordes of slaves were needed.

Bush's story was subsequently reprinted by *Science Digest* and *Smithsonian* magazines, and there have been a few other accounts, but the response from the archaeological world has been deafening silence. A logical next step for Bush seemed to be a public demonstration, and it took place on October 17 at the Boston Sand and Gravel Company in Charlestown, Massachusetts. Four wooden cradles were tied to the faces of a 2¼-ton concrete block so it would roll like a drum, and a rope sling was hooked over an upright at the top of a 25-foot-long, 10-degree ramp. The ends of the rope were passed under the cylinder, across the top, and into the hands of six men, forming a parbuckle. With the song "Just Like a Rolling Stone" sounding out, the crew took hold and began to pull. One minute, 32 and 29/100 seconds — and a little panting — later the block rested at the top of the ramp. To prove the feat wasn't an accident, the group did it again, bettering their first time by 3/100 of a second.

Consulting engineer Bush is encouraged by the success of his experiment, which seems to validate his theory. The pyramids *could* have been built this way. Maybe someday a lucky and/or perceptive archaeologist will find out whether they actually were.

Medals for Merit

AMONG tangible honors awarded to scientists for distinguished research are various badges, ribbons, medals, and other decorations. Over the years Caltech's faculty have received a great many of them. As a part of last fall's 90th birthday celebration, a small sample was assembled, which we show below with a chart coded for easy identification. Number one is the James Douglas Medal (American Institute of Mining and Metallurgical Engineers), awarded in 1940 to trustee Louis D. Ricketts. Numbers 2, 5, 6, 11, 14, 19, and 22 belonged to Theodore von Kármán. They are, in order: the first National Medal of Science; the first von Kármán Medal (AGARD/NATO); Timoshenko Medal (American Society of Mechanical Engineers); Ludwig Prandtl Ring (German Society for Aeronautics); Vincent Bendix Award (American Society for Engineering Education); Medal of the Royal Aeronautical Society; Daniel Guggenheim Medal (also ASME). Numbers 3 and 4 are Davy Medals (the Royal Society) presented to Arthur Amos Noyes. Robert A. Millikan earned nine of this group — numbers 7, 8, 10, 12, 13, 15, 17, 20, and 21 — which are, in order: his decorations for becoming a Chevalier of France's National Legion of Honor; Franklin Medal (Franklin Institute); Faraday Medal (London Chemical Society); Medal of Honor (Roosevelt Memorial Association); Medal (ASME); Hughes Medal (the Royal Society); Nobel Prize Medal (Royal Swedish Academy); Matteucci Medal (Italian Society for Science); and the medal of the Society of Arts and Sciences. Numbers 9 and 16 were awarded to Alfred H. Sturtevant by the National Academy of Sciences; 9 is the Kimber Genetics Award, and 16 is the Carty Medal. Number 18 is a medal awarded to Thomas Hunt Morgan by the Institute of France.