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.

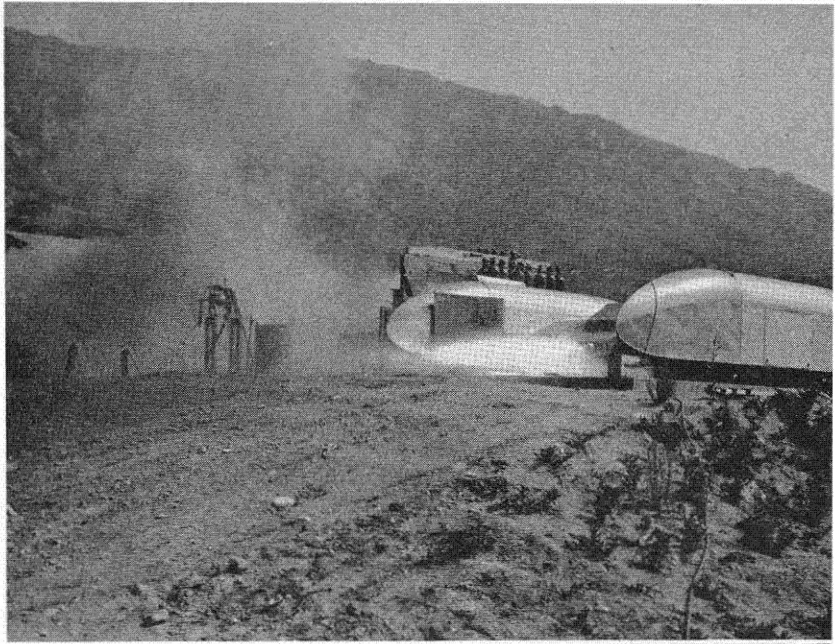
Like the earlier tests with the Ercoupe, those with the A-20A were highly successful. Reduction in distances required to take off were very close to those predicted. And the experience gained in the development of the experimental unit cleared the way for the design and manufacture of a service type.

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.



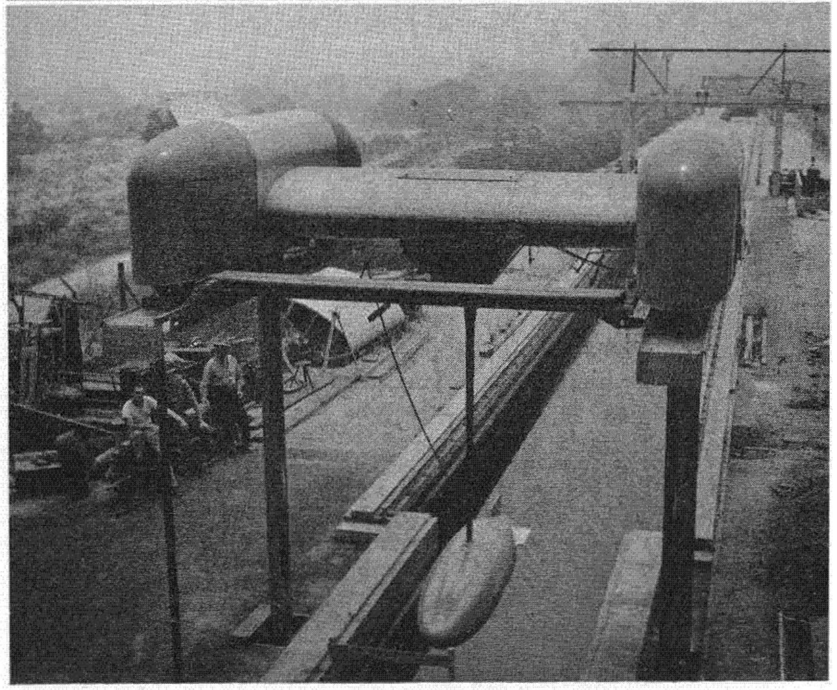


FIG. 7. (Top): Static test of rocket-propelled towing car.
FIG. 8. (Bottom): Full scale model of Hydrobomb constructed by the United Shoe Machinery Company.

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.

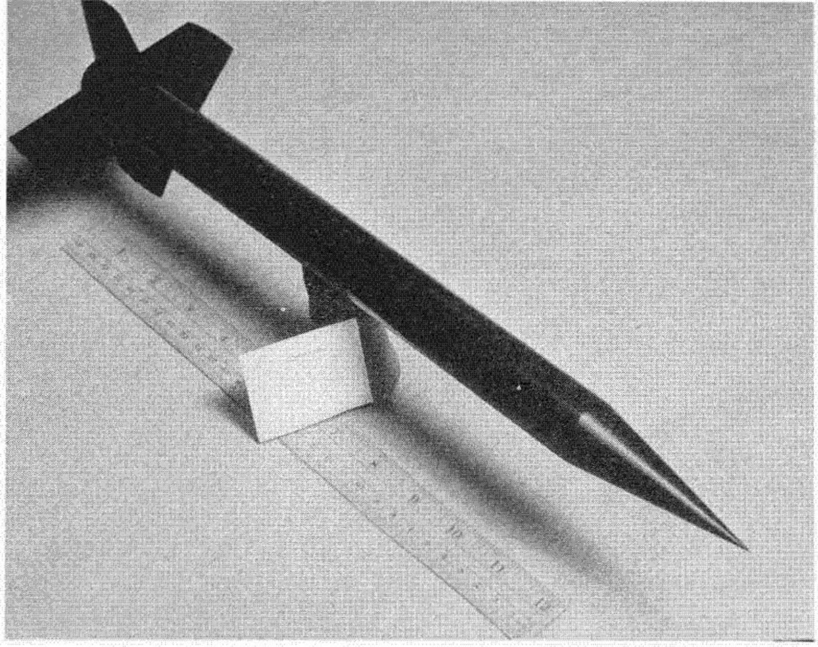


FIG. 9. An early model of the Wac Corporal missile with four fins.

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