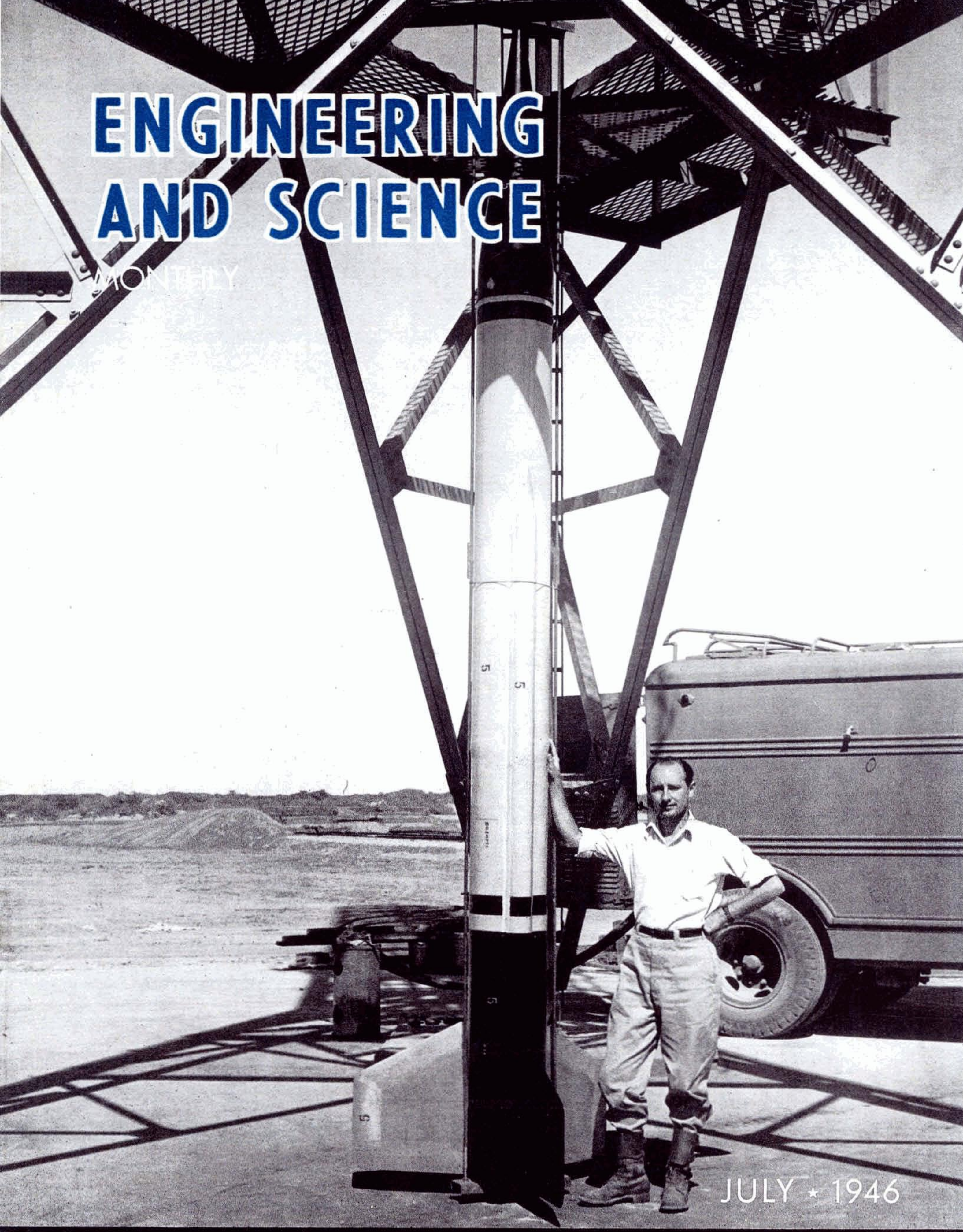
# ENGINEERING AND SCIENCE

MONTHLY



JULY ★ 1946

PUBLISHED BY CALIFORNIA INSTITUTE OF TECHNOLOGY ALUMNI ASSOCIATION

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## Index to Advertisers



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**COVER ILLUSTRATION**

**Dr. Frank J. Malina with the WAC CORPORAL, high altitude smashing rocket developed by the Jet Propulsion Laboratory, GALCIT, for the Ordnance Department, A.S.F. The rocket is capable of reaching an altitude of around 230,000 feet in vertical flight.**

**Dr. Malina was a member of the original rocket research group.**


# ENGINEERING AND SCIENCE

*Monthly*

*The Truth Shall Make You Free*


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**ENGINEERING AND SCIENCE MONTHLY**

***Edited at California Institute of Technology***

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## THE PRIVATE A

Driven by a solid-propellant rocket thrust of 1,000 pounds for over 30 seconds, the Private A reached a maximum range of 20,000 yards (11.3 miles) when fired at tests carried out at Leach Springs, Camp Irwin, near Barstow, California, between December 1 and 16 of 1944.

# ENGINEERING AND SCIENCE
## Monthly

Vol. IX, No. 7 July, 1946


Dr. Theodore von Karman, center, Director of GALCIT, confers with members of the rocket research group who are, left to right—Dr. C. B. Millikan, Dr. Martin Summerfield, Dr. von Karman, Dr. F. J. Malina, and Captain H. A. Boushey, Jr.

## RESEARCH AND DEVELOPMENT AT THE JET PROPULSION LABORATORY, GALCIT[1]

THE Galcit Rocket Research Project was initiated more or less informally in 1936 at the California Institute of Technology with full encouragement of Dr. Theodore von Karman, Director of GALCIT. The original research group was composed of Frank J. Malina, Hsue-Shen Tsien, A. M. O. Smith, John W. Parsons, Edward S. Forman, and Weld Arnold. Early phases of the research were financed by a gift from Mr. Arnold. It was Dr. von Karman who foresaw the importance of rocket propulsion and the great possibilities of Caltech research in this field. A theoretical and practical research program was conducted during the next two years, and in December of 1938, General H. H. Arnold, Commanding General of the Army Air Corps, requested a group of scientists comprising the Committee for Air Corps Research of the National Academy of Science to sponsor a program for several problems of vital interest to the Air Corps. One of these problems was the development of rocket units suitable for boosting airplanes. Dr. Theodore von Karman chose the rocket problem for Caltech and the committee appointed a sub-committee on Jet Propulsion with him as chairman. In July, 1940, the Army Air Corps effectively assumed sponsorship of the Project, and during the first two years of the war when the United States was working to make up lost time, the GALCIT Project was constantly expanding.

The many sub-contractors who were called in to lend their special skills to the success of the Project invariably gave the utmost of their ingenuity, cooperation, and loyalty.

The articles contained in this month's *Engineering and Science* were based on a release by the Committee on Publications of the California Institute of Technology for the California Institute of Technology, A.A.F. Materiel Command, and A.S.F. Ordnance Department, prepared by Professor Roger Stanton.

[1]GALCIT is a composite of the capital initial letters in the following: Guggenheim Aeronautical Laboratory of the California Institute of Technology. This abbreviation is widely used both in this country and abroad.

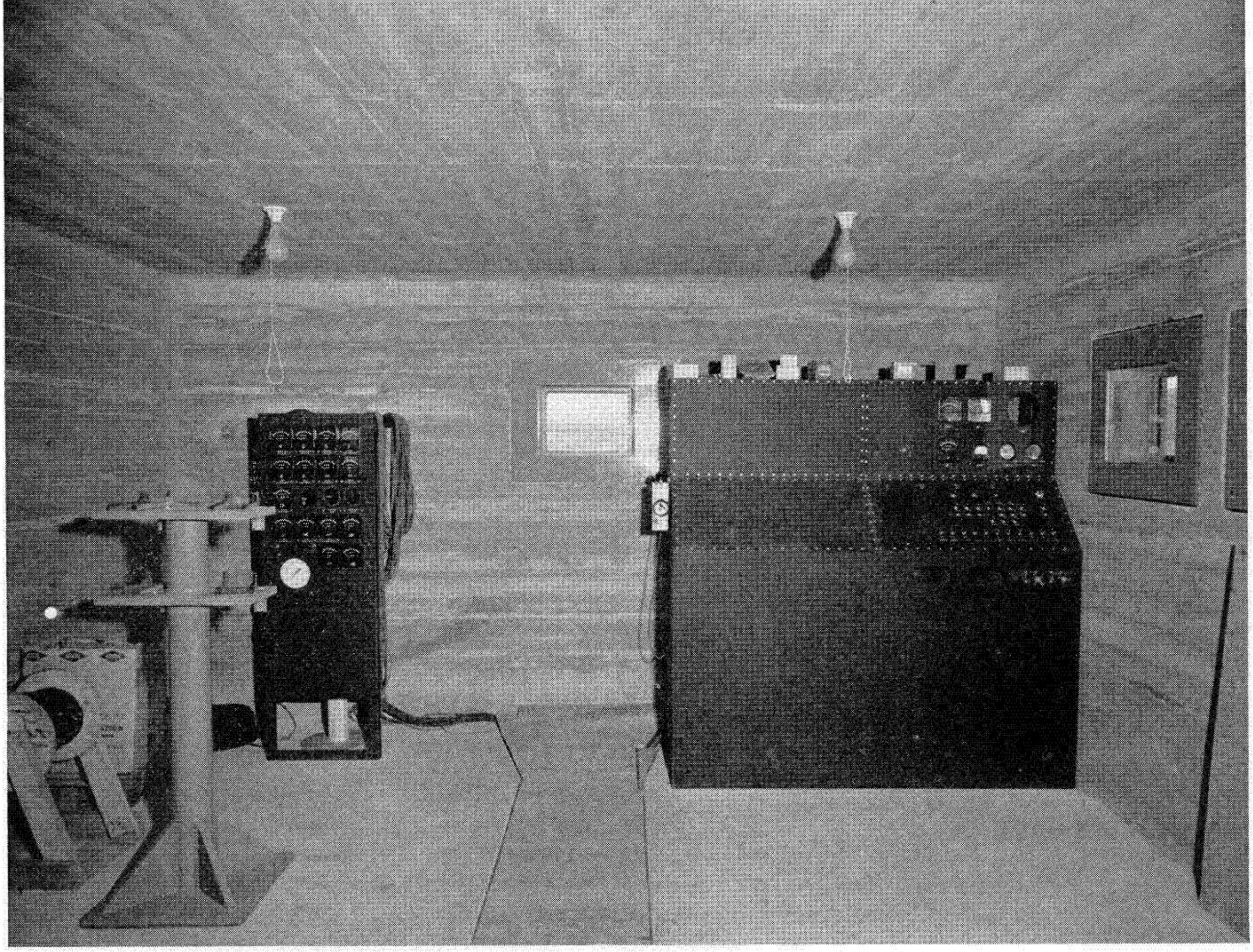


FIG. 1. The Muroc Test Station control room at the Muroc Army Air base, California.

THE Jet Propulsion Laboratory is located within a fenced enclosure covering approximately forty acres near the western limits of the city of Pasadena, California. Within the enclosure are more than eighty structures of widely-varied types. Dominating the entrance is the Administration Building. Beyond it are numerous test pits for the development of propulsion systems for solid and liquid-propellant rockets, and for ramjets and turbojet engines; laboratories for research in high-temperature resistant materials, and the processing of solid propellants; a towing channel for research on underwater missiles; and machine, sheet metal, and welding shops.

Under construction is a compressor house to supply highly-compressed air for thermojet research.

The staff at the Laboratory numbers more than 385. The facilities with equipment are valued approximately at $3,000,000.

Various laboratories on the campus of the California Institute of Technology also are utilized; for example, the 10-foot wind tunnel of the Guggenheim Aeronautical Laboratory. Expert consultation on special problems is provided by staff members in several departments. A Chemistry Group, under the direction of Dr. B. H. Sage of the Department of Chemical Engineering, has been conducting special research for the Laboratory for several years.

A test station for the investigation of large, liquid-propellant rocket units is being operated by the Laboratory for the A.S.F. Ordnance Department at the Muroc Army Air Base, California, parts of which are shown in *Fig. 1* and *Fig. 2*.

Numerous contracts under the different research projects have been placed with industrial organizations in various parts of the United States, including many companies throughout the Los Angeles area.

## JATO STUDY BEGUN

The research begun in 1939 on Jet-Assisted Take-Off for Aircraft under the auspices of the National Academy of Science, continued the modest work that had been initiated in 1936. It was understood, as it continues to be, that the Laboratory primarily should be concerned with the solution of basic research problems, to enable the Armed Services to develop equipment of novel type.

One of the immediate objectives of Frank J. Malina, John W. Parsons and Edward S. Forman, appointed to carry out the research program for the first year, was to develop two types of rocket motors; one, utilizing the energy of a solid propellant, the other, a liquid propellant. Both types had to be capable of delivering a constant and sufficient thrust for a period long enough to assist a plane to take off and reach an altitude considered safe to continue its flight unassisted. The period specified was of the order of ten to thirty seconds.

The first year was devoted mainly to a survey of early experience in the field and to study of the fundamental properties of propellants. Little information was available on powder rockets with duration longer than one second. Two ways suggested themselves to solve the problem of delivering a prolonged thrust. The first was to install in a plane a group of motors loaded with fast-burning solid charges, and to fire them one at a time in quick succession so as to produce a prolonged thrust. Experiments conducted by a number of investigators were discouraging in that successive firing at split-second intervals was not dependable; hence thrust was delivered not constantly but by fits and starts, strenuous on pilot and plane alike. The second way that suggested itself was to develop a restricted-burning propellant that would burn at one end only, like a cigarette, in order to produce a constant, prolonged thrust. Profiting by knowledge of the difficulties encountered in attempts to develop the first method, the Project directed its efforts toward development of the second.

The first experiments were conducted with commercial stick powders, made to specification. The experimental motor was built of steel tubing two feet long and one inch thick. The inside diameter was three inches. One end was plugged; the other end was fitted with a pipe flange eight inches in diameter. The motor nozzle also was fitted to a flange to match the one on the motor so that the nozzle and motor were connected by bolting the two flanges together. The bolts, made of relatively soft steel, were of a diameter calculated to give way when pressure inside the motor became dangerously high; thus the nozzle was permitted to fly off and save shattering the motor. Powder charges were ignited at the nozzle end of the motor by an electric squib; near the nozzle end, also, the motor was tapped to permit pressure measurements.

One of the dangers anticipated in the operation of the experimental motor was that, under the pressure created, the gaseous flame at the end of the solid powder stick might strike down between the charge and the chamber wall. If it did, the whole charge would burn so rapidly that the result might be an explosion. Or, possibly, the transfer of heat down the walls of the chamber might ignite the whole charge. To prevent such possibilities, experiments were conducted with various types of liners whose function it was to seal off effectively the space between the powder and the chamber walls so as to restrict burning to the end of the stick.

Over a two-year period, with personnel augmented only in the second year, the Project made many hundreds of tests. Different powder combinations were tried with various loading techniques, and with dissimilar nozzles. By the summer of 1941, a dependable, small-scale motor and a propellant had been developed and put into limited production for experimental purposes. The motor delivered a maximum thrust of 28 pounds for 12 seconds. Unloaded, the unit weighed 10.7 pounds; the powder charge weighed approximately 2 pounds.

The propellant developed, named GALCIT 27, was an amide powder prepared from commercial ingredients. Each two-pound charge had to be pressed into the combustion chamber of the motor in a series of 22 separate increments, each under a pressure of 18 tons. Loading with large, hence fewer, increments, or loading under lighter pressure, produced powder sticks that were likely to explode.

### THE ERCOUPE FLIGHT TESTS

Calculations had revealed that the combined thrust of six of the new motors was sufficient to justify their application to a light airplane. It was feasible, moreover, to fire six of the units simultaneously.

The Germans already had used jet propulsion to assist gliders into the air. We Americans had not. Our knowledge was limited to calculations based upon theory. Obviously, data based on actual tests were much needed to check against theoretical predictions of the distance jet propulsion could shorten take-off, with and without overloading a plane. If experiment proved the theoretical calculations to be sound, then they could be relied upon to predict the performance of any airplane equipped with jets. It was desirable to know, too, what effect the jet thrust would have upon the stability and control of an airplane, and what effect the hot jet blasts would have upon the plane structure.

For flight tests, therefore, the Air Materiel Command made available to the Project a low-wing monoplane, known as the Ercoupe. Its weight, empty, was 753 pounds. Captain H. A. Boushey, Jr., the test pilot, flew the plane from Wright Field, Dayton, Ohio, to March Field, near Riverside, California. Two identical assemblies, each incorporating three rocket units, were installed on the plane, one assembly under each wing. As a safety precaution in case of explosion, each unit was designed so that both the exhaust nozzle and the combustion chamber were free to fly clear of the plane.

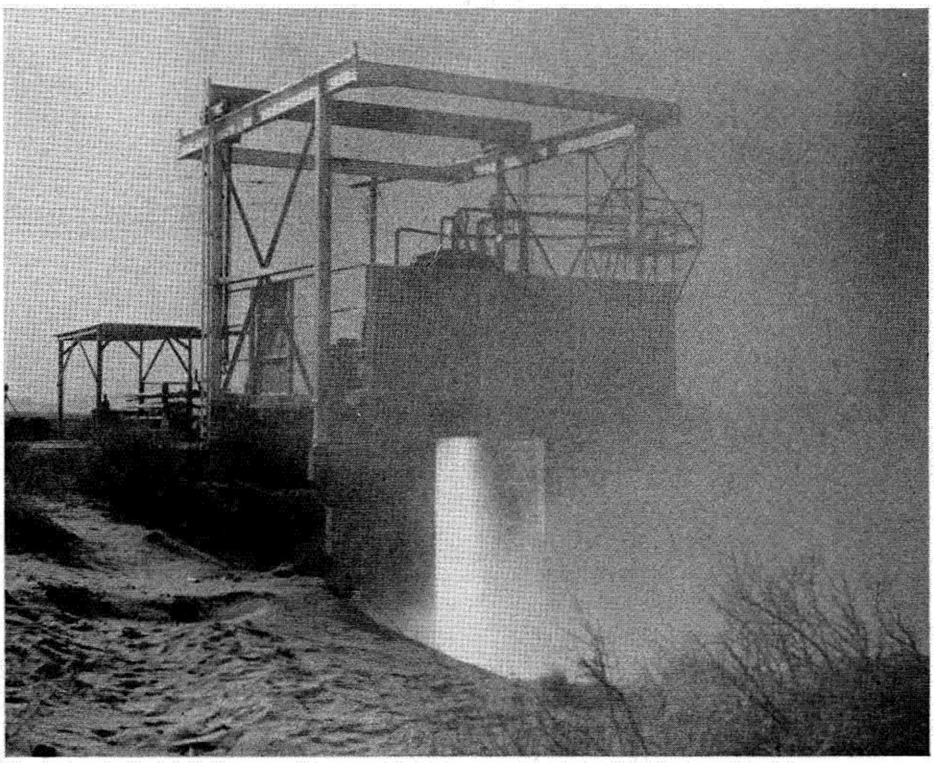


FIG. 2. The Corporal E motor in operation at the Muroc test station. In designing the Corporal E a new method of fabrication and assembly had to be introduced.

FIG. 3. Ercoupe take-off assisted, versus Porterfield take-off unassisted.

An electrical switch, mounted on the control panel, controlled ignition of the rocket motors.

The test program was conducted at March Field, August 6 to August 23, 1941. Witnesses, including both Army and Navy personnel, viewed the first take-off in the United States of an airplane assisted by jet propulsion. With the exception of several failures in preliminary trials, the tests were successful, the experimental results checking satisfactorily the theoretical predictions.

With jet assistance, shown in *Fig. 3*, the distance required for the plane to take off was shortened from 580 feet to 300 feet, a saving of 48.3 per cent. The time required to take off was shortened from 13.1 seconds to 7.5 seconds, a saving of 42.8 per cent. With an overload of 285 pounds, the distance was shortened from 905 feet to 438 feet, a saving of 51.6 per cent. The time was shortened from 18.8 seconds to 9.5 seconds, a saving of 49.4 per cent.

The operation of the jet units, 152 being operated in succession without the failure of a motor, had no adverse effect upon either stability or control or upon the plane structure. The pilot remarked, in fact, that the auxiliary thrust had made easier the handling of the plane throughout the take-off run. In short, results of the flight tests fully justified proceeding with plans to develop and test both solid and liquid-propellant jet motors designed to deliver 1,000-pound thrust.

LATER DEVELOPMENTS OF JATO

Simulating a period of twenty-eight days, tests were run to determine the keeping qualities or storage life of the new propellant, GALCIT 27. Under test it deteriorated too fast for use in the services. Shrinkage of the powder stick tended to draw it away from the liner, thus breaking the seal of the propellant across the diameter of the combustion chamber and permitting flame to penetrate below the surface and cause an explosion. In September an experimental program was started to improve both liner and powder.

Early in 1942, while the program was still in progress, the report of the Navy Officer who had witnessed the Ercoupe flight led to action. The Navy contracted with the Project to develop for experimental purposes a jet unit, with acceptable storage life, to deliver 200-pound thrust for eight seconds, shown in *Fig. 4*. The Project planned to incorporate in the unit the improvements expected to result from the program in progress. In May a greatly improved solid propellant and a suitable motor were ready for testing. The improved propellant was designated as GALCIT 46.

Meantime, the Project had been investigating the whole subject of solid propellants with the intent to develop one better than GALCIT 46. The latter had good storage life, but good only within too narrow a range of ambient temperatures for use in global warfare, which demands propellants suitable for use anywhere from Alaska to Africa.

To determine chances for success with any formula combining ingredients essential to all types of propellant like GALCIT 46, an investigation was made of the crystalline properties and the thermal expansion rates of such ingredients. The investigation suggested that both crystalline changes and expansion rates, over a wide range of temperatures, varied so that probably any compound would crack and disintegrate in burning.

After exhausting other possibilities, the investigators turned to a radically different type of propellant made by a different process, namely casting the ingredients in a mold rather than compressing them. What they turned up with was designated as GALCIT 53, the number being suggestive of the amount of developmental work the Project had done on solid propellants.

First tests of the molded propellant were made in June, 1942—by coincidence while the test program on GALCIT 46 was still running its course. GALCIT 53 showed such promise that the Project decided to give it priority over the other, to hasten its full development.

The oxidizer in GALCIT 53 was potassium perchlorate, in form a white powder. In addition to being plentiful, it combines the optimum in available oxygen, heat of combustion, and chemical and physical stability. The fuel in the new propellant was a special type of asphalt; added to it was a small percentage of oil with an asphalt base.

The mixture was prepared by heating the asphalt and oil in a mixing kettle to a temperature of 350°F., then stirring in the perchlorate. Before the combustion chambers were loaded with the finished propellant, they were lined with a hot mixture of asphalt and oil. When the propellant had cooled sufficiently, it was scooped into the combustion chambers, which were bounced a few times to assure uniform settling, then set aside for the propellant to harden.

In its finished form, GALCIT 53 is a black plastic, at ordinary temperatures resembling stiff paving tar. It can be detonated with difficulty if at all. Only with patience can it be ignited with a match flame; but once ignited it burns fiercely, emitting a white light and dense white smoke. Burning in a combustion chamber under pressure of 1,800 pounds per square inch, the propellant gives an average exhaust velocity of 5,300 feet per second at an average burning rate of 1.25 inches per second.

The new asphalt-base propellant had several advantages over all the earlier ones. It was easier to prepare, and ingredients were more readily available; it could be stored at wider temperature limits, and within those limits it could be stored indefinitely without deteriorating, whereas the earlier propellants had a tendency in storage to pull away from the liner, leaving tiny cracks, which led to explosions.

Units loaded with the new propellant were recommended to be fired at temperatures between 40°F. and 110°F. Much above the recommended temperature it became viscous and flowed. Therefore, it was imperative that invariably the JATO units be stored right side up, as they are in *Fig. 4*.

The rocket motor designed for use with GALCIT 53 was constructed to meet specifications set by the Bureau of Aeronautics, Navy Department. It was approximately thirteen inches long and five and one-half inches in diameter. The nozzle plate, which was screwed into the end of the combustion chamber, was equipped with a nozzle, an ignition squib, and a safety device, called a blow-out plug. The plug was a copper disk designed to blow out at a pressure approximately of 3,000 pounds per square inch, thus permitting excess gases to escape. To prevent danger from flying pieces and temporary excessive thrust of the jet unit at the instant of failure, a cap with four holes in its side walls was screwed over the disk. The holes in the cap permitted the gas flow to emerge in four jets which mutually canceled thrust in any one direction.

In 1943 the Navy, having a greater use for jet-assisted ake-off than the Army, began placing large orders for motors delivering not only 200, but 500 and then 1,000-pound thrust.

### RED FUMING NITRIC ACID AS AN OXIDIZER

As part of their work between 1936 and 1939, the GALCIT Research Group had made some preliminary study of liquid oxidizers, starting with a review of the data their predecessors had made available. After four months of work in 1939, they had reduced to four the compounds that recommended themselves for further study. Within an additional six weeks, by still more rigorous process of elimination, they had reduced the four to one; namely, red fuming nitric acid, a solution of nitric acid and nitrogen dioxide, with the chemical formula $HNO_3NO_2$.

The Project celebrated its first birthday, July 1, 1940, by initiating a program for the development of nitric acid as an oxidizer. For the time being at least, the many difficulties inherent in the development of liquid oxygen could be forgotten. The way was open to develop, as directed by the Army Air Corps, a liquid-propellant rocket unit to deliver 1,000-pound thrust for approximately one minute.

### THE FIRST 1,000-POUND THRUST MOTOR

Engineering practice suggested that the development of the projected motor and its assembly should proceed, not in a single step from a small model to the full-size one, but through intermediate models graduated in size, in order to minimize the difficulties likely to arise as scale increases. Another reason for making haste slowly was that manpower and facilities were strictly limited. As a starter, then, the Project designed a unit to deliver thrust of 200 pounds.

Time out to clear ground and construct buildings during the summer of 1940 delayed development of the projected unit. But late in February, 1941, it was assembled in the new test pit designed to house it. One end of

FIG. 4. Motors with 200 pound thrust, 8 second duration, ready for delivery to the U. S. Navy.

FIG. 5. A bi-motor Douglas bomber, the A-20A, takes off assisted by two 1,000 pound thrust, 25 second duration liquid motors.

the structure was left open to expedite the escape of fumes. The open end faced into a hillside, where the solid earth should act as a cushion for flying missiles in case of explosions. As an added precaution, walls were built of heavy railroad ties set upright like the timbers in a stockade.

The chief difficulty in tests on the unit was with ignition. Unless it was instantaneous—and often it was not—such quantities of propellants collected in the chamber that, when they did ignite, the motor blew up.

The first tests were a decided disappointment. Sometimes ignition was delayed; sometimes it failed altogether. And in addition a new trouble appeared. Sporadically, the motor began to pulse, slightly at first but increasing in intensity until at the fourth or fifth throb, if not shut off, it would blow up.

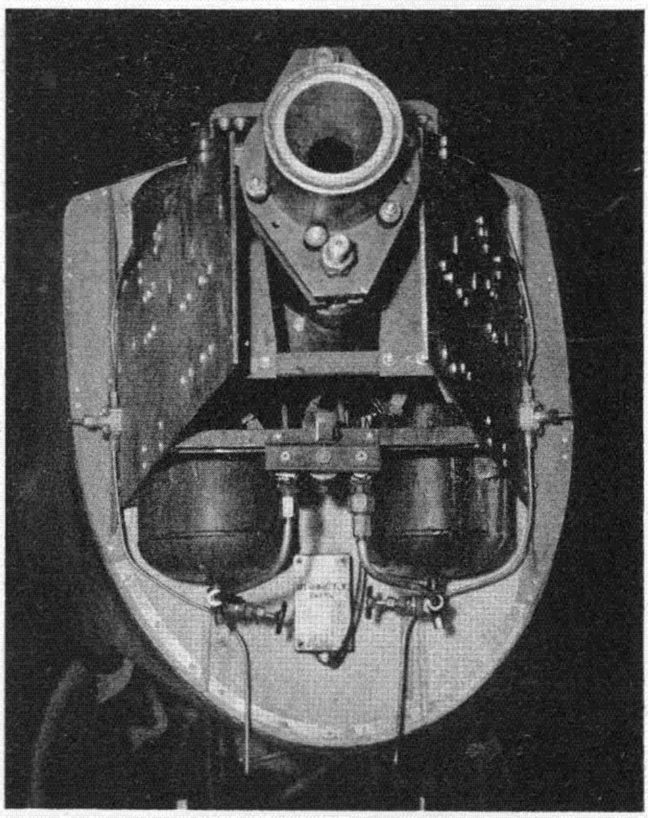


FIG. 6. A 1,000 pound A.T.O. unit on an A-20A airplane with the nacelle cone removed.

For four months the Motor Group labored to improve ignition and combustion, and to stop throbbing. In the end, though ignition was improved so that it worked possibly 80 per cent of the time, throbbing still presented a baffling problem.

### ANILINE AS A FUEL

At the Naval Experiment Station, Annapolis, Maryland, another group of investigators had been having trouble with the combustion of nitric acid and gasoline. They suggested, talking it over with Dr. Malina who was visiting the Station, that perhaps the addition of aniline to the gasoline might help. Dr. Malina telegraphed his group in Pasadena, suggesting aniline, not simply as an additive to gasoline but as a substitute for it.

Put into practice, the suggestion worked. Not only did it work, but it led to the discovery in the United States that aniline is spontaneously combustible with red fuming nitric acid. Thus, at once, ignition, combustion, and throbbing problems were solved.

But there was still a serious question to be decided. Should the attempt be abandoned to develop gasoline as a fuel in favor of aniline? Gasoline has a great advantage for military operations in that it is available, as are facilities for handling it and operators who know how. Aniline, on the other hand, though available, is a toxic liquid that affects the blood, and it is readily absorbed through the pores of the skin. If adopted, facilities for handling it would have to be developed, and crews would have to be taught how to use it properly. But the decision was made, in the end, to adopt aniline.

### THE A-20A FLIGHT TESTS

The chief purpose of the projected flight tests was to gain information about air-borne equipment and control devices essential for practical application to liquid-propellant rocket units.

The choice of an airplane suitable for mounting and testing a pair of units, each with 1,000-pound thrust for a duration of approximately 25 seconds, settled upon a bi-motor Douglas bomber, the A-20A which is shown taking off in *Fig. 5*. The weight of the plane, empty, was 14,000 pounds. Its tail surfaces were high enough to clear the jets from the motors; and the nacelle tail cones, which projected rearwards well behind the wings, provided ample space to house a unit. This space is used sometimes to mount a machine gun firing aft.

The Design and Control Group was responsible for all installations. Early in the winter of 1941, the Group was engaged in preparing a complete mockup, or dummy, of the motor and all the equipment, exactly as the assembly would be mounted in the A-20A. The work was expedited in January when the A.A.F. sent detailed drawings of the plane and an actual nacelle cone to work with. *Fig. 6* shows a 1,000-pound JATO unit on an A-20A airplane, nacelle cone removed.

A simplified description of the assembly and its installation in the plane is as follows: the nitrogen tanks to supply pressure for the propellants were located in the forward bomb bay, with a line leading to each nacelle cone. In each cone were located a motor, two propellant tanks, and a valve—actuated by hydraulic pressure—to control the propellant supply. The end of each cone was cut off in order to give the exhaust nozzle necessary clearance. In the rear cockpit were six pressure gauges to measure the performance of the installation, and eleven controls, all accessible to the operator stationed there.

Among the numerous safety precautions taken, two especially deserve notice. Each motor, mounted on slides, was restrained by hydraulic thrust jacks in order to permit recoil so that, if there was an explosion, the plane would not have to absorb the forward thrust of the combustion chamber. The purpose of the second precaution was to avoid destructive thrust if the nozzle was blown off. It was coupled to the motor body by a pair of shock absorbers so that the two units could react upon one another instead of one of them reacting on the plane; moreover, both of them would be brought to a full stop within a few inches.

The flight tests with the A-20A were conducted at the A.A.F. Bombing and Gunnery Range at Muroc, California, April 7 to April 24, 1942. The pilot was Major P. H. Dane. During the tests forty-four successive runs were made without any misfires or explosions. For the first time in the United States, an airplane had taken off, assisted by liquid-propellant rocket units.

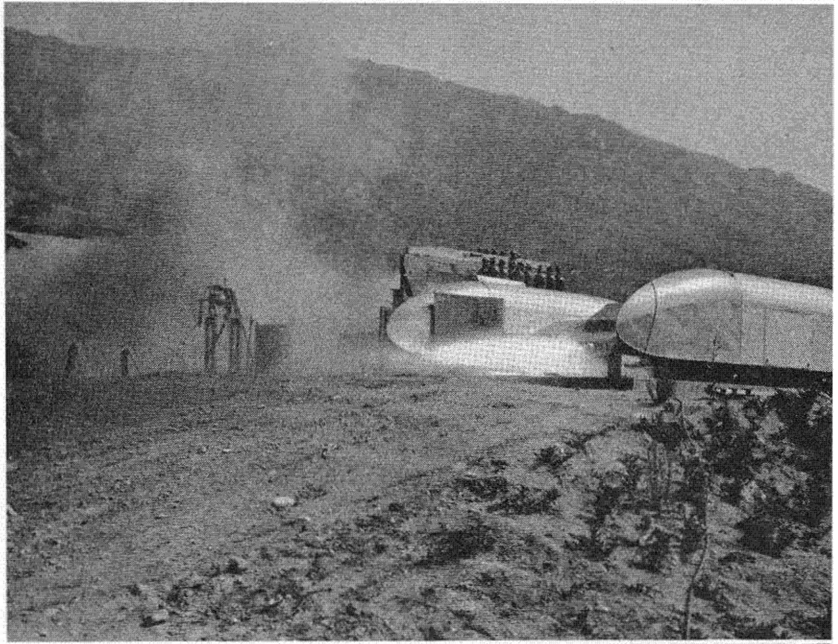
Like the earlier tests with the Ercoupe, those with the A-20A were highly successful. Reduction in distances required to take off were very close to those predicted. And the experience gained in the development of the experimental unit cleared the way for the design and manufacture of a service type.

## THE HYDROBOMB

In 1943, the Armament Laboratory of the A.A.F. arranged with the Jet Propulsion Laboratory, GALCIT to develop a missile to be launched from a bombing plane and to be propelled at high speed under water by means either of solid- or liquid-propellant rocket units.

The missile at present under development is called the hydrobomb. Two different prototype models have been built for the A.A.F.; one by the Westinghouse Manufacturing Company, and one by the United Shoe Machinery Company. The Laboratory has designed and constructed half-scale models of these prototypes.

A full-scale model, constructed by the United Shoe Machinery Company, and reproduced in *Fig. 8* is more than 10 feet long, with a maximum diameter of 28 inches. Designed to be launched at speeds up to 350 miles per hour, and to travel under water at 70 miles per hour, the missile is driven by a solid-propellant rocket unit delivering 2,200-pound thrust for 30 seconds. The range of the missile is 1,000 yards; gross weight, approximately 3,200 pounds; and the weight of the warhead, 1,250 pounds.



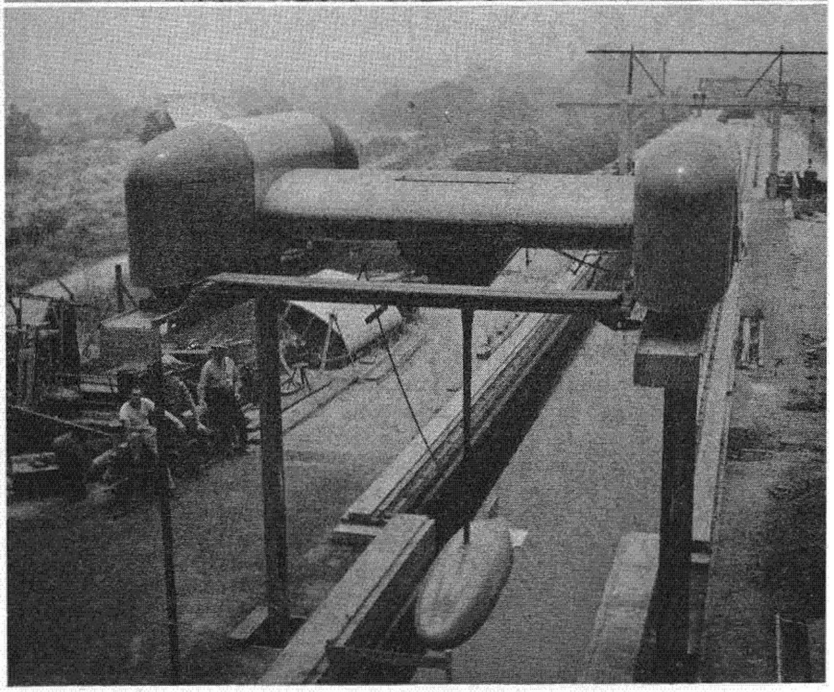


FIG. 7. (Top): Static test of rocket-propelled towing car.
FIG. 8. (Bottom): Full scale model of Hydrobomb constructed by the United Shoe Machinery Company.

### FACILITIES FOR RESEARCH

Of fundamental importance in the research program undertaken to develop the hydrobomb was basic information upon the hydrodynamic characteristics of the proposed missile. It was imperative to know, for example, the effect of jet propulsion upon stability and performance of an underwater missile, and the effect of jet propulsion upon cavitation, a phenomenon well known to designers of high-speed underwater craft.

The experimental part of the research program set up to develop the hydrobomb demanded elaborate apparatus, useful also in other investigations of propulsion under water. This apparatus is a towing channel equipped with facilities for observing and measuring the behavior under water either of models or of full-scale craft.

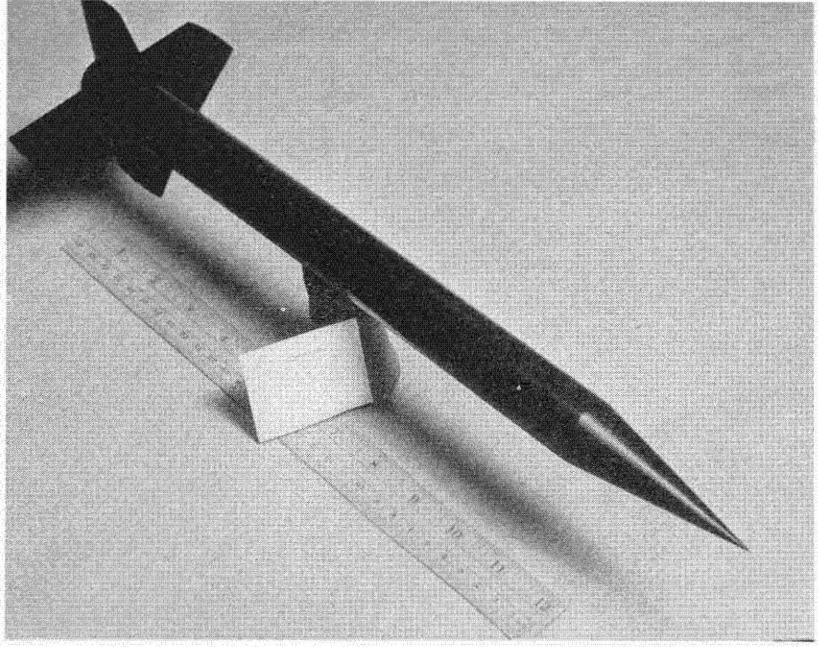


FIG. 9. An early model of the Wac Corporal missile with four fins.

The towing channel built at the Laboratory is open to the weather. Constructed of reinforced concrete, it is 500 feet long, 16 feet deep, and 12 feet wide. Astride the channel rides a towing carriage, the wheels mounted on carefully-leveled steel tracks running the length of the channel. The carriage, driven by an electric motor, can run faster than 40 miles per hour. Originally, it was driven by three liquid-propellant rocket units.

Preparatory to a model test, the carriage is raised on hydraulic jacks. Suspended from the center of the carriage is a strut, adjustable to any length up to 12 feet. A model is attached to the free end of the strut. When the carriage is lowered, the model is submerged ready for testing. Electrical strain-gauges installed within the model connect through the strut with an oscillograph in the carriage. As the carriage tows the model the length of the channel, the strain-gauges measure the hydrodynamic forces acting upon the model, and the forces are recorded by the oscillograph. The quantities to be measured are known technically as lift, drag, and pitching moment.

On one side of the channel, midway between the ends, is an underground observation room with a glass window let into the channel wall. The behavior of flow over the surface of a model is studied visually and recorded by cameras.

### RESEARCH ON THE HYDROBOMB

Responsibility for the actual design of different experimental models of the hydrobomb rests with agencies other than the Jet Propulsion Laboratory. The responsibility of the Laboratory in the development of the models is to measure the lift, drag, and pitching moment; in other words, the hydrodynamic forces exerted upon a model in motion. The shape of a model and the size of the control surfaces (fins and rudders) influence not only the behavior of these forces but the extent of cavitation as well.

A special propellant had to be developed for the hydrobomb because its geometry is such that a solid propellant must be made to burn at the rate of one inch per second if the missile is to deliver a 2,200-pound thrust for 30 seconds. The result was GALCIT 65, a modification of GALCIT 61-C, an earlier development of the Laboratory. Work on the new propellant proceeded rapidly after potassium nitrate was introduced in order to slow the burning rate.

The new propellant, sealed into rocket motors with the standard liner mentioned in connection with JATO units, was subjected to tests simulating launching from an airplane flying at different velocities up to 400 miles per hour. *(See Fig. 7.)*

A rocket unit launched at high velocity hits the water with such terrific force that it was feared the impact might crack the propellant or liner, or else separate the propellant from the liner, or perhaps separate the liner from the steel walls of the motor. Any one of these mishaps would render undependable the firing of a unit. It was necessary, also, to determine the effect of temperature upon the ability of the propellant and liner to withstand the impact following launching.

The test procedure was to launch a dummy torpedo fitted with a loaded, solid-propellant motor, then later to fire the unit in a test pit where, if it exploded, it would do no harm. Results showed GALCIT 65 capable of withstanding impact resulting from launching velocities up to 385 miles per hour. The launching tests were made at the Torpedo Launching Range developed by the California Institute of Technology for the Navy at Morris Dam, California.

## THE ORDCIT PROJECT

The ORDCIT Project was initiated as the result of a memorandum submitted by Dr. von Karman, H. S. Tsien, and F. J. Malina to the Ordnance Department in November, 1943. In January, 1944, Major General G. M. Barnes requested, in a letter addressed to Dr. von Karman, that the Jet Propulsion Laboratory undertake a research and development program on long-range, jet-propelled missiles. The project was the first of its kind in the United States and is based upon a contract between the A.S.F. Ordnance Department and the Laboratory. As a result, the A.A.F. and the Ordnance Department utilize cooperatively the staff and facilities of the Laboratory.

The primary purpose of the contract is to obtain fundamental information to assist the development of long-range, jet-propelled missiles, together with suitable launching equipment.

### THE PRIVATE A AND THE PRIVATE F

The first step toward the primary objective—a long-range guided missile propelled by rocket thrust—was the design and fabrication of the Private A. Its purpose was to provide experimental data on the effect of sustained rocket thrust on a missile stabilized by fixed fins, and to provide knowledge on the use of booster rockets for launching missiles.

Approximately 8 feet long, the Private A tapered to a sharp nose designed for supersonic flight, and it was guided at the aft end by four fins, each extending 12 inches from the motor body. Its gross weight was more than 500 pounds, including a pay load of 60 pounds. Driven by a solid-propellant rocket unit, the missile delivered thrust of 1,000 pounds for over 30 seconds.

Firing tests of the Private A were carried out at Leach Spring, Camp Irwin, near Barstow, California, December 1 to December 16, 1944. Twenty-four rounds were fired in all. The average range was approximately 18,000 yards; the maximum, 20,000 yards (11.3 miles). See *frontispiece.*

In the spring following the tests of the Private A, another experimental rocket was ready for testing. It was designed to explore the effect of lifting surfaces upon a guided missile. Called the Private F, it was essentially the same rocket as the Private A; but, instead of four symmetrical guiding fins at the aft end, it had one fin and two horizontal lifting surfaces with a total span of nearly five feet. At the forward end of the missile, to trim it in flight, were two stubby wings, their total span less than three feet.

The firing tests were at the Hueco Range, Fort Bliss, Texas, April 1-13, 1945. The Range was equipped with radar for tracking the flight path of missiles, and with cameras for recording initial trajectories. Though the tests provided valuable data of a highly-technical nature, they demonstrated that a missile with lifting surfaces requires flight control equipment for regular flight.

### THE WAC CORPORAL

By far the most spectacular missile the Laboratory has developed is a rocket with the code name Wac Corporal. It was tested during the autumn of 1945. Some information about the missile was released in March, 1946. Now that the ORDCIT contract has been reclassified, the Army Ordnance Department is at liberty to release more about the story of the Wac Corporal from its inception to the flight test already reported.

In December, 1944, the Ordnance Department requested the ORDCIT Project to investigate the feasibility of a high-altitude rocket to carry twenty-five pounds of meteorological equipment to an altitude of at least 100,000 feet, or almost nineteen miles, in accordance with a requirement of the Signal Corps.

The investigation evaluated alternatives for meeting certain of the requirements. It was decided, for example, to initiate flight with a booster, and to use a launching tower for guidance of the missile until it achieved a velocity safe for holding vertical flight. The alternative would have required equipment even more complicated than a launcher and booster to control the flight of the missile on its upward course.

A feature of the experimental program was the fabrication and test of a one-fifth scale model of the Wac Corporal. The purpose of the test was to determine whether three tail fins would suffice instead of the usual four, and whether the missile-booster combination chosen provisionally would perform as anticipated. Tests of the Baby Wac, made at Goldstone Range, California, July 3 to July 5, 1945, confirmed the choice of three fins and the missile-booster combination selected.

Approximate outside dimensions of the Wac Corporal were: length 16 feet from the needle-pointed nose to the tri-finned tail; diameter 12 inches. The gross weight was 665 pounds. Empty, the missile weighed less than 300 pounds. It delivered thrust of 1,500 pounds for 45 seconds.

The source of power was a liquid-propellant rocket motor. The motor was cooled by the flow of fuel within the jacket walls just before it entered the combustion chamber. The Laboratory adapted the motor to utilize nitric acid as an oxidizer; and aniline as a fuel—a spontaneously-combustible propellant combination the Laboratory had begun to develop in 1942, shortly after the test flight of the A-20A.

The pressure required to force the propellants into the combustion chamber was supplied by compressed air instead of nitrogen, conventionally used for the purpose. The substitution was made to simplify operation in the field.

The propulsive system was started by the operation of a device known as an inertia valve, incorporated in the compressed-air circuit. When the booster accelerated the missile out of the launcher, the force of inertia automatically opened the valve, which transmitted air pressure, at one and the same time, to the propellant tanks and to the actuating piston of the main propellant valve.

Fitted into the nose of the Wac Corporal, in addition to meteorological instruments, were parachute and automatic devices for releasing both the entire nose cone and the parachute; an arrangement that recommended itself if the instruments installed were to be recovered intact.

The booster, planned originally to accelerate the missile, proved to be inadequate. Substituted for it was a modification of the Navy rocket known as Tiny Tim. Changes were made in the fins and nose and thrust was increased. Designed to deliver thrust of 30,000 pounds for one second, the rocket was modified to deliver 50,000-pound thrust for little more than half a second.

Calculations indicated, however, that in little more than half a second the booster and missile would rise some 216 feet, a prohibitive height for a launching tower. It was decided, therefore, to retain a tower height of 100 feet, the height agreed upon earlier to meet specifications as planned originally. Design had to allow, then, for part of the boost to take place in free flight, unguided by the launching tower.

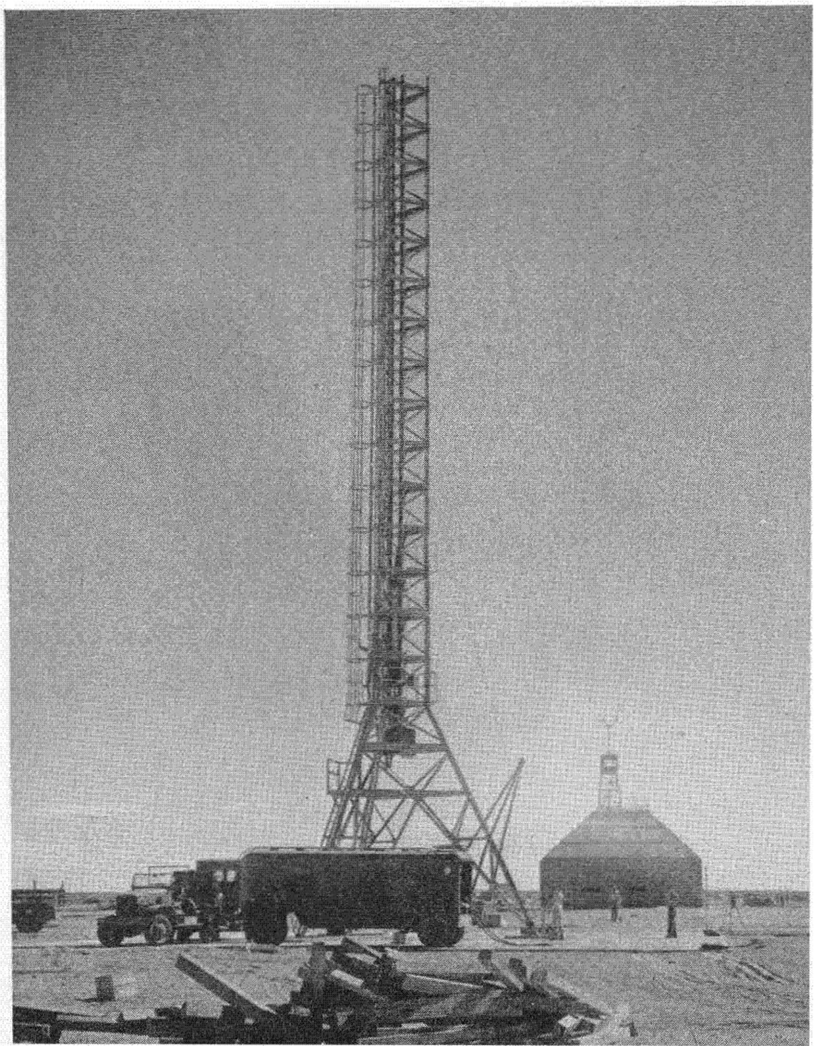
The launcher, fabricated of structural steel, as depicted in *Fig. 10*, was a triangular tower 102 feet high, with three launching rails set 120° apart, providing an effective length slightly more than 80 feet, after allowance for the height of the tower base. Piping was attached to the launcher for servicing the missile with propellants and compressed air. A Field Service Trailer simplified the handling of the propellants.

A bomb-proof control house, erected approximately 500 feet from the launching tower, housed measuring instruments and fire control and communication equipment.

### THE TESTS

Firing tests of the Wac Corporal were carried out

**FIG. 10. Launcher of the Wac Corporal at the White Sands Proving Ground.**



at the White Sands Proving Grounds, Las Cruces, New Mexico, between September 26 and October 25, 1945. Tracked by radar the missile reached, as reported, an altitude of about 43.5 miles in vertical flight. The great increase in altitude over that planned in preliminary estimates was the result primarily of reduction in weight achieved by changes and improvements made as the design matured, and of the added impulse provided by the Tiny Tim rocket adopted as a booster.

The Ordnance Department acted as coordinator for the various organizations involved in the development and firing of the missile. The ORDCIT Project was responsible for the preparation of each round for firing, and for the technical phases of the firing program. The Signal Corps, besides providing weather data, provided the equipment for tracking and for receiving signals from radio sonde sets released from the missile. The Aberdeen Ballistic Research Laboratory installed and operated five special camera units and three radar stations located at strategic points around the launcher.

### REMOTE CONTROL AND THE TRANSMISSION OF FLIGHT DATA

As part of the ORDCIT Project, the Laboratory is at work upon a system designed for the remote control of guided missiles; and upon two systems for transmitting to ground stations data from vehicles in flight.

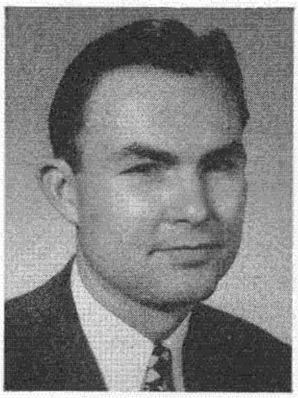
This control system has been designed, not to meet service requirements, but as a means to study control problems. The position of the missile in flight will be plotted by radar, recording the trajectory in both horizontal and vertical planes so that deviations will be apparent. A radio link will be provided for an operator on the ground to signal corrections to the missile, which automatically will apply them. All the control equipment is to be mounted in the nose cone of the missile.

### THE GRADUATE COURSE IN JET PROPULSION

At the request of the A.A.F. Materiel Command, three years ago, a course in Jet Propulsion was instituted at the California Institute of Technology by the staffs of the Guggenheim Aeronautical Laboratory and the Jet Propulsion Laboratory. The course has been limited to officers of the Army and Navy assigned for graduate study at the California Institute of Technology. However, provision has recently been made to open the course to a few especially-selected civilian students.

The course covers the basic principles of all known jet-propelled power systems, and the performance of jet-propelled devices. The Laboratory offers the students first-hand experience with working models of various types of power systems.

# Retiring Directors of Alumni Association



Karl Hegardt

Paul Hammond

IN OUR June issue we presented the four new members of the Board of Directors of the C.I.T. Alumni Association: Howard B. Lewis '23, W. Morton Jacobs '28, Frederick T. Schell '27, and James R. Bradburn '32. We have the less pleasant task in this issue of saying goodbye to the four Board members whose terms of office expired in June. The four retiring members are Harry K. Farrar '27, Karl Hegardt '32, J. Stanley Johnson '33, and Paul H. Hammond '36.

To these four men the Alumni Association owes a vote of thanks for the time, thought, and effort that they have so willingly expended in an effort to maintain and improve the activities of the Association.

Harry K. Farrar

*Harry K. Farrar* '27 has been active on the Board of Directors since 1942. Four years ago he was drafted as Treasurer of the Association. Having fulfilled this thankless task with distinction, Harry was elected a Board member and given more jobs for the 1943-44 fiscal year. In 1944 the Board elected Harry as President of the Association. After completing his term as President he was reelected to serve as a Board member through June 1946.

At present Harry Farrar is engaged in planning and engineering long distance telephone facilities for the toll transmission department of the Southern California Telephone Company. While at C.I.T. his activities included basketball, football, the Executive Committee of the Associated Student Body, Drama Club, Honor Key, Cosmo Club, Delta Mu Beta, A.I.E.E., Tech Staff of which he was managing editor in his senior year, the Big T Staff, Y.M.C.A. Cabinet, and the Press Club. He is also a member of the "Pharos" and Tau Beta Pi. His family consists of his wife, Frances Elizabeth Farrar, and his daughter, Mary Elizabeth.

*Karl Hegardt* '32 has been Treasurer and Director of the Association for the past two years. As Treasurer he has done a praiseworthy job and his calm, cool judgment has been an invaluable asset. He, like Mr. Farrar, is a

Southern California Telephone engineer in the exchange transmission group of the chief engineer's office.

During his undergraduate days Karl was President of Ricketts House, a member of Tau Beta Pi and of A.I.E.E. He also worked on the Tech, sang in the Glee Club, and played on the baseball team. He acquired early training for his Association duties by serving as Treasurer of the Associated Student Body. Karl and his wife, Phyllis Hegardt, have three children.

*J. Stanley Johnson* '33, our third departing Director, was also a Ricketts House officer in undergraduate days. He was President of Pi Kappa Delta and a member of Tau Beta Pi. He was also active in Debate and the Glee Club as well as Secretary of the Associated Student Body and Vice-President of the Y.M.C.A. After graduation Stan was with the Southern California Gas Company until 1935, working in the sales and personnel departments. At that time he went to the Taylor Forge and Pipe Works in Chicago in connection with a new automatic welding process being installed. This work was an outgrowth of research done on welding at C.I.T. when Stan was winning his M.S. degree. He returned to California in 1938 and purchased the assets of the Foss Heating and Engineering Company of Pasadena, manufacturers of residential furnaces. The company is now known as the Holly Manufacturing Company.

*Paul H. Hammond* '36, in leaving the Board also relinquishes the difficult tasks of Secretary.

When Paul was at C.I.T. he was, according to the Big T, a very busy man. He was President of Pi Kappa Delta and of the Student Body. Again quoting the Big T, he was "debator supreme" with a first place in Western

States Extempore and an award of the Conger Peace Prize. He was a Key man, a member of Blacker and Tau Beta Pi. In 1936 Paul joined the Southern California Gas Company. He was with the gas company until 1940 when he resigned to enter the Holly Manufacturing Company. He was made Secretary of Holly in 1946 with responsibility for purchasing, personnel, general office management, and governmental regulations. He has a wife, Olena, and two daughters.

## PERSONALS

**IT WILL be helpful if readers will send personal items concerning themselves and others to the Alumni Office. Great interest has been shown in these columns, but more information is required. Do not hesitate to send in facts about yourself, such as change of position or location, present job, technical accomplishments, etc. Please help.**

**—Editor.**

**1920**

GEORGE L. CORY, who has been chief engineer for the Otis Elevator Company since his graduation from C.I.T., has returned from Service where he served as a Major in Ordnance. He has now established his own business in Newark, N. J., his company being called the Luxcraft Corp.

**1926**

WALLACE C. PENFIELD is a partner of the firm Penfield & Smith, registered civil engineers, Santa Barbara, Calif.

ALLEN L. LAWS, who has been Vernon district manager for the Southern California Edison Company since 1941, has been transferred to the company's general office in Los Angeles as assistant commercial manager. This change was effective June 1.

**1927**

FRED SCHELL, former assistant manager, industrial sales, of the Southern California Edison Company, has been promoted to district manager of the Edison Company at Compton, California; the change being effective June 1.

**1930**

HOWARD CARY recently was made president of the Applied Physics Corp. of Pasadena, Calif.

**1931**

WILLIAM M. COGEN, former Major in the Army Air Corps, returned from India last December where he was assigned to a photo-intelligence detachment covering operations in Burma for 28 months.

**1934**

ERNEST R. HOWARD became the father to James Douglas Howard, born on April 19.

DAVID W. LUTES visited the campus May 6 from San Francisco where he was general superintendent for W. C. Tait, Contractor.

GEORGE SIDNEY SMITH, JR., with two partners, has gone into business in Seattle, Washington, selling and engineering industrial electronic controls.

**1935**

DR. J. E. HOBSON, director of Armour Research Foundation, is serving on the Illinois Professional Engineers' Examining Commission in connection with the registration of engineers by the State of Illinois.

M. VAN REED, former Major in the U.S.A. Corps of Engineers, was released from Service in May. Major Van Reed was an instructor at Ft. Belvoir, Va., for the past three years.

**1937**

ROBERT S. CAMPBELL is working in the Frequency Change Dept. in charge of customer contact work for the Southern California Edison Co. Bob was recently assigned to industrial accounts in the central manufacturing district of the company.

HOLLOWAY H. FROST has been transferred from Socony-Vacuum Oil Co. of

Venezuela to Socony-Vacuum Oil Co. in Egypt where he will be chief geophysicist.

**1938**

LEROY B. KELLY, former Lieutenant in the Navy, was released to inactive duty in February after a period of active duty of over four years, three of which were spent overseas in the South Pacific areas. For the past four months, Mr. Kelly has been working at the Naval Ordnance Test Station, Inyokern, Calif., as a mechanical engineer in research work.

**1939**

H. D. STRONG is now employed by the Corbett Industries, Montrose, Calif.

**1940**

CHARLES PALMER, JR., has accepted a position with the Rocket Division of the General Tire and Rubber Co. at Pasadena and started to work in June.

JAMES WHITTLESSEY is working for the Gladden Products Corp., Glendale, Calif.

**1941**

CHARLES L. COBB (AETM 3/c) was released from Service May 16. Charles served in the Pacific area with CASU 66 about eight months subsequent to training period.

JOHN B. HIATT, former Lieutenant (jg), was released from Service in May. John was stationed at Puget Sound Naval Ship Yard, Bremerton, Washington, as ship repair and maintenance officer.

**1942**

ROBERT L. MOORE, former Lieutenant in the Navy, is now released from Service and plans to stay in California. Bob spent one year on the east coast, one year on Atlantic duty and two years at Mare Island, in Naval Ordnance.

MARTIN GAYER has been released from Service, having served with the Seabees on Attu this past year. Martin is the father of a son, Paul, born on Feb. 22.

JOHN R. ALLAN, radio technician 3/c, was discharged from the Navy in April after returning from Pearl Harbor where he was stationed eight months. John was formerly employed by Todd Shipbuilding and has returned there as a design engineer.

GEORGE W. LIND, JR., former Lieutenant (jg), was released from Service in April after return from the Pacific area where he served aboard the U.S.S. North Carolina for one year. George returned to Portland, Oregon, to work for his father in general contracting.

R. A. COOLEY has accepted a position at N.O.T.S., Inyokern, Calif.

**1944**

JOSEPH S. BULLER is employed by Harman Equipment Co., Los Angeles, Calif.

WILLIAM HAMILTON has accepted employment with The Standard Oil Co. of California and is working in Northern California.

1ST LIEUT. JAY R. BORDEN is Commanding Officer of H.Q. & H.Q. Company, 3141 Signal Service Group at Caserta, Italy.

1ST LIEUT. WILLARD A. DODGE is Teletype Officer at the 8th Army Headquarters Signal Center in Yokohama, Japan.

1ST LIEUT. WILLIAM TRIMBLE is Motor Officer of the 24th Signal Company at Okayama, Japan.

1ST LIEUT. WHEELER J. NORTH is Supply Officer of the 25th Signal Company at Osaka, Japan.

LIEUT. CLIFFORD I. CUMMINGS is Liaison Officer to the British Forces at Allied Force Headquarters, Naples, Italy.

LIEUT. ROBERT J. PARKS was with the Signal Corps in Belgium when last heard from.

LIEUT. LEROY SANDERS is with the Signal Corps in the Army of German Occupation.

LIEUT. (jg) KENNETH DE REMER, who was radar officer on the U.S.S. Biloxi, was released from Service in June.

ENS. RAYMOND J. PALMER, Seabees, recently returned from the Philippine Islands where he had been stationed 13 months working with a wood-construction and earth-moving equipment crew. Ray is now on civilian status and may return to school for his M.A.

**1945**

ENS. CHARLES CUTLER escorted a draft of sailors to San Francisco from Great Lakes in late May and visited the Campus on his return trip.

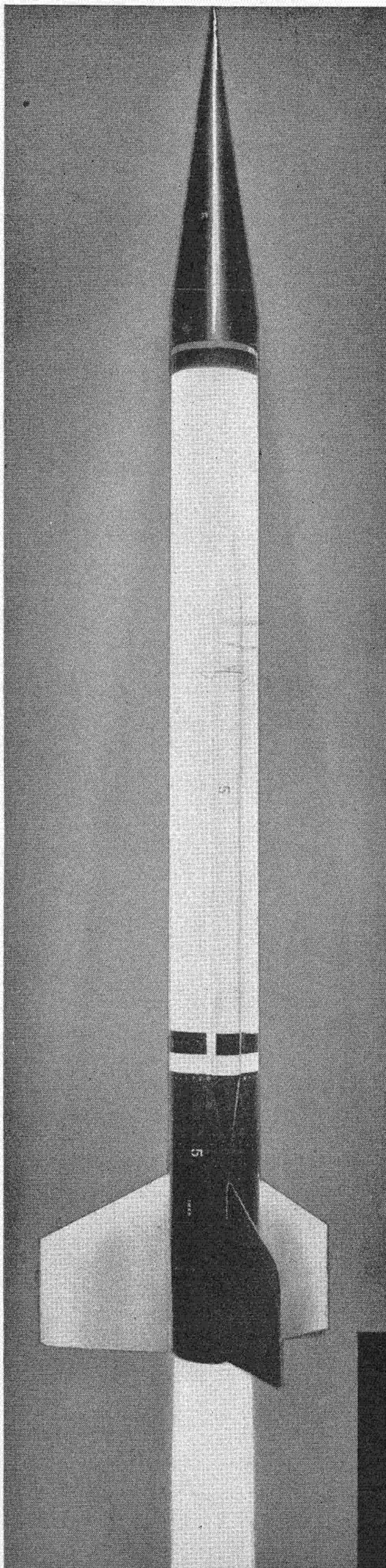
ENS. JOHN STERN, recently returned from Okinawa, is now released from active duty.

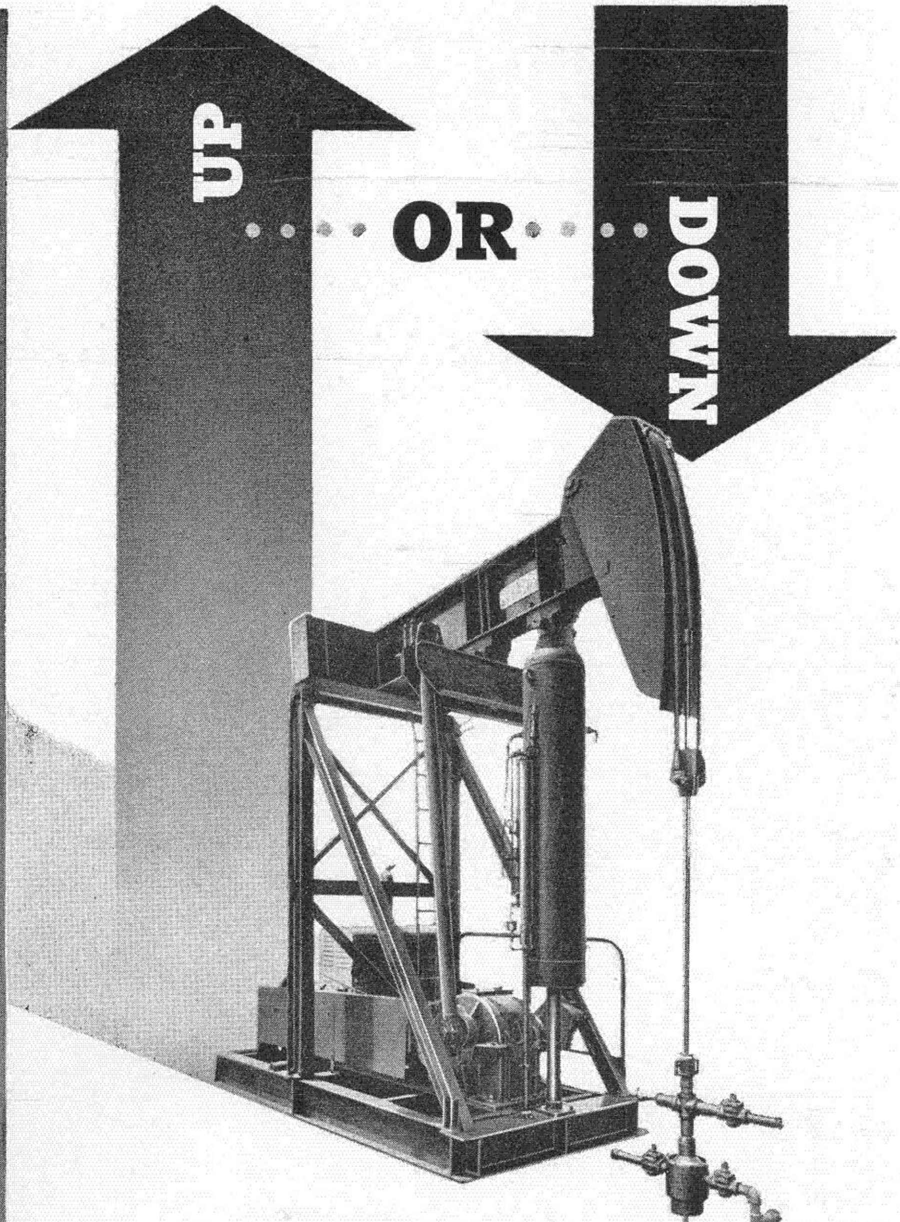
ENS. ROBERT F. SCHMOKER was married to Miss Donna Mathews on March 2 in a formal evening ceremony at Pasadena. Mr. and Mrs. Schmoker are now living in Coronado, Calif.

ENS. BILL McDONNELL visited the campus in May while his ship, the APA-188 Olmsted, was in San Francisco. Bill hopes to be released from Service in midsummer.

BOB KIECKHEFER, JR., is at Great Lakes Naval Base as discharge yeoman for about 4,000 men. When discharged, Bob intends to go into a civilian job at the American Lace Paper Co. in Milwaukee.

WILLIAM J. ELLIOTT has completed his training at the Westinghouse Electric Corp. and has been transferred to a permanent position in the Foreign Engineering Dept. at the East Pittsburgh Works.



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**CALIFORNIAN,** friendly Golden State Route train, now runs in two sections and has been speeded up.