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CONTENTS

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Announcement . . .

Attempts to include highly technical articles embodying quite a bit of mathematical formulae in the Journal of the American Rocket Society have caused the delay in the current issue. Lack of facilities for printing such material in a small issue order coupled with current labor strikes have prevented the Society from printing these articles. They will begin to appear in forthcoming issues.

Because the Board of Directors feels that the membership is entitled to the fullest possible information on subjects associated with rocketry and jet-propulsion, this issue represents the combined June and September numbers and totals 48 pages.

Beginning with the next issue every effort will be made to continue the increased paging for each quarterly number.

The members of the Society, as well as general readers who are engaged in any phase of jet propulsion or interested in the aims of the society, are earnestly requested to submit material for publication.

THE EDITOR.

Ercoupe take-off assisted versus Porterfield take-off unassisted.

RESEARCH AND DEVELOPMENT

at

THE JET PROPULSION LABORATORY, GALCIT*

The California Institute of Technology

Pasadena, California

I. AN HISTORICAL SKETCH OF THE JET PROPULSION LABORATORY, GALCIT[1]

Basic research in the field of jet propulsion has been in progress at the California Institute of Technology since 1936. It is convenient historically to divide the work into three phases.

The GALCIT Rocket Research Project

The 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 as follows: Frank J. Malina, Hsue-Shen Tsien, A. M. O. Smith, John W. Parsons, Edward S. Forman, and Weld Arnold. The early phases of the research were financed by a gift from Mr. Weld Arnold. Dr. von Karman foresaw the importance of rocket propulsion and the future possibilities of Caltech research in this field.

A theoretical and practical research program, conducted throughout the next two years, was directed primarily toward the design of a high-altitude sounding rocket. The modest program led to the publication of several reports,[2] and to the preparation of several others for aircraft concerns and government agencies. Some of the latter reports suggested application of rocket units as boosters for airplanes, the primary purpose being, first, to shorten take-offs, hence runways; and, second, to boost heavily-loaded planes which, without assistance, could not take off at all from many existing fields.

Army Air Corps Jet Propulsion Research Project, GALCIT Project No. 1

In December, 1938, General H. H. Arnold, Commanding General of the Army Air Corps, requested the Committee for Air Corps Research of the National Academy of Science, consisting of scientists from various research institutions, 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. von Karman chose for Caltech the rocket problem and the committee appointed a subcommittee on Jet Propulsion with him as chairman.

On July 1, 1939, sponsored by the National Academy of Science, the AAC Jet Propulsion Research Project was initiated at the California Institute of Technology with Dr. von Karman as Director. Frank J. Malina, John W. Parsons, and Edward S. Forman, members of the original rocket research group, were selected to start the program.

A year later, in July, 1940, the Army Air Corps effectively assumed sponsorship of the Project. During the first two years of the war (1942 and 1943), when the United States was working to make up lost time, the GALCIT Project was constantly expanding.

The Jet Propulsion Laboratory, GALCIT

In January, 1944, arrangements were

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*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.

2. "Experiments With Powder Motors for Rocket Propulsion by Successive Impulses." **Astronautics**, No. 43, 1939, p. 4.
"Characteristics of the Rocket Motor Unit Based on the Theory of Perfect Gases." **Jour. Franklin Inst.**, No. 4, Vol. 230, 1940.
"THE GALCIT Rocket Research Project", **Astronautics**, No. 41, 1938, p. 3.
"Flight Analysis of a Sounding Rocket", **Jour. Aero. Sci.**, Vol. 5, 1938, p. 199.
"Flight Analysis of a Sounding Rocket With Special Reference to Propulsion by Successive Impulses", **Jour. Aero. Sci.**, Vol. 6, 1938, p. 50.

initiated for the Army Service Forces, Ordnance Department, to participate with the AAF Air Materiel Command in the research program. In the interest of efficient administration, reorganization was called for. On November 1, 1944, the Project became the Jet Propulsion Laboratory, GALCIT. The policies of the Laboratory are determined by an Executive Board appointed by the Trustees of the California Institute of Technology. The Board is responsible directly to the Trustees, two of whom are included in its membership.

In December, 1944, Dr. von Karman, who personally had directed the work of the Project and its reorganization, took leave of absence to become Expert Consultant to the Commanding General, AAF. Dr. Clark B. Millikan was appointed Acting Chairman of the Executive Board; Dr. Frank J. Malina, Acting Director of the Laboratory; and Dr. L. G. Dunn, Assistant Director.

As a result of ASF Ordnance Department participation in the work of the Laboratory, facilities and equipment have increased materially.

Liaison with the military and naval services is maintained as follows:

Col. B. S. Mesick, ASF Ordnance Dept.

Col. E. H. Eddy, AAF Air Materiel Command

Comdr. H. A. Tellman, USN, Bureau of Ordnance

Lieut. Col. J. C. Nickerson, U. S. Army Ground Services

Major K. S. Jackson, ASF Signal Corps

Col. Mesick in August, 1945, replaced Col. L. A. Skinner, widely known for his work on the development of the bazooka. From June, 1943 to March, 1945, Col. W. H. Joiner represented the War Department.

Facilities and Subcontracts

The Jet Propulsion Laboratory is located within a fenced enclosure covering approximately 40 acres near the western limits of the city of Pasadena, California. Within the enclosures are more than 80 structures of widely-varied types. Dominating the entrance is the Administration Building. Beyond it are:

1. Numerous test pits for the development of propulsion systems for solid- and liquid-propellant rockets, and for ramjets and turbojet engines;
2. Laboratories for research in high-temperature resistant materials, and the processing of solid propellants;
3. A towing channel for research on underwater missiles;
4. 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 ASF Ordnance Department at the Muroc Army Air Base, California.

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.

II. JATO (Jet-Assisted Take-Off for Aircraft)

The research begun in 1939, 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 the three young men 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, of 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 10 to 30 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. How the Project developed a successful, solid-propellant rocket motor is told first.

Solid-Propellant Rocket Motors

In 1939, 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 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.

Another danger anticipated was that a stick of powder might crack or crumble under the high pressure induced by combustion, hence burn too fast and explode. To minimize this danger, powder sticks were molded in an hydraulic press under very high pressure.

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 different loading techniques, and with different nozzles of various design, and with different construction materials. 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 lb; the powder charge weighed approximately 2 lb.

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. 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, 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 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 28 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. 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.

Ballistite, a different type of propellant, also was investigated. A compound essentially of nitrocellulose and nitroglycerine, the type then available had a much-desired high-energy content; but it had two serious drawbacks. First, the high temperature of combustion made motor design difficult, and the hot blast made it unsuitable for use on carrier decks. Second, the release of its energy content is too sensitive to temperature changes. For example, a rocket unit loaded with ballistite and designed to deliver 1,000-pound thrust at 90°F could deliver at most only 600-pound thrust at 40°F. Though the duration of thrust at the lower temeperature would be lengthened, an aircraft assisted by such thrust might fail to take off from a short runway.

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 compressina them. What they turned up with was designated as GALCIT 53, the number being suggestive of the amount of development 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.

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 13 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 cancelled thrust in any one direction.

Once the development work was finished on the rocket unit just described, the Navy contracted with the Aerojet Engineering Corporation of Pasadena to manufacture a limited number for experimental purposes. In 1943 the Navy, having a greater use for jet-assisted take-off than the Army, began placing large orders for motors delivering not only 200-pound thrust, but 500- and then 1,000-pound thrust. Developmental work on these larger units was carried on both by the Laboratory and by Aerojet. Today JATO is a commonplace word among fliers throughout the Armed Services.

Since 1942, most of the work done by the Laboratory to improve solid propellants has been directed toward widening the temperature limits for safe operation. In 1943, the Laboratory developed GALCIT 61-C, which the Navy continued to use until the war ended. Increasing the size of rocket units utilizing solid propellants is largely a matter of scaling up smaller models. Application of solid propellants to other kinds of vehicles, however, is another subiect. It will be dealt with in a later section.

Liquid-Propellant Rocket Motors

Simultaneously with the development of solid-propellant motors in July, 1939, the Laboratory undertook the development of liquid propellants more satisfactory than any then in use.

One of the initial difficulties was to find a suitable liquid oxidizer for the liquid fuel which, it was taken for granted, would be some one of several easily obtainable. The conventional choice of an oxidizer would have been oxygen itself. Commercially, it was available in both gaseous and liquid forms; but gaseous oxygen is impracticable for use either in a rocket or airplane because storage tanks strong enough to contain it are prohibitively heavy. Liquid oxygen was also objectionable because its physical properties made it difficult either to store or to transport; thus its use in mobile warfare was limited.

But if pure oxygen had its drawbacks, so had chemical compounds that liberate free oxygen when combined with suitable fuels. Earlier experimenters had found that, if the compounds worked at all, they were likely either to produce residues that eroded exhaust nozzles, or else cause some other difficulty that seriously lowered the efficiency of motors.

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 (referred to hereafter simply as nitric acid or acid).

It was recognized that, on account of its poisonous properties, the chemical would have to be handled carefully; and that its corrosive characteristics would restrict its use exclusively to those metals and other materials it could not corrode. The limitations, however, were not considered insuperable. But it remained to be seen whether the acid could be made to decompose and burn completely with a fuel. Preliminary tests, completed just before Christmas, 1939, proved that it did, and notably well with gasoline and benzine. The tests were conducted in open crucibles.

Work began on the design of a small motor and accompanying apparatus to test the behavior of the nitric acid and fuel in a combustion chamber, as well as to study methods for cooling the motor, for injecting the fuel, and for measuring thrust. The finished assembly consisted of the following: a device to measure thrust, a rocket motor with a conventional spark plug let into the side wall, two propellant-supply tanks, and a cylinder of nitrogen under pressure to inject the liquids into the combustion chamber.

Because the combustion temperature for liquid propellants under pressure is higher than the melting point of many metals, precaution had to be taken. The combustion chamber, the end plug, and the nozzle block were solid copper; for, in spite of its relatively-low melting point, the metal absorbs heat faster than any except silver; hence copper could be relied upon to keep the temperature safely below the melting point — provided, of course, the motor was operated only for short periods. The motor walls were very thick, moreover, because the more of the metal there is, the more heat it absorbs.

In May all was in readiness to test the behavior of nitric acid and fuel in a combustion chamber. All the tests performed were an unqualified success. Judging by the clean flame, combustion had been almost if not quite complete.

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.

Development of 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 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.

In the first test, the motor blew up. But safety bolts sheared as calculated, and the three essential parts of the motor remained intact. In all, some fifteen tests on the motor failed. Meantime, a Chemistry Group, under direction of the Department of Chemical Engineering at the California Institute of Technology, undertook to investigate the reaction of nitric acid and gasoline.

While the tests on the first motor were still in progress, a second motor with 200-pound thrust was speeding its way from the design board to the machine shop. The end plate, made of stainless steel, was utilized as an injector, with four small orifices; two for gasoline, and two for nitric acid. The combustion chamber was a length of steel tubing with a spark plug let into the wall. The exhaust nozzle was copper.

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.

In May, a third motor was ready for testing. It blew up on the first test, the blazing propellants setting fire to the test pit.

While repairs were under way, work was going forward on a fourth motor, which incorporated a new injector design. Six orifices, manifolded and drilled in a circle about the center of the end plate, injected gasoline; twelve more, manifolded in a larger circel, injected acid. All orifices were drilled at an angle so that the propellants impinged at a common focal point, thus mixing and dispersing the liquids in a fine spray. To insure a smooth stream flow, each orifice was equipped with a carefully-machined tip that screwed into place. The spark plug was protected by a safety shield to prevent the propellant components from short circuiting it.

Early in July, 1941, the fourth motor was ready for testing. It worked. Operation throughout the test period justified the next step in the developmental program, the design of a motor to deliver 500-pound thrust.

Except for a single explosion, the test program carried out on the 500-pound thrust motor was successful. The program yielded invaluable information, notably:

1. how to reduce the pressure of the nitrogen, which fed the propellants to the combustion chamber, thus permitting a simpler and lighter propellant-supply system;

2. how to select the propellant mixture ratio to control combustion temperature;

3. and how to design an exhaust nozzle that the hot gases eroded less than any earlier one.

Tests on the 500-pound thrust unit

coincided with the Ercoupe flight tests at March Field. By September, three important decisions were made:

1. to proceed at once with a design for a liquid-propellant rocket motor, to deliver 1,000-pound thrust;

2. to increase the personnel, and to divide it into two groups; one to develop motors, the other to work on problems of installation and controls that had to be solved before the projected units could be tested in an airplane;

3. to request the AAF to provide a plane suitable for mounting and testing twin assemblies, each with thrust of 1,000 pounds.

The first rocket motor designed to deliver 1,000-pound thrust was ready for testing in October. It differed from the preceding one not only in scale but in that it was equipped with two spark plugs instead of one, and with a manifold injector having 45 orifices instead of 18.

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.

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.

A-20A Take-off assisted by two 1000 pound thrust, 25 second duration liquid motors.

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.

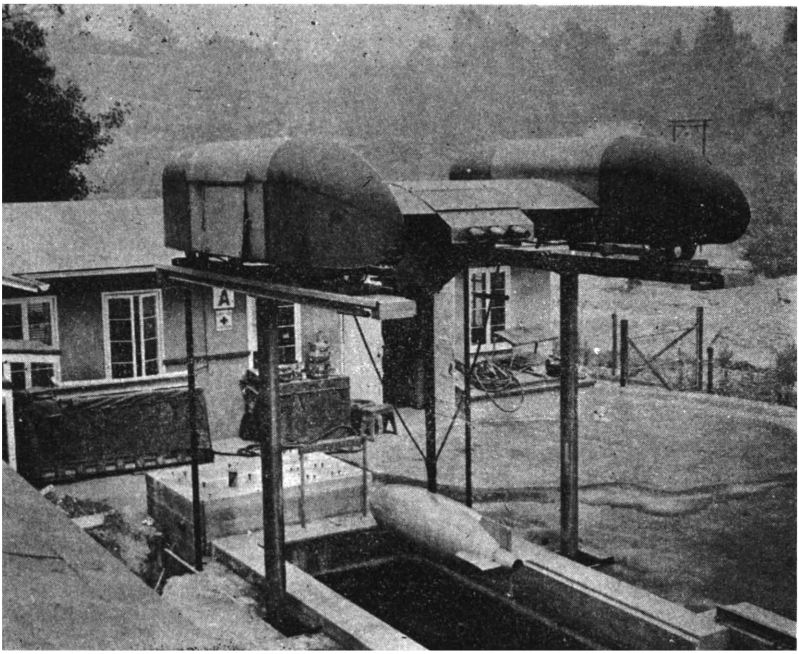
Put into practice, the suggestion worked. Not only did it work, but it led to the discovery in the United States that aniline is spontaneously combustible with red fuming nitric acid. Thus, at once, ignition, combustion, and throbbing problems were solved.

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 first two injectors designed to spray aniline and acid into the combustion chamber were failures. In the third, eight jets of liquid impinged in pairs equidistant from one another. Each of the four resulting jets formed a stream practically parallel with the walls of the combustion chamber so that little of the propellants washed against the chamber walls. With the third injector, combustion in the 1,000-pound thrust motor was instantaneous and infallible.

The A-20A Flight Tests:

The chief purpose of the projected flight tests was to gain information about air-borne equipment and control



Full size model of United Shoe Machine Co. Hydrobomb #30-A.

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. 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 AAF sent detailed drawings of the plane and an actual nacelle cone to work with.

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 AAF Bombing and Gunnery Range at Muroc, California, April 7 to April 24, 1942. The pilot was Major P. H. Dane. During the tests 44 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. Accordingly, the Aerojet Engineering Corp. took over. Development of both larger and different types has been carried out since by Aerojet and by the Laboratory, working cooperatively and independently.

III. JET PROPULSION UNDER WATER

The Hydrobomb

In 1943, the Armament Laboratory of the AAF 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 AAF; 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, is more than 10 feet long, with a maximum diameter of 28 inches. Designed to be launched at speeds up to 350 miles an hour, and to travel under water at 70 miles an hour, the missile is driven by a solid-propellant rocket unit delivering 2200-pound thrust for 30 seconds. The range of the missile is 1,000 yards; gross weight, approximately 3200 pounds; and the weight of the warhead, 1250 pounds.

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 cause of cavitation may be explained as follows: when a streamlined body moves through water, the water pressure at certain portions of the surface is reduced. As the speed of the craft increases, the pressure further decreases until, at a certain critical value, the pressure drop is so great that the water vaporizes and forms bubbles. The bubbles cling to the surface where they are initiated. Extensive cavitation seriously impedes the motion of an underwater craft by increasing its drag in the water. Designers, therefore, exercise every precaution to reduce it to a minimum.

Information concerning fundamentals such as those suggested is procured through the interplay of theoretical and experimental methods. One acts as a check upon the other until at last all the desired information is at hand.

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.

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, in the carriage. As the carriage tows the model the length of the channel, driven by an electric motor, can run faster than 40 miles an hour. Originally, it was driven by three liquid-propellant rocket units.

Static test of rocket propelled towing car.

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 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.

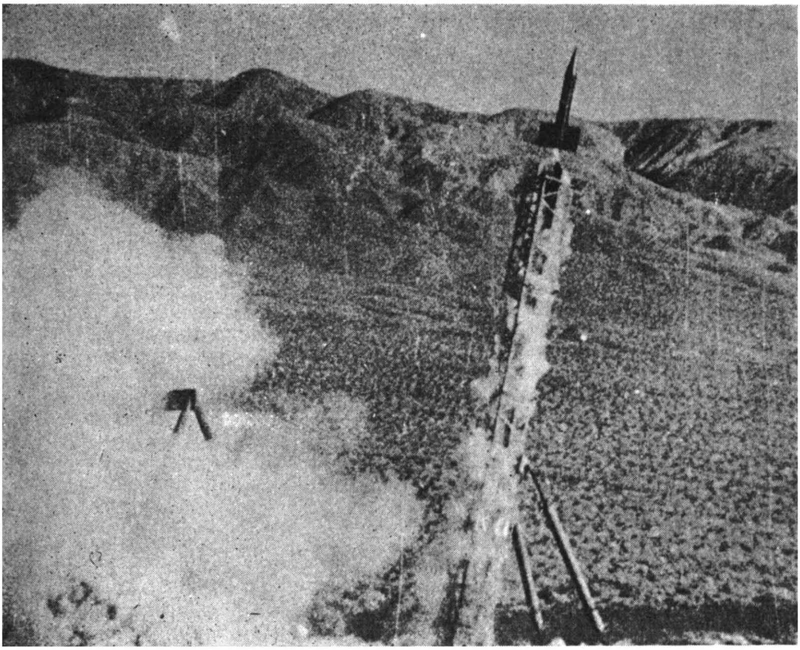
On one side of the channel, midway between the ends, is an underground observation room with a glass window let into the channel wall. The behavior of flow over the surface of a model is studied visually and recorded by cameras.

One of the chief difficulties encountered in the operation of the towning channel has been to overcome vibration in the carriage when it runs at high speeds, for vibration seriously interferes with the accurate recording of the oscillograph. Operation has been improved considerably by coating the steel wheels with rubber and by stiffening the carriage structure as a whole.

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 hydrobomb 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.

The motor used for testing the hydrobomb model burns a solid propellant delivering the specified thrust of 2,200 pounds for a duration of 30 seconds. A long exhaust nozzle was necessitated by the required length of the missile;



Private "A" leaving launcher.

and the heat the nozzle developed had to be ascertained accurately to make sure it was not great enough to affect the operation of control mechanisms installed adjacent to the nozzle.

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 2200-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

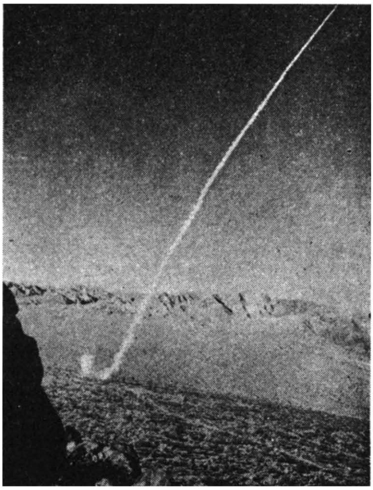
A rocket unit launched at high velocity hits the water with such terrific force that it was feared the impact might crack the propellant or liner, or else separate the propellant from the liner, or perhaps separate the liner from the steel walls of the motor. Any one of these mishaps would render undependable 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.

Objective

IV. 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,



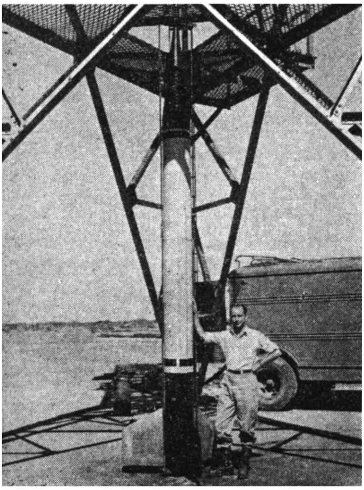
Round #10. PRIVATE "A"

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.

The Project is based upon a contract between the ASF Ordnance Department and the Laboratory. As a result, the AAF 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 contract calls for the design and fabrication of prototype test vehicles, delivered ready for firing tests — the actual test programs to be carried out under the supervision of the Ordnance Department at whatever ranges they designate But the scope of the contract is sufficiently broad to include basic research on:

1. Propellants and materials essential for ;et-propulsion devices,
2. Equipment for the remote control of guided missiles,
3. The aerodynamics of guided missiles (i.e., missiles stabilized and guided by fins and wings).



View of WAC CORPORAL high altitude sounding rocket developed by the Jet Propulsion Laboratory, GALCIT, California Institute of Technology for the Ordnance Department ASF. The rocket is capable of reaching an altitude of around 230,000 ft. in vertical flight.

The following account of the research and development at present under way is in the nature of a progress report on work being done under the ORDCIT Contract.

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 manufactured by the Aerojet Engineering Corporation, the missile delivered thrust of 1,000 pounds for over 30 seconds.

The booster unit, which supplied auxiliary thrust to initiate quick take-off, was a steel casing designed to mount four Ordnance aircraft armament rockets, each 4½ inches in diameter, and manifolded so as to insure simultaneous firing. Open at the center to permit clearance of the jet blast from the PRIVATE, the booster was designed to deliver thrust of more than 21,500 pounds. Devices were installed to prevent rotation in the launcher both of the booster and the PRIVATE; and both vehicles were held in intimate contact by a shearing pin in order to prevent the destructive impact which otherwise would have occurred when the booster unit was fired, as it had to be, an instant after the main motor of the PRIVATE was fired.

The launcher was a rectangular steel boom of the truss type, with four guide rails inside its rigid structure. The boom was mounted on a steel base by means of a pivot joint so that it was adjustable both laterally and vertically. The length of the boom was 36 feet. The function of its length was twofold; to support the missile and guide it on its course until it attained velocity sufficient to gain aerodynamical stability, and to allow the booster unit to burn completely and to disconnect itself from the PRIVATE before the missile cleared the launcher.

Firing tests of the PRIVATE A were carried out at Leach Spring, Camp Irwin, near Barstow, California, December 1 - 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).

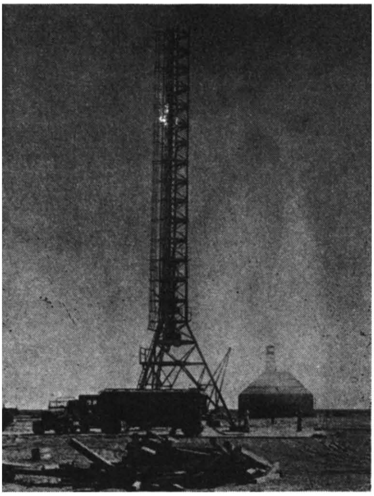
In the spring following the tests of the PRIVATE A, another experimental rocket was ready for testing. It was designed to explore the effect of lifting surfaces upon a guided missile. Called the PRIVATE F, it was essentially the same rocket as the PRIVATE A; but, instead of four symmetrical guiding fins at the aft end, it had one fin and two horizontal lifting surfaces with a total span of nearly 5 feet. At the forward end of the missile, to trim it in flight, were two stubby wings, their total span, less than 3 feet.

Few changes were made in the booster for the PRIVATE F, but the spread of the wings and lifting surfaces on the missile dictated changes in the launcher. It had two rails above, rather than four inside, the steel framework.

The firing tests were made 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. Seventeen rounds were fired. 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.



Launcher, control house and weather tower at White Sands Proving Ground.

Preliminary Problems:

In December, 1944, the Ordnance Department requested the ORDCIT Project to investigate the feasibility of a high-altitude rocket to carry 25 pounds of meteorological equipment to an altitude of at least 100,000 feet, or almost 19 miles, in accordance with a requirement of the Signal Corps.

Early steps toward the fulfillment of the assignment included a series of studies. First, a theoretical study was made to determine whether, with the rocket propulsion systems available at the time, the requested performance for the rocket could be achieved.

When the theoretical study indicated that the requested performance was possible, an investigation was begun to determine the required weight of the missile, its thrust, and the duration of thrust; for upon these and other such requirements its design would be based.

The investigation also 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.

Innumerable essentials of the proposed design, including both missile and auxiliaries, called for technical knowledge obtainable only through experiment. Therefore, as a prerequisite to the actual designing of many essential parts, an experimental program had to be carried out.

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 - 5, 1945, confirmed the choice of three fins and the missile-booster combination selected.

The missile, booster, launcher, and other equipment as finally approved and fabricated for the tests are described herewith.

The Missile:

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 1500 pounds for 45 seconds.

The source of power was a liquid-propellant rocket motor developed by the Aerojet Engineering Corporation. 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.

Pictures of the WAC CORPORAL show a blister running along part of its length. The blister is a fairing which covers the pipe lines running forward from the air tank, and aft from the propellant tanks (see cut-away sketch of the WAC CORPORAL).

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:
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.

Earlier experience with the PRIVATE A had taught much about the technique for coupling booster and missile in close contact for the duration of a boost, and about the automatic release at the end of the period. Experiments with the one-fifth scale BABY WAC had confirmed the design chosen for the contact-release mechanism, not to mention the fact that a 100-foot tower was high enough.

The Launcher:
The launcher, fabricated of structural steel, 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, developed by Aerojet for the Navy, 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 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, beside 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.

So much, then, about the missiles already completed and tested under the ORDCIT contract.

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.

Autopilot:

A guided missile, the German V-2, for example, is one stabilized by fins and guided, or controlled, by movable surfaces. The automatic system that controls these movable surfaces is called an autopilot.

The Sperry Gyroscope Company, in consultation with the Jet Propulsion Laboratory, has designed and developed an automatic pilot for the control of forthcoming guided missiles. It utilizes three gyroscopes to control, respectively, angle of flight, veering off course, and roll. Whenever the rocket veers from its predetermined course, the gyroscopes signal small motors, one mounted on each of the four fins that stabilize the missile. The tail end of each fin is a movable segment or rudder, controlled by a motor. The action of these rudders keeps the missiles on its course.

The gyroscopes, the amplifiers for the signals, and the motors are operated pneumatically, and the compressed air comes from the same tank that supplies pressure to the propellants.

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 flgiht 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.

Telemetering:

Certain instruments installed in a missile take critical measurements of its behavior in flight. These measurements are relayed to the ground by radio. Application of such a system is known as telemetering, or measuring at a distance. It is planned to report ten quantities continuously to a ground station during flight. The quantities will be the following: angular rates about each of the three axes of the missile, position of each of the control surfaces (rudders), hinge moment on one control surface, longitudinal and transverse acceleration.

The telemetering system developed operates by making each mechanical quantity the frequency-controlling element of an audio-frequency oscillator. Thus, variations in the quantity to be measured result in variations of the audio frequency. Five such audio oscillators of different frequencies are then made to modulate a radio-frequency carrier operating at a frequency of about 100 megacycles. At the ground station the five frequencies are selected by suitable filters, passed into frequency-sensitive circuits and recorded on graphic recorders. The complete ten-channel system consists of two five-channel groups using slightly different radio frequencies. The two transmitters use a common antenna projecting from the nose of the missile.

RAFT (Rocket Air Foil Tester):

The RAFT is a rocket designed to fly model airfoils (airplane wings) and to record their aerodynamic characteristics. This method for obtaining aerodynamic characteristics is an important supplement to wind-tunnel tests, which in certain speed ranges are unreliable.

A model airfoil to be tested by the RAFT is attached to a beam protruding from the nose of the rocket. Inside the nose, the beam is supported at three points. At these points, the areodynamic forces acting upon the model produce pressures, which are measured by strain-gauges.

The strain-gauges for the RAFT are a magnetic type that operates by simple electronic circuits. The gauge is made the frequency-controlling element of an audio oscillator. The measured frequency at the ground station then measures the required force. The radio transmitter used to carry the information from the strain-gauge to the ground operates at about 60 megacycles. By insulating the nose of the rocket from the motor, the complete rocket is made to act as an antenna, somewhat less than a half wavelength long.

The RAFT employs a fin-stabilized aircraft rocket, five inches in diameter. Known as the HVAR, it was developed by the NDRC at the California Institute of Technology. Adapted for use as a RAFT, the rocket has a special head.

V. INVESTIGATION OF LIQUID-PROPELLANT ROCKET SYSTEMS

Facilities for Research

Test facilities include seven concrete test pits located at the Laboratory proper, and one special test station at the AAF Muroc Flight Test Base. Each of the Laboratory test pits is capable of handling rocket units with thrusts up to 2,000 pounds; and each is equipped with tanks for handling propellants under pressure, and with an explosion-proof observation room for operators and engineers. At present one pit is devoted to testing a propellant of the liquid-oxygen type, one to hydrogen peroxide, two to a nitromethane propellant, and three to the nitric acid-aniline propellant. The large test station at Muroc is designed for testing motors up to 20,000-pound thrust, for durations somewhat longer than one minute. A motor of this size consumes propellant at the approximate rate of three tons per minute.

One concrete test pit at the Laboratory is devoted principally to the study of pump feed systems for propellants. In this pit is also installed an experimental turbine wheel for pump power supply. It is driven bv a device, similar to a rocket motor, which generates gas from propellant liquids.

Other test pits are assigned part time to the study of gas-generating devices both to drive turbines and to pressurize propellants.

Each pit for testing liquid rockets is eauipped with instrumentation for measuring motor thrust, the pressure in the reaction chamber, the rate of consumption of propellant, various temperatures, and other quantities of interest. Data are recorded automatically, and the results of each experimental run are reduced by a staff of computers.

Research

A brief review of the research the Laboratory is conducting in the further development of liquid propellant rocket systems may be presented in three parts.

Motors:

The purpose of continued investigation of liquid motors is to improve their performance, to discover better methods for cooling them, and to lengthen their service life.

The propellant used essentially determines the maximum performance of a liquid motor. But how closely this limit is approached depends markedly upon the type of injection device used and upon the geometrical configuration of the combustion chamber. Each propellant presents its own set of problems to be solved. A typical acid-aniline motor, for example, gives about 90 per cent of the jet velocity calculated theoretically.

Most motors today are cooled by the propellants themselves which carry away, through the chamber and nozzle walls, the heat transferred by the hot gases of combustion. A promising technique now being investigated is the protection of the inner chamber wall with a film of liquid which evaporates and thus absorbs the heat that otherwise would be transferred to the motor walls. This method is commonly referred to as film cooling.

Research devoted to extending the service duration of several types of liquid-propellant rocket motors has been fruitful. The acid-aniline rocket motor, which the Laboratory has worked on longer than any other, is the most highly developed. Acid-aniline motors of 1500 pound thrust, with a thrust-weight ratio of 30 to 50 have a service duration which can be measured in hours.

A 200-pound thrust motor utilizing a nitromethane monopropellant has operated repeatedly for five-minute periods. The jacketed motor is cooled by the flow of the propellant through the jacket. At present data are being accumulated on the characteristics of motors designed to utilize as oxidizers hydrogen peroxide and liquid oxygen.

Propellant Flow Control:

The Laboratory is developing at present light-weight valves to control the initial flow of propellants with great precision. If flow is not predetermined exactly, quantities of propellants, with their violent chemical reactions, may accumulate within a combustion chamber with disastrous effect.

Propellant Feed Systems:

Liquid propellants must be fed to the combustion chamber of a rocket motor under pressure. Several methods are available for the purpose, depending upon the specific requirements of the propulsion system in question. The Laboratory is investigating many of them.

Gas pressure will often serve the purpose if the thrust required is of short duration; but when thrust is required for longer periods, the weight and bulk of a pressurized gas becomes a serious limitation.

The Germans, after a considerable period of development, replaced gas pressure tanks with a system, incorporated in the V-2, which is called a turborocket. The system supplies pressure to the propellants by means of light centrifugal pumps. A turbine operates the pumps, and is driven by exhaust gases generated in a special combustion chamber.

Still another system to supply pressure for propellants is to produce gases from chemicals installed in the missile for that express purpose. This system gives promise of being lighter in weight than any other. The Laboratory initiated studies on it more than a year ago.

VI. THE SEARCH FOR MATERIALS

Need and Facilities for Research

Other things being equal, the higher the heat of combustion in a rocket motor, the higher the exhaust velocity; and the higher the exhaust velocity, the lower the propellant consumption. In their present state of development chamber temperatures of motors utilizing aniline and nitric acid are in the range from 3500° to 5000°F. The reaction of gasoline and liquid oxygen may produce temperatures as high as 6000°F The numerical values of heat released in such reactions are at least ten times greater than the maximum values encountered in modern furnace practice.

With motor walls of aluminum or stainless steel, the propellant may be utilized to absorb the heat rejected to the surface, even when the temperature developed inside the motor is approximately 5000°F. On the other hand, no material has been found to withstand the hottest flame obtainable with some propellants. Further improvements in the performance of rocket motors, therefore, require either the discovery of new materials to withstand high temperatures or else further development of known ones.

The Laboratory has assembled complete equipment for research in the field of temperature-resistant alloys and ceramics. Six electric furnaces for the heat treatment of metals and for the firing of ceramic pieces have the capacity to handle full-sized units, not merely scale models. Temperatures ranging from 1400°F to 3500°F are obtainable in any atmosphere, and still higher temperatures are obtainable for special studies and to determine melting points. An induction furnace is available for melting and casting alloys.

For research in the relatively new field of powder metallurgy, the Laboratory has an hydraulic press with a capacity of 1800 tons. Equipment is on hand, also, to test accurately various properties of materials as follows: density, porosity, melting point, strength at moderate and high temperatures, thermal expansion and conductivity, resistance to thermal shock and impact strength. The physical structures of alloys and ceramics are studied both by the microscopic method and by that of X-ray diffraction.

Research

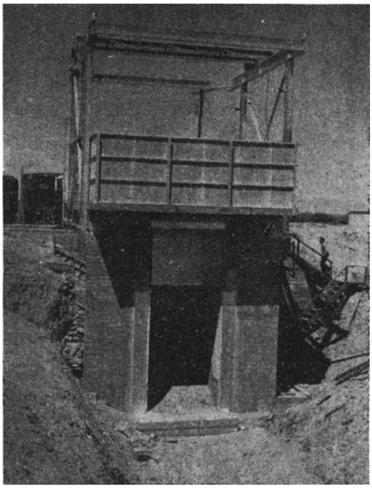
As the result of research conducted by the Laboratory, valuable improvements have been made in a chrome-plated copper nozzle designed for rocket motors utilizing nitric acid and aniline. Suitable non-corrosive bearing materials have been found for pumps utilizing nitric acid. Temperature-resistant alloys have been used successfully to construct a cooled liquid-propellant motor with a thin, hence lighter, shell Tests of ceramic liners for rocket motors are yielding encouraging results.

Ceramic materials, it is anticipated, will play an important part in future developments because they have such high melting points. But because they are brittle and crumble easily, probably they will be used in conjunction with metals rather than replace them. Several methods for producing a bond between ceramics and metals are being investigated. By means of techniques employed in power metallurgy, a composite material made of layers of metal and ceramic already has been obtained.

At present materials are being developed for uses as follows: liners for chambers of liquid-propellant rocket motors; heat and erosion-resistant materials for exhaust nozzles; porous liners (metal or ceramic) for chambers and nozzles of liquid motors, through which a propellant may be injected to act as a cooling medium; ceramic materials for a turbojet unit, including ceramic turbine blades.

VII. RESEARCH ANALYSIS

The importance of theory in the development of jet propulsion cannot be overemphasized. In the early stages of all such development work, knowledge is meager. The systematic way to acquire it is through the interplay of theory and experiment. First, a problem is attacked theoretically. Then the initial solution is applied experimentally. The data thus collected are used in turn to correct or refine the theory. Frequently the cycle must be repeated several times before the desired knowledge is acquired.



Muroc test station motor mount structure and jet deflector.

The section of the Laboratory devoted to research analysis is responsible for carrying out the theoretical analysis of many problems arising in the field of jet propulsion, particularly those requiring the application of advanced mathematical techniques for their solution.

Solutions are required by many sections of the Laboratory to assist in the guidance of their experimental programs. The armed forces, also, through their inquiries, have suggested problems with regard to possible applications of jet propulsion.

Information requested falls within two categories; information to determine whether or not a new rocket type or a new application for an established one is feasible; and information prerequisite to the solution of specific problems in design. The first category was in demand, for example, when the Ordnance Department requested the Laboratory to examine the feasibility of high-altitude rocket to carry meteorological equipment; the second type, when the engineers began their design study of the forthcoming missile.

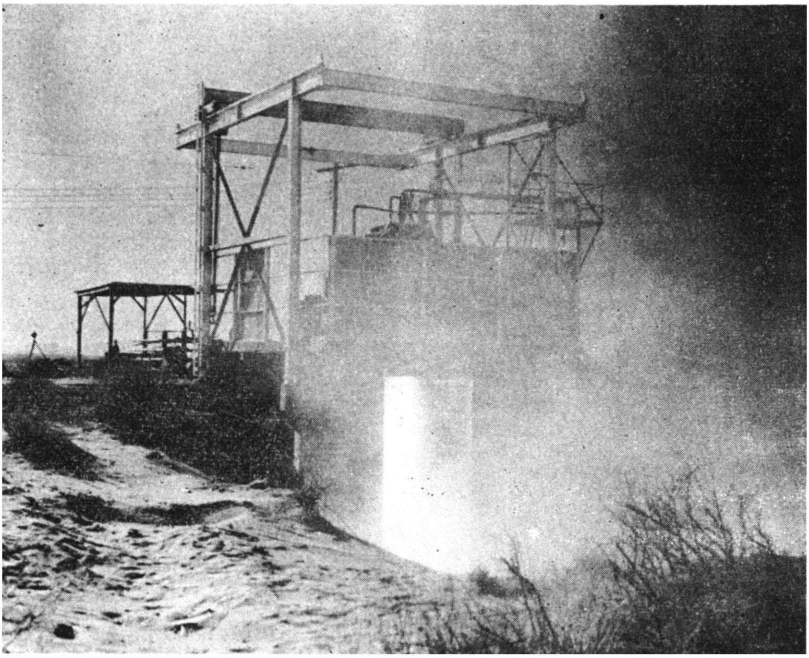
Another example of research prerequisite to the solution of a specific problem in design was a method to determine the aerodynamical force exerted against the surface of a missile whenever it veers even slightly from its predetermined trajectory. Applied to the WAC CORPORAL, the calculated results, within the limits of experimental accuracy, checked against the data supplied by tests of a model in a wind tunnel. Thus, the application of theoretical methods to determine aerodynamic forces may often be substituted for expensive wind-tunnel tests.

A great many theoretical calculations of missile trajectories also have been made. For example, the expected trajectories of the WAC CORPORAL were computed to provide the data necessary for the design of the aero-dynamic control surfaces. Another trajectory study was made to determine the feasibility of the WAC as an anti-aircraft missile.

VIII. THE GRADUATE COURSE IN JET PROPULSION

At the request of the AAF Material 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.



CORPORAL E Motor in operation. Muroc test station.

The Rating of Rocket Fuels

Rocket Fuels Using Atomic Energy As A Primary Heat Source

By THOMAS S. GARDNER, Johnson City, Tennessee

The first paper (1) in this series developed methods for the evaluation of rocket fuels using chemical sources of oxidizers for the thermal reaction. In the last few years several factors have appeared which make it desirable to extend this work into the use of atomic energy as a primary heat source rather than using chemical reactions of substances to furnish the necessary heat for expansion of gases to use as thrusts on the basis of Newton's Third Law of Motion.

The use in Germany of a true rocket ship, the Me-163 as a fighter plane, conclusively shows the practicality of the rocket as a power source extraneous to and independent of the atmosphere to supply one of the components of the fuel system as exemplified by the jet plane and the conventional type of screw drives of the airplane. The V-2 and the Me-163 used chemical fuels. The V-2 (2) used calcium or sodium permanganate with hydrogen peroxide to yield super-heated steam to drive a turbine connected to the rocket motors. This is similar to the MnO_2-H_2O_2 system examined earlier in the series (1). The V-2 then utilized hydrazine and hydrogen peroxide in methanol solution to heat the fuel chambers by a strong exothermic reaction, while the main drive consisted of alcohol or gasoline and liquid oxygen as the oxidant. Some of the thermodynamic properties of the first and last systems of the V-2 were examined (1) and shown to be inferior to the CS_2-N_2O system investigated in this country. The fuel system of the Me-163 was probably similar to the V-2 but it has not been published in detail at the present time. It is now no longer possible to ignore the rocket drive principle as a major form of propulsion.

Popular qualitative and historical descriptions of rockets have been described recently (3). However, it is possible that chemical rockets may become obsolete even before they are perfected for primary rocket drives. This is due to the development of atomic energy. At the present time atomic energy is utilizable either as a relatively low temperature reaction in the pile, or as a violent explosive form as in the atomic bomb (4). In neither case is atomic energy applicable to a rocket drive. However, the utilization of atomic energy is in the most elementary phase, and many scientists having any knowledge of it or of atomic and nuclear reactions believe that it can be developed for many sources of primary heat engines, and by extrapolation, as a primary heat source useful for rocket drives.

Therefore, in order to examine some of the theoretical uses of atomic energy as a rocket drive, we have to make only one assumption. We have to assume that atomic energy using small amounts of an atomic fuel can furnish a constant, controllable, high temperature (1000-5000° A) heat source. We can then apply certain analytical processes to the concept and develop some conclusions as to the secondary fuel conditions if we make this assumption which is probably realizable within ten years.

It would be impractical to eject sufficient atomic fuel alone to yield the thrust required by the application of Newton's Third Law. The quantity would be prohibitive from the cost standpoint, and in no case would it be possible to utilize over a fraction of the available energy. This is due to the fact that all rocket motors are limited by temperature considerations. There are no known metals or alloys of metals that will stand a working temperature of 5000° A, or even for that matter 3000° A for any length of time. The complete composition of the alloys used for jet planes has not been published. Columbium (5) has been reported to be used in jet turbines, and also molybdenum (6) for temperatures of about 1500° F. (816° C). Turbo-jet motors have been stated to operate at only about 1000° C. (7) It may be safely assumed that no present type of engine operates with a wall temperature much above 1500°

C (1773° A). Therefore we can reasonably assume that about 2000° A (1727° C) is the maximum temperature attainable in a rocket motor within the near future. Rocket chambers with removable interior linings of metallic molybdenum or tungsten processed by the powder metallurgy technique could probably withstand these conditions for a while. Thus we probably cannot use atomic energy directly but only as a primary, constant heat source to eliminate chemical reactant fuels. However, chemical reactant fuels may still be useful for some years due to the development of compounds such as ClF_3 (b. p. 12° C.) that react violently with water to yield incandescent gases (8).

If a very small quantity of atomic fuel can be used without having to obtain the minimum mass for an explosive reaction, it can be fed into the rocket chambers simultaneously with any substance that has certain engineering and thermodynamic properties to yield a suitable thrust for rockets. In such a case we can eliminate the greatest single hazard of rocketry, the unstable oxidants that often require refrigeration, pressure tanks, or have to be used within a certain period of time of filling the tanks such as in the case of Loxygen without refrigeration. For example, any fuel that can be fed easily into the rocket chambers would be utilizable, provided it would yield gases at a relatively low temperature (cir. 500° C.), or that decomposes to yield gases at low temperatures by heat alone. The fuel, to be practical, should either be a gas or a liquid, such as water. Also the rocket fuel should absorb heat easily, i. e., have strong absorption bands in the infra red and up to about 30,000° A. The incandescent gases should not dissociate at too low a temperature nor absorb large quantities of heat on dissociation such as the formation of atomic hydrogen from hydrogen gas.

The kinetic energy of a gas is a function of temperature only, but the momentum of the gas molecule is a function of mass and velocity, and at constant temperature the momenta of different gases are proportional to the square root of their molecular weights. Therefore a comparison of the momentum function ($\sqrt{M}$) on a unit weight basis is indicative of relative momenta capable of being imparted by the gases at the same temperature. However, the thermal efficiency of a rocket fuel at a maximum constant temperature of operation of 2000° A would be a function of available thrust, i. e., volume of gases and heat absorbed per mole of fuel, and in the final analysis, per gram of fuel carried (i. e., unit weight basis). The thrust delivered per unit weight is very important as the rocket must carry its fuel and every extra pound requires a greater fuel load. Thus in the use of an atomic heat source the efficiency of the fuel systems used might be written as a first approximation on a thermodynamic basis from engineering consideration as:

$$E_{ae} = V_1/Q_1$$

in which E_{ae} is the efficiency using atomic energy; V_1 volume of gases per unit weight (gram) at the maximum temperature utilizable (2000° A); and Q_1 the Kcal. of heat absorbed per unit weight from the standard temperature selected (27° C) to the maximum temperature.

The following thermodynamic data was used for these calculations:

Most of the heat equations were the ones previously used (1) and had been calculated from band spectra accurate to within 3% up to 2000° A (9).

$$O_2;\ C_p = 6.26 + 2.746 \times 10^{-3}T - 3.43 \times 10^{-7}\ T^2$$

$$H_2O;\ C_p = 6.89 + 3.283 \times 10^{-3}T - 3.43 \times 10^{-7}\ T^2$$

$$SO_2;\ C_p = 8.12 + 6.825 \times 10^{-3}T - 2.103 \times 10^{-6}\ T^2$$

$$CO_2;\ C_p = 6.85 + 8.533 \times 10^{-3}T - 2.475 \times 10^{-6}\ T^2$$

$$H_g;\ C_p = 1.666$$

The heat capacity of mercury vapor has been checked as a monoatomic gas for 548-629° A (10). The specific heat of liquid mercury per gram was taken as $3.336 \times 10^{-2} - 6.9 \times 10^{-6}$ T after Winkelman (11).

The following heats of vaporization per gram at 27° C (300° A) were used (12):

H_2O, 581.1 g-cal/g; SO_2, 81.8; CO_2, 18.9; and for Hg at 357° C, 70.8.

It has been previously shown that the decomposition of 100% hydrogen peroxide would raise the decomposition gases, water vapor and oxygen, to about 1270° A by the heat of decomposition. It is possible at the present time to produce, stabilize and safely store, concentrated hydrogen peroxide. The Elektrochemische Werke Muenchen A. G. developed a vacuum concentration method of producing hydrogen peroxide of 80% or higher strength (13.). This material was used as a fuel in submarines, rockets, rocket aircraft, torpedoes, etc. In this country the Buffalo Electro-Chemical Co., Inc., of Buffalo, N. Y. (14) independently developed a process for producing hydrogen peroxide of 90+% concentration. The heat of decomposition of 30% H_2O_2 is $-\Delta H = 12.13$ kcal; and 100% material, $-\Delta H = 12.88$ kcal. (1). As data on 90+% solutions have not been published the data on 100% material was used in these calculations with proper allowances for the water content on a 90% basis.

The amount of heat required to raise the rocket gases to 2000° A were calculated using the heat equations by the well known thermochemical relation:

$$-\Delta H = \int_{300}^{2000} C_p \, dT.$$

On applying these principles we obtain the following table for a few of the most important fuels to be used as probable secondary systems using atomic heat as the primary heat source.

Compound	M. W.	M	M/g.	Q_1	V_1	$E_{a.e.}$
H_2O	18.0	4.24	0.24	1.46	9.16	6.27
CO_2	44.0	6.63	0.15	0.47	3.75	8.00
SO_2	64.0	8.00	0.12	0.40	2.57	6.43
Hg	200.6	14.16	0.07	0.13	0.82	6.31
H_2O_2 (100%	34.0	5.83	0.17	0.41	11.73	28.81
H_2O_2 (90%)a	(31.2)	(5.59)	0.18	0.48	13.67	28.49

a. 2.65 moles hydrogen peroxide, 0.56 moles water. Thermochemical data for the calculations used that for 100% hydrogen peroxide. In both cases for hydrogen peroxide the Q_1 values are low because only atomic heat is required to raise the temperature from 1270° A to 2000° A, as the heat of decomposition is sufficient to yield the temperature cited for 100% hydrogen peroxide and the same value was used for the 90% material. Spontaneous decomposition takes place at 151° C (15), and this is ideal for a rocket chamber kept to a high temperature by atomic heat.

An examination of the systems in the table shows that hydrogen peroxide is far superior to any other fuel investigated due to its stored chemical energy and decomposition into water and oxygen, thus increasing the volume of the gases and thrust thereby. In this case atomic energy would be a booster for the gases to yield the desired thrust.

The heavy pressure cylinders required by carbon dioxide and sulfur dioxide minimize their value in spite of their $E_{a.e.}$ values which appear very favorable. For example, the weight of the pressure cylinder is usually greater than the weight of the liquified gases, which would more than halve their efficiency, and put both materials well below water and hydrogen peroxide.

An examination of the relative momenta on a unit weight basis of the gases shows that water is superior to all other fuels investigated, and hydrogen peroxide comes in second but still far above the other compounds.

The poor showing of mercury in regard to the momentum factor is in contrast to the hopes placed in it by some investigators who have not followed through the thermal efficiencies and other factors that are necessary for a fuel which has to be transported by the expenditure of other fuel.

For a closed svstem flight of long duration it would be necessary to remove from the atmosphere carbon dioxide and water eliminated by the crew of a ship. If atomic energy is used as described they can be used as fuel for the ship. All organic waste products convertable to liquids or gases could also be used for fuel. It is evident that, if atomic energy be used to maintain a rocket chamber at a high temperature, entirely new systems of fuels become of interest. Thus hydrogen peroxide would probably be best for the main drive whenever available, but water could be used if the cost of atomic fuel should be sufficiently low to allow the generation of the extra heat required between water and hydrogen peroxide with its stored chemical energy. If space for storage were at a premium, hydrogen peroxide would be superior to water. Both water and hydrogen peroxide require only light weight containers.

The use of atomic energy will not make superstratospheric flight easy, but it will simplify problems. The unfortunate fact is that we would like to have a new principle of free space flight in addition to the use of Newton's Third Law which necessitates the loss of a part of the mass of the rocket ship in order to have motion at all. It is also unfortunate that at the present time we do not have a new principle of free space flight in sight in our present system of physics. Further study in the gravitational field equations may result in such a new principle and be as fruitful as the use of the Maxwell-Hertz field equations have been for electro-magnetic and electrostatic fields. Until that date we must utilize the rocket thrust principle as our sole method of free space flight.

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Progress of Astronautics in Great Britain*

A Brief History Of British Societies

By E. BURGESS

It can truly be said that the interplanetary movement first began in this country in October 1933 when P. E. Cleator of Wallasey founded the British Interplanetary Society. This society had its headquarters in Liverpool, the General Secretary being L. J. Johnson, and the president being the founder. A journal was first issued in 1934.

The next important step was the formation by E. Burgess, in June 1936, of the Manchester Interplanetary Society, which body had a spectacular rise into the notice of the public. To say that the resulting publicity was not all that could be desired would be to make an understatement. In those days rockets and atomic bombs were considered to be possibilities of the remote future. A journal called the "Astronaut" appeared in April 1937.

Just after the formation of the M.I.S. a London group of the B.I.S. was inaugurated and Prof. A. M. Low became president of the society upon the transfer of its headquarters from Liverpool to London.

Events followed in quick succession. The Paisley Rocketeers Society was formed by J. D. Stewart in Scotland, a Leeds Rocket Society was started under the leadership of H. Gatcliffe, and J. A. Clarke inaugurated a Hastings Interplanetary Society. A schism then occurred in the committee of the M.I.S. and T. Cusack and E. Burgess formed a new society called the Manchester Astronautical Association in December 1937. By early 1938 the Hastings and Leeds groups had disbanded, but the remaining groups became affiliated to the B.I.S.

The outcome was the production of a common bulletin which also contained news of a Midlands group of B.I.S. members, who, organized by G. Richardson, held several meetings during this period.

A few months before the war, the M.I.S. voluntarily disbanded and the P.R.S. followed suit. The B.I.S. continued and convened an emergency meeting at the commencement of hostilities at which it was decided that the society should cease to function for the duration. The M.A.A. thus became the only functional society by holding its meetings and issuing periodically a journal "Spacewards."

Actually there was another group of interplanetary enthusiasts operating at Surbiton, Surrey. This was the Astronautical Development Society, and K. W. Gatland was responsible for its organization. Contact between these two societies was first made through the correspondence columns of Flight in 1941, and in early 1942 a joint monthly Bulletin was issued, followed in October by the joint journal, "Spacewards."

Combined British Societies

In order to ascertain the possibility of forming one society from these two organizations E. Burgess visited the southern group twice in 1943. The result was the affiliation of the two, and Gatland and Burgess then organized the Combined British Astronautical Societies early in 1944. A Midlands group of this society was formed by G. Richardson, and J. Humphries started a Farnborough group. The inaugural meeting of the C.B.A.S. Eccles group was called by J. D. Page, H. N. Mitchell and T. Gainsborough for June 21, 1944.

About this time also P. E. Cleator, A. C. Clarke and R. A. Smith, in the interests of the B.I.S., circulated a policy file, with officials acting for the C.B.A.S., which contained plans for a postwar society.

On the 21 September 1944 regular meetings of the C.B.A.S. were commenced in Manchester and E. Burgess addressed the Northern Branch at the Adult Educational Institute.

A few months later a possible amalgamation of the B.I.S. and the C.B.A.S. was discussed, a draft proposal was prepared, and a meeting took place in

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Wallasey on December 10th.

Events now began to move quickly. A general meeting of technical members of the C.B.A.S. and B.I.S. was convened by the Farnborough group and held in London on January 20, 1945. Speakers, who advocated the formation of a national society, were A. M. Low, A. C. Clarke, A. V. Cleaver and E. Burgess. J. Humphries and J. Davison spoke for the Farnborough group and put forward several propositions for the reorganization for the C.B.A.S.

In February, as C.B.A.S. president, E. Burgess visited Farnborough and addressed a meeting of the group. He discussed in more detail the proposals put forward at the London meeting. Another meeting followed in Manchester mingham to confer with G. Richardson during March and then he visited Biron the same point of reorganization. From the discussions, Burgess was ablė to compile a new constitution which he placed before meetings at London, Manchester and Birmingham in June, and which was adopted by the whole society.

The next important step was the formation in August 1945 by L. Gilbert, G. Brosan, C. Fleisher, D. G. Ford and others, of London group of the C.B.A.S. At the inaugural meeting of this group which was held in August, the C.B.A.S. president expressed the opinion that he hoped the headquarters of the society would be transferred to the new group. This transfer did take place sooner than was hoped, as the London group grew rapidly in numerical strength. Plans were made at this time for the incorporation of the C.B.A.S.

Previously, on June 13, an informal but important meeting of the B.I.S. had taken place in London, at which it had been decided to reform the society and apply for incorporation. In August P. E. Cleator and E. Burgess exchanged correspondence regarding the prospects of a National Society. The former stressed the importance of being quick to take action before the B.I.S. became incorporated. The C.B.A.S. president then suggested to the B.I.S. that a joint committee meeting should be held before either society applied for incoropration. This suggestion met with unanimous approval and a meeting of the following representatives of the two societies took place in London on 25 September, 1945.

For the B.I.S.

R. A. Smith, L. J. Carter, H. E. Ross,
A. V. Cleaver, R. C. G. Slazenger.

For the C.B.A.S.

G. Brosan, L. Gilbert, C. Fleisher,
Miss D. H. Burgess, E. Burgess.

At the meeting it was unanimously decided that a National Society should be incorporated under the name of the British Interplanetary Society, Ltd. L. J. Carter was authorized to prepare a Memorandum and Articles of Association and to make the required application for incorporation.

Winding up meetings were then called by the B.I.S. and the C.B.A.S., and at London on the 8 December, 1945 the winding up resolutions for the C.B.A.S. were presented by the president and carried unanimously. R. A. Smith presented the resolutions to the B.I.S. on the same day and these were also carried unanimously. Immediately following this meeting of the 8th the subscribers to the Memorandum and Articles of Association of the new society met and made arrangements for various administrative details.

The Certificate of Incorporation was obtained on the 31 December 1945, and the British Interplanetary Society commenced its activities as the National Society at the beginning of 1946.

Possible Defenses Against Atomic Rockets*

Reported by MAX SPITALNY

In this new atomic age, what can we do to defend ourselves against rockets carrying atomic explosives, or rockets driven by atomic power?

While such weapons were not a reality a few weeks ago, they were considered possible. And in March of this year it was reported (*) that United States research scientists had developed, beyond the blueprint stage, a guided missile which can carry an atomic warhead nearly 5,000 miles and strike within one mile of a predetermined target!

How can we defend ourselves against such a missile if it should be used against us? That vital question, more appropriate now than ever, was discussed from many angles at a roundtable in New York conducted by the American Rocket Society on March 15 — a scant forty-eight hours before the report that the United States had produced just such a weapon.

Although a great many schemes were presented to the meeting of rocket proponents, it was quite apparent that an adequate defense against such high-speed devices will be a most difficult technical problem. It was conceded that the only real hope is a world organization which can effectively outlaw war, and even then eternal vigilance by peaceloving nations may continue to be necessary.

The problem was presented by Louis Bruchiss, Editor of the Journal of The American Rocket Society. He cited the German V-2 rocket as evidence that the problem is a real one. The British and the Russians, in addition to the United States, have some of these rockets and have been experimenting with them.

While the range of the German V-2 was only a few hundred miles, we know that this can easily be extended to over one thousand miles by the use of boosters and wings. It is readily conceivable that continued development may result in a rocket capable of crossing the 3,000 miles of ocean separating us from Europe — possibly across the Pacific too.

Then again an attacking enemy might not use rockets, but planes, possibly carrying atomic bombs. There have been conflicting reports about the size of the atomic bomb. Does it require a B-29 or can it be carried by a small fighter? Certainly the B-29 carried it and, therefore, it can not be larger than about the size of a piano. Actually the B-29 had to transport the bomb from a distant base and carry a sufficient crew and instrumentation to handle this weapon while still in an experimental stage. It is quite possible the atomic explosive may be carried by jet-propelled fighter planes or by rockets in the future.

What are our possible defense measures? Against planes, radar warning systems would be quite effective for alerting and launching a counter-attack. Obviously large air fleets would be used and some would get through. Of 1000 attacking planes, perhaps 10 would survive. These 10 might cause terrific damage, but the operation would be costly.

It is far simpler for rockets to be used in such an attack. They possess two important elements, speed and surprise. We know that after the first 30 seconds of gaining momentum and reaching the upper atmosphere the V-2 traveled at a speed of 3,000 miles per hour, reducing its speed only slightly as it fell to earth. Thus we are dealing with a speed of the order of 1 mile per second.

It is hard to conceive of a countermeasure against such a device. Radar has been used to plot the trajectory of an enemy shell. Only a flash or two was observed on the screen, but that was enough to plot the trajectory and to direct return artillery fire against the

(*) Joseph and Stewart Alsop in N. Y. Herald Tribune, March 18, 1946.

attacking site. However, rockets traveling at great speed at great range, beyond the horizon, are difficult to detect. This may be a bit easier if the rocket travels on a high trajectory or if the searching radar is located on high towers or patrolling aircraft.

But even if the approaching rocket is detected, what then? So far we do not know of counter-rockets, atlhough their development may be possible.

We must look for a more basic solution: seeking out the rocket bases and launching sites. An initial answer may be better military and diplomatic intelligence, including an improved State Department. If a rocket attack should occur, it is almost sure to be unannounced and we may not even be able to identify the aggressor!

A complete ring of defense around the United States would be difficult and costly to develop and maintain. Island outposts are necessary, not so much as launching sites for counter-rockets, but as outposts for radar warning equipment.

To develop an intercepting rocket we must deal with very high speeds. An exceptionally high launching acceleration would be necessary to get the intercepting rocket into the upper atmosphere in a position to intercept. Because of the high speeds and brief warning time, computing a collision or even near-collision course is difficult. Proximity fuses have proved very effective against airplanes, but their effect against rockets is very doubtful because of the difficulty in getting a counter-missile close enough to the attacking rocket.

Attacking rockets would probably be launched against cities. It is possible to bombard the upper atmosphere in the path of the approaching rockets in the hope of detonating the charge. This is possible, but far-fetched. However, the problem does make us realize that we know very little of the stratosphere above a height of 20 or 30 miles from the earth's surface.

High-altitude vertical rockets have been used to explore the upper atmosphere and have reached a height of 50 miles, but we need to know far more of the upper atmosphere. Among other things, we will want to know how electronic and mechanical control apparatus will function at such great heights.

We must not discount the possibility to accomplish anything really decisive, but the danger of an atomic bomb orsabotage in an atomic age. Sabotage with ordinary explosives cannot hope to accomplish anything really decisive, but the danger of an atomic bomb planted in a strategic city is much greater. A logical solution advocated by many of our scientists is dispersion of the population and the armoring of vital establishments . Then, even if an attack developed, we would stand a chance of surviving it.

The spirited discussion which followed Mr. Bruchiss' presentation of the problem reflected the interest and concern of the group, including a sprinkling of men in uniform, in a solution of this difficult problem.

While the prevention of sabotage is primarily the job of the F. B. I., it was pointed out in the discussion that inspection of incoming ships and commercial and private planes would be difficult. It normally takes place after arrival of the vessel within our shores, where an atom bomb explosion could be disastrous.

There was some difference of opinion in regard to the feasibility of armoring essential installations against atom bomb attack. It was noted that while concrete buildings in Hiroshima and Nagasaki are still standing, their interiors were burned out. Jacques Martial, an engineer who has been designing structures to withstand such shocks, recommended the use of refractory cement in building construction. He suggested a design of rounded surfaces and abutments to withstand blast effects. He estimated that for an atomic explosion at 1800 feet above ground, the heat developed at ground level would not be above the heat-resisting power of refractory cement. However, the effects of gamma ray radiation could be prevented only by walls of solid lead shielding three feet thick.

Such shelters with rounded surfaces, constructed of refractory cement, could be built by mass porduction methods by means of moulding machines. Any steel supporting the structures would need to be completely covered with the cement. It is conceivable that within 50 years all buildings may be of this type. Even at present, with known methods, a residence cellar can be made reasonably bomb proof for less than $2,000. Against atomic explosives this requires the construction of an extra wall of refractory cement. We would then be in the position of going **inside** the "furnace" for protection from extreme heat outside. It is probable that such construction will be tested at Bikini Island.

Getting back to the stratosphere, Professor Ragazzini of Columbia University stated that control devices have been developed for missiles operating at comparatively low speeds. It is possible that similar methods can be used to control counter-measure rockets operating at great speeds. However, the problem is difficult. The attacking missiles must first be spotted, which would require sufficient spotting stations operating 24 hours daily. Once spotted, the missile must be identified as unfriendly, and identification must be made correctly and quickly. Remember Pearl Harbor!

A possible defense method suggested was rocket or jet-propelled planes with radar search equipment constantly patrolling between a series of island outposts. These might be supplemented by ships and fixed shore stations. The system would serve to detect and report the presence of an enemy missile. While these outpost stations might themselves be equipped to launch counter-rockets, they would provide that extra bit of time required to enable counter-missiles to be launched from the mainland.

Against an attacking rocket no time can be lost. A counter-rocket must be ready to be sent up from a prepared launching platform provided with radar and director mechanism which can promptly launch the counter-missile on a computed collision course. The device may have to travel faster than the attacking rocket to reach within a half-mile or a mile of it. It is then possible to switch to automatic homing control to chase down the enemy rocket. This has been done at lower speeds by heat and light-sensitive devices or radar control.

A mathematical porblem showing the difficult technical problem involved was presented by one of the military men present.

Against an attacking missile traveling at a rate of 5000 feet per second at a height of 100,000 feet, we may have sufficient warning to allow 50 seconds to launch and propel a counter-missile into the upper atmosphere on a collision course.

The counter-missile should have a greater speed than the attacking missile; let us assume 10,000 feet per second. This is equivalent to a Mach number, $M = 10$, that is ten times the speed of sound. Under these conditions there is an adiabatic compression of the air ahead of the missile which heats up the skin or surface in accordance with this formula:

$$T_s = T\left(1 - \frac{\alpha - 1}{2} M^2\right)$$

where T_s = skin temperature

T = atmospheric temperature (Rankin)

α = atmospheric density

M = Mach number

For conditions encountered below 100,000 feet, this would be:

$$T_s = T(1 + .2M^2)$$

$$= T(21) = 380(21) = 7{,}980$$

$$T_s = 7{,}980 \text{ degrees Rankin}$$

This is an exceedingly high temperature, and it shows why meteors burn up when they travel through our atmosphere.

Actually temperature measurements were made (presumably by the Germans) for the V-2 rocket traveling at 5,000 feet per second. These showed a skin temperature (TS) of 1300°C and an internal temperature of 910°C. The lower internal temperature was due to radiation and conduction of the surface heat. However, the temperature developed within the rocket constituted an over-heating hazard which had to be considered in the rocket construction. It was suggested that the surface could be coated with refractory cement.

Then again the problem of maneuverability of a controlled missile at high speed and high altitude is most difficult. In performing a turn we deal with a centrifugal force of V^2/r, which increases as the square of the velocity.

Even if the device is maneuverable at such high speeds, there is still the problem of tracking and homing on the attacking rocket. This would call for computer equipment carried by the counter-missile to determine its own path and the path of the rocket, and to compute and steer a collision course.

The problem may be still further complicated by a flock of attacking rockets, some of them carrying "window"— discharging metal strips at intervals, to jam or confuse search radar. This problem, it was pointed out, might be overcome by utilizing higher frequency radar, (from 3 to 1 cm waves) where better definition is obtained. Or other methods rather than radar could be used, for example, utilization of infra red rays.

Long-range search may be possible with cw waves utilizing the doppler echo from the fast-moving rocket for detection and identification and then using pulse radar for ranging. It should be possible with this method to locate the launching site, which can then be attacked as the best defense against further launchings.

The accuracy of the V-2 rocket was stated to be ½ to 1% of the range, and this can be improved. There was a remarkable consistency in the flight of these rockets, one period resulting in a concentration of hits within a localized area of 20 by 15 miles.

The range of rc·kets of this type is dependent to a laı̮e extent upon the fuel-to-weight ratio. This is at least 2 to 1 and in the case of the V-2 was 3 to 1. The range can be increased by the use of booster rockets and wings which can be extended automatically or by remote control. If it is possible to harness atomic energy as the driving power, a much greater pay load can be carried, and for a much greater distance. This would solve some problems — and would undoubtedly create many new ones.

In summing up the discussion, Mr. Bruchiss stressed:

1. The need for further development of radar equipment to plote the course of a rocket at great distances.

2. The need for development of counter-missiles with self-contained computer mechanisms.

3. The need for plenty of bases all around the continent, preferably island outposts, both as radar warning and counter-measure launching stations.

4. The need for preparation of a defense system of shelters, including dispersion of the population.

5. Counter-measures cannot be fully effective. It is far better not to have another war. Make the U. N. work.

Project Bumblebee — the Navy's Ram-Jet

By ROBERT W. BASS

On June 8, 1946, the Navy disclosed another of its wartime developments — Project Bumblebee. The bumblebee is a kerosene-fueled rocket which scoops its oxygen directly from the air and is not dependent on any self-contained oxidizing agent. Designed for supersonic speeds up to 1,500 miles per hour and having already flown at speeds exceeding 1,400 miles per hour, this jet-propelled missile should prove to be several times as effective as either the V-1 buzz-bomb or the V-2 rocket.

The seventy pound bumblebee or flying stovepipe is the creation of the Applied Physics Laboratory of the Johns Hopkins University, of which project Dr. Richard B. Roberts is director.

The bumblebee is powered by a ram-jet engine. This has no moving parts, is but six inches in diameter, yet develops 2,000 horsepower. It holds the title of "the world's simplest engine", but the many problems associated with its development caused Dr. W. H. Goss, assistant director of the project to remark that "We pay for this simplicity in the long run."

The basic idea of the ram-jet, as Dr. Goss states it, is "merely to bring air into one end of a tube, burn this air in combination with some hydrocarbon fuel, and provide thrust for propelling the thing forward by means of reaction from the exhaust gases escaping out of the rear end of the tube."

The ram-jet engine of the bumblebee consists of three principal sections: (1) the nose, a cone shaped chamber into which air traveling at or above the speed of sound is admitted and compressed by diffusion; (2) the combustion chamber, in which this air is mixed with kerosene and burned, increasing its momentum and producing a strong back pressure which exerts forward thrust on the inner walls of the diffuser; (3) and an exhaust nozzle, through which the exhaust gases escape.

First proposed in 1913 by a French engineer, M. Lorin, the ram-jet principle remained undeveloped for many years. Before the Navy disclosed its Project Bumblebee, however, it was known that several private investigators, including Bernard Smith, Zygmunt Fonberg, and two G.E. engineers, had successfully tried the scheme. But designing a really useful ram-jet presented so many problems that it was not until war-time pressure permitted an all-out attack on them that the first workable flying model of a ram-jet was produced.

The first problem was to design a combustion chamber in which a stable flame front could be maintained while gases were flowing through it at supersonic speeds. The second problem was to produce a burner sufficiently complex to insure unifrom and complete combustion of the fuel, and at the same time not cause excessive drag in the engine.

The reason that the ram-jet must be traveling at supersonic speeds to function efficiently is that its maximum thrust is reached only when it is traveling at sonic velocity. At all supersonic speeds its thrust remains constant. But at the speed of sound the compressibility of the air offers a barrier in the form of resistance that is extremely difficult to pierce. Once the rocket is through this barrier, however, the resistance of the air to passage through it rapidly decreases. Thus to obtain maximum thrust with the least drag it is advisable to fly the ram-jet at speeds well over the velocity of sound.

But at the time tests on the engine were started, there was only one supersonic wind tunnel in the country. A ram-jet model six inches in diameter requires about 100,000 cubic feet of air per minute, and a supersonic wind tunnel suitable for ground testing of such an engine would cost in the tens of millions of dollars. Furthermore, there was no time to build such a wind tunnel. The problem was solved by the use of small free-flight models, costing from $300 to $400 each, and accelerated through the aid of launching rockets to a speed of 1,900 feet per second in the initial second.

Still another problem was that of developing new means of telemetering back to field equipment at the test site such information as fuel pressure, combustion chamber pressure, static pressure, impact pressure, fuel flow, combustion chamber temperature, rate of acceleration, velocity, and altitude.

It was necessary to fit a four channel radio system, complete with power supplies, measuring instruments, and broadcasting equipment, into a space only six inches in diameter. "Without the components developed for the proximity fuse, the job of relaying the data back to the ground for analysis could not be done," Dr. Roberts said.

Work on the ram-jet began in 1945, when the Navy, needing a supersonic guided missile to combat Japanese **kamikaze** bombs and other enemy aerial weapons, gave the job to a group of contractors under the technical direction of the Johns Hopkins University's Applied Physics Laboratory near Silver Springs, Maryland. Within a month the first models were flown without fuel so that the flight characteristics of the engine carrier might be determined, and six months later, on June 18, 1945, a ram-jet engine was flown successfully for the first time in history at Island Beach, New Jersey.

"We have flown numerous models of the ram-jet successfully at speeds far above the speed of sound, but we are still a long way from the end of the road" said Dr. Roberts.

"In fact, it would be more accurate to say that we are just at the beginning of our work."

The truth of this statement was evidenced at the first public demonstration of the bumblebee, made at Fort Miles, on the Delaware coast, on the first anniversary of the initial test firing. Four rockets were launched. The first developed a yaw and did not travel far. The second suffered from irregular fuel consumption. The third fell into the sea after three seconds of flight because of a failure in the launching mechanism. But the fourth was a success, hurtling 29,490 feet in 5.8 seconds.

"Actually, I would have been amazed if all four rockets had gone off without a hitch," said Dr. Goss. "We realized that failures are inevitable when it is necessary to make flight testing serve the purpose of a laboratory, as we have had to do in this project.

"Even so, we can fire many thousands of ram-jet models for the cost of one small wind tunnel, and even if we had unlimited tunnels we would still not be able to tell what one of the things would do in flight without firing it."

The physicists have obtained information on the flight characteristics of the models they have been firing for the past year by tracking them with cameras at triangulated observation stations on the range, by tracking them with radar, and by telemetering information directly from the projectiles. Two independent systems of checking are maintained on every important bit of data they seek. So far they have learned that ram-jets are capable of maintaining themselves in flight and have definite properties of thrust and acceleration.

But many problems will have to be overcome before an engine large enough to do a useful job of propulsion can be constructed.

The exhaust of the ram-jet has a temperature of about 1000° F. Temperatures inside go up to 3000° F. or above. Metals are known that can withstand such heat for the 10, 20, or 30 seconds a flight now lasts. But metals must be developed which can stand such temperatures for several hours. Perhaps it will be necessary to liquid-cool the engine walls.

While war-time developments have made possible launching from stationary platforms with the aid of booster rockets, major launching problems must yet be solved. One need is for a short launching apparatus to fire ram-jets from warships.

Designing larger ram-jets capable of useful work with the flight characteristics of six to eight inch models as a guide also brings up complex problems of supersonic aerodynamics which are yet to be solved.

So long as it remains within the atmosphere, the higher the ram-jet climbs the faster it goes. Tests have been made up to 20,000 feet but the bumblebee's present ceiling is unknown. Many more high altitude tests must be carried out before the J.H.U.A.P.L. physicists reach their ultimate goal of 2,800 miles per hour, plus an altitude capacity of from 60,000 to 100,000 feet.

"We have come a long way in a short while, but we still have many thousands of man-hours of research, engineering, and flight testing ahead of us", said Dr. Roberts. He and his associates are of the opinion, however, that none of the problems which they now face are any more difficult than some of those they have already overcome.

Dr. Goss thinks that two more years will be required before a useful ram-jet is produced. "All we are concerned with doing now is developing a ram-jet engine which the Navy Bureau of Ordnance can use as a means of propulsion of long-range guided missiles. We may find time to think of other applications when that has been accomplished."

When ram-jet engines are applied to airplanes, they will probably be used in combination with some lower speed engine. They may be used as boosters on an interceptor to give it sudden bursts of tremendous speed when needed. They could also be used for high-speed cruising, if the plane was equipped with a launching motor to bring them up to operational speed.

The tips of an airplane propellor often approach the speed of sound. Small ram-jets might be applied to each tip, thus making possible conventional airscrew propulsion at low speeds. And applied to the tips of a helicopter's blades, ram-jet thrustors could eliminate the need for contra-rotating blades or other forms of compensation for motor torque.

Ram-jet-propelled missiles could be used to zoom mail from coast to coast in two hours or less. The V-2 ceases propulsion at a height of 25 miles; could not a ram-jet able to accelerate to an altitude of 100,000 feet or above penetrate far enough into the uppei layers of the atmosphere to gather the meteorological data that the scientists at White Sands, New Mexico, are now seeking with cumbersome liquid-oxygen-carrying rockets?

If human beings are to ride in such wingless projectiles, means of accelerating the ram-jet at a fairly low rate until it has reached supersonic velocity will have to be employed. Perhaps the ram-jet might level off at its ceiling and slowly accelerate in an orbit around the earth until it has built up a speed sufficient for extra-terrestial travel. Theoretically, a ram-jet requires about ⅓ the fuel that a rocket must carry to meet the same conditions. But could it operate at a level where the density of the air was low enough to prevent it from burning up by friction at such a speed?

Atomic Hydrogen — The Fuel Of The Future

By LOUIS C. YOUNG

Recent developments in the field of atomic energy have been of special interest to rocket engineers. Atomic power promises more energy per given fuel mass and greatly increased exhaust velocities. By increasing exhaust velocity we can bring the required mass ratios down to a point where the dream of space travel becomes a reality.

It has been estimated that the atomic bomb explosions created velocities of 100,000 miles per second with temperatures as high as 4,000,000 degrees. It is quite obvious that designing an engine to handle such power is an impossibility. Much has been said about the promise of atomic power but few practical applications have been advanced to date. One possibility would be an engine which included a machine such as the cyclotron, but extremely smaller and lighter than present models, to provide a supply of bombarding neutrons. The fuel would contain only a small percentage of uranium in a compound requiring enormous heat and pressure for manufacture. The nuclear fission of the uranium provides the energy for the disintegration of the compound, and the resulting explosion creates exhaust velocities hundreds of times more powerful than present fuels. Such an engine will not be the result of one man's genius but rather the result of the labors of hundreds of engineers, physicists, chemists, and metallurgists. Until such an engine is developed, the Uranium Pile can be of some value. The uranium pile generates a great amount of heat but the mass of particles discharged is too small to be of value, however, the heat can be utilized to impart very high velocities to other substances.

The best chemical fuel for rockets is hydrogen. Burning a mixture of hydrogen and oxygen gives us a theoretical exhaust velocity of 17,000 feet per second; a well designed engine might produce a working velocity of 12,000 ft/sec. This is sufficient for meteorological rockets and makes a moon rocket possible if the mass ratio is high enough.

We have what might be termed a sub-atomic fuel if we can utilize atomic hydrogen. Many of us are familiar with the atomic hydrogen welding torch. As the stream of hydrogen gas passes through an electric arc the molecules are broken into separate atoms which upon recombining a split second later release tremendous heat. For each gram of hydrogen passing through the arc, 100,000 calories of energy are absorbed from the arc and released when the atoms recombine to form H_2 molecules.

One gram of hydrogen combines with eight grams of oxygen to form nine grams of water vapor with a release of 28,900 calories of energy. Using atomic hydrogen we have a potential 128,900 calories available for the same amount of fuel with a theoretical velocity of 21,000 meters or 69,000 feet per second. An engine with a 70% thermal efficiency would have a working velocity of 48,000 ft/sec., six times as powerful as the V-2. The V-2 has a mass ratio of 6-1 and has reached an altitude of 104 miles in test flights. An atomic hydrogen rocket with the same mass ratio could go to the moon and come back.

Why not use hydrogen alone? Atomic hydrogen is 31 times as powerful as chemical fuels and 7 times as powerful as atomic-hydrogen combustion. An engine with an exhaust velocity of over 50 miles a second would make a Buck Rogers ship seem commonplace.

Uranium piles are expensive and extremely heavy, and quite obviously could not be used for small rockets but a successful moon rocket must be large. Experts have spoken of 100 ton rockets; such a rocket is conceivable now.

Let us compare two 100 ton rockets. Rocket No. 1 is powered by an efficient hydrogen-oxygen engine, No. 2. by a sub-atomic engine of the type I have proposed. Both engines develop a 250 ton thrust; No. 1 burns over 1300 pounds of fuel each second, but No. 2 uses only 335 pounds of fuel during the same period. Rocket No. 1 carries 90 tons of fuel and has a mass ratio of 10-1. The uranium pile, radio-activity shielding, etc. of Rocket No. 2 adds ten tons weight, its fuel load is only 80 tons and mass ratio 5-1. With all fuel exhausted, the first rocket could attain a speed of 27,600 ft/sec. if launched in an absolute vacuum. Launched from the earth, it could rise well above the atmosphere with a horizontal range of several thousand miles. By contrast, Rocket No. 2 has a maximum potential speed of 79,000 feet per second, and a possible round trip to the moon. After a high speed has been reached, preferably outside the atmosphere, the oxygen supply can be shut off and the engine develops 125-150 tons thrust using only 37 pounds of hydrogen gas per second.

These figures may seem high, but Dr. Goddard stated that an engine with a 70% thermal efficiency is a possibility. The storability of liquid hydrogen presents another difficult problem; a gallon weighs only nine ounces and its critical temperature approaches absolute zero. Perhaps a methane series hydrocarbon could be substituted but the performance figures would be considerably reduced.

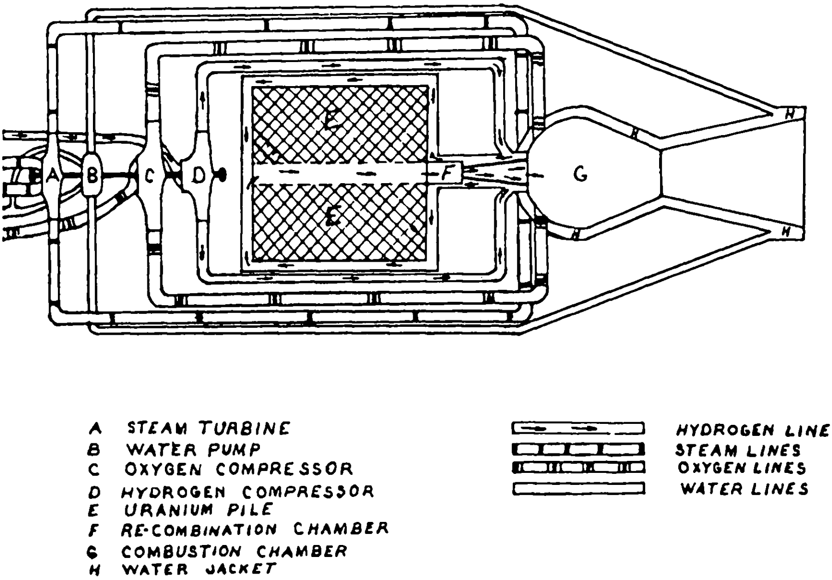
In his recent article "Next Stop The Moon", G. Edward Pendray predicted a rocket with an initial weight of sixteen to twenty thousand tons for a round trip to the moon carrying five men. A rocket with sub-atomic power should do the same job with a weight of less than a thousand tons. The cooling system and other necessary equipment may require that the engine be fairly small in relation to the size of the rocket. Should such be the case, a two step principle would be needed, with a step powered by chemical combustion to lift the main rocket to the upper atmosphere. Without the friction of the air, a relatively small engine is sufficient.

The design of the sub-atomic engine is fairly simple, as shown in the sketch. Hydrogen gas is pumped to the engine by the compressor (D), which insures a constant supply, to the outer jacket of the recombination chamber, then through the jacket surrounding the uranium pile (E) that provides the heat to complete the change from molecular to atomic form in the tube through the center of the pile. In the recombination chamber (F) the gas returns to the molecular state and passes through the nozzle at terrific speed and into the main combustion chamber (G) to ignite the oxygen and provide the major thrust of the engine. The combustion chamber is cooled by a water jacket which provides the steam to operate the turbine (A) which turns the pumps and compressors. Initial starting of the turbine is done by hydrogen peroxide decomposition.

The cooling problem would be greatly simplified in space by designing the rocket with a double hull having a refractory exterior. The steam is piped to the forward portion of the hull and is condensed by radiation of its heat. Acceleration creates an artificial gravity which forces the water to a well in the rear of the ship from which it can be pumped back through the system. Several hundred gallons will be necessary for the crew. It could also cool a fairly large engine. A purification system would enable its re-use.

This engine is designed primarily for operation in space. The tremendous heat developed by such an engine involves cooling problems insoluble at present in our atmosphere. Until such problems are solved it will be necessary to add a second step to project the rocket to the outer air or into space itself.

No provision has been made for a shield to repell lethal radiation from the uranium pile. The heavy lead shielding in use at present would defeat the purpose of this engine because of the excessive weight of such an installation. Such shielding may not be needed for a robot rocket but a lighter method of shielding is necessary before this engine can be adapted to a man-carrying ship.



The Exponential Law Of Motion

Mass-Ratio As Applied To Rockets

By CEDRIC GILES

The exponential law of motion for determining the ratio between the weight of the fueled and the empty rocket has been treated to some extent in most technical works on rockets; but due in many cases to the absence of certain fundamental considerations or the advanced mathematical calculations involved a general knowledge of the exponential expression is many times difficult to grasp. In order to better familiarize the reader with this, one of the most remarkable expressions in the mathematics of rockets, this article is offered.

Equal Fuel-Rocket Weights

First it may be well to momentarily consider the case of a rocket with its net weight equal to its fuel load, and discharging the entire fuel mass at once. Part A of Fig. 1 shows such an event; the pressure created by the burning fuel causes the rocket unit to move to the left while the gas particles move to the right. Under this hypothetical condition the velocity of the rocket will instantly equal the speed of the exhaust gases, as expressed by Newton's Third Law of Motion that action equals reaction, $MV = mc$. While exceedingly rare the circumstance is a fair analogy to the firing of a projectile from a gun.

It can be mathematically established that, when disregarding fuel required to transport fuel, a rocket will reach its exhaust velocity at the moment all fuel is expended. The jet speed or duration of firing does not need to be limited, and fuel may consist of any adaptable substance—alcohol, gasoline, gunpowder or even water for producing a steam jet. As no present feasible means supplies fuel from a distance source, the unburned fuel needs additional fuel to accelerate it. Consequently, to achieve the ideal rocket function the fuel mass must be greater than the mass of unfueled rocket.

Velocity Increase

The ever-increasing velocity of the rocket mass produced by a constant consumption of fuel when rocket weight equals fuel weight is also represented in Fig. 1. Part B shows a block of fuel moving to the right as the larger rocket mass (including unburned fuel) moves to the left. A second block of fuel is expelled in Part C supplying an additional impetus to the rocket. In Part D the reactive thrust is again increased by the exhausting of the remaining fuel. While all of the fuel is expended with a constant velocity in relation to the rocket mass, the rocket is increasing its velocity in proportion to each successive thrust and loss of fuel load.

The ratio of rocket weight and fuel weight can be mathematically computed by using rocket and jet exhaust values in a manner similar to the following simplified example. On referring to Fig. 1, Parts B, C and D, it will be readily noted that at the end of the third and final step the rocket's velocity is 2350 ft. per sec. — 600 + 750 + 1000. As this velocity figure is less than the jet velocity (3000 f.p.s.) the result suggests the need of a still larger percentage of fuel weight to attain equal fuel and rocket velocities.

The e Number

Computation of the equation of motion will only be considered in the simplest manner as advanced methods for obtaining the number e are presented in mathematical textbooks, especially those dealing with calculus and logarithms. For interested persons a lengthly worked out proof of the equation will be found in L'Astronautique* Although in French this source is ofttimes referred to by exponents of the mass-ratio theory.

Calculation Of e

The exponential law provides: A rocket will attain its own exhaust velocity when its mass is 1/e of the original mass. In order to determine the value of e in the law of growth reflect on the following method of calculation.

With the empty rocket mass represented as 1 and using a convenient fuel amount of one-tenth (10%) of the rocket weight to be expended in one firing period, initial overall weight would be 1 + 1/10 or 1.1. On using additional fuel at the same rate, likewise, (1 + 1/10) (1 + 1/10), (1 + 1/10) (1 + 1/10) (1 + 1/10), and so on.

The algebraic equations denoting the initial rocket mass M_0 for the several stages now because $(1 + 1/10)^1$, $(1 + 1/10)^2$, and $1 + 1/10)^3$.

When the fuel consuming periods reach 10 the resulting expression is

$$M_0 = (1 + 1/10)^{10}$$

If fuel is fired 20 times and 1/20 of the rocket mass is used each time

$$M_0 = (1 + 1/20)^{20}$$

With n expressing the firing periods and 1/n the fuel expended during each period

$$M_0 = (1 + 1/n)^n$$

*Esnault-Pelterie, Robert, L'Astronautique, Paris, pp. 49-52, 1930.

Presented in Table I are some formulated quantities calculated by common logarithms as n approaches infinity (OO).

Table I

n	$(1 + 1/n)^n$	M_0
1	$(1 + 1/1)^1$	2.000
2	$(1 + 1/2)^2$	2.250
10	$(1 + 1/10)^{10}$	2.594
100	$(1 + 1/100)^{100}$	2.704
1000	$(1 + 1/1000)^{1000}$	2.717
OO	——	2.718

Fractional Series

The base of the natural or Napierian system of logarithms, which is used in the calculation, is valued at approximately 2.72 and is indicated by the Greek letter e.

From textbook formulae series are worked out as,

$$e = 2 + 1/1.2 + 1/1.2.3. + 1/1.2.3.4. + \ldots\ldots\ldots$$

and

$$e = 2 + 1/2 + 1/6 + 1/24 + 1/120 + \ldots\ldots\ldots$$

The number e is now developed by expressing the fractions as decimals or by simply dividing each decimal by a series of whole numbers, as .5 divided by 3, 1.666 ÷ 4, etc., and adding the result. This unending decimal carried out to ten places,

2.
.5
.1666666666
.0416666666
.0083333333
.0013888888
0001984127
.0000248015
.0000027557
.0000002755
————
2.7182818284 +

This constant 2.72 (approx. 2 5/7) as it is conveniently written is better known among rocket technicians as the mass-ratio or weight-ratio figure.

The most important of derived formulae from lengthy mathematical calculations, when v = velocity of rocket, c = velocity of exhaust gases and M_1 = final mass of unfueled rocket, state that

$$M_0/M_1 = e^{v/c}$$

and

$$v = c \text{ when } M_0/M_1 = e$$
$$v = 2c \text{ when } M_0/M_1 = e^2$$
$$v = 3c \text{ when } M_0/M_1 = e^3$$

2.72 Divisions

A breakdown of the general number 2.72 reveals that the mass of the unfueled rocket equals 1, fuel required to propel the rocket mass to attain jet velocity is 1, and fuel needed to sustain unburned fuel and fuel in turn is .72. Continuing further, and using 5/7 instead of .72, rocket weight to fuel weight is 1 : 1 5/7 with the entire weight 2 5/7, the e number. With the rocket equaling 7 units, the fuel will be 12 units and the combined weight 19 units.

While only of theoretical value it is interesting to contemplate an example using the exponential law of motion. In Fig. 2 the base line has been divided into two parts of 7 units and 12 units. The unused seven units constitute the 7 equal-weighing units of empty rocket mass and the remainder the 12 equal-weighing units of fuel, or in all 19 units. Again employing the easily workable jet velocity figure of 3000, the fuel section is divided into the consecutive thrust velocities given the rocket by the 12 discharges of fuel (in the manner outlined in Fig. 1). Advancing step by step from right to left the accumulated rocket velocity in this case amounts to 3136, a sum somewhat more than the jet velocity due to the relatively large masses of fuel ejected.

To achieve the mass-ratio figure the fuel—powder, liquid or gas—must be expelled in infinitely small particles as is customary in the gaseous jet exhaust of rockets. The reactive thrust is constant with the entire rocket mass variable as fuel is expended.

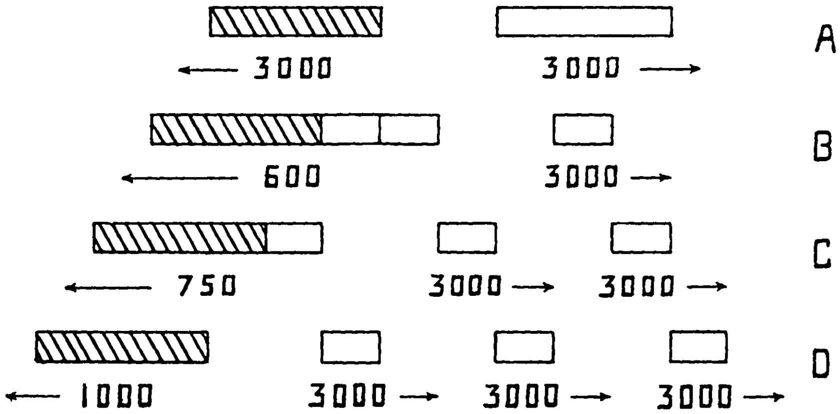


Fig. 1. Rocket mass velocity increases as fuel masses are expelled.

Acceleration Of Rocket

Knowing the rate and velocity of fuel exhausted per interval of time, the time of firing, acceleration, velocity and distance of travel can be readily computed for a 2.72 rocket. This concept of action is purely theoretical and can only hold true in space as the effect of air resistance is ignored.

The acceleration of the rocket at any particular time is found by simply dividing the jet velocity by the fraction of fuel of the remaining entire rocket mass expended in the indicated time

$$A = \frac{c}{a}$$

Although the jet velocity and amounts of expended fuel mass during duration of firing are constant, the proportion of the remaining fuel mass to net rocket mass continuously decreases. From this consideration the rocket acceleration and velocity grows at an accumulating rate.

*Altitude of powered flight may be quickly determined, being ½ of 3000 x the 12 ejection periods.

As the ultimate rocket velocity will be equal to the speed of the jet, the velocity of the rocket can be expressed as

$$v = A + A + A + \ldots\ldots$$

with v found by adding the rocket velocities of each time period.

Altitude Of Rocket

In the usual case of a body having uniform acceleration, the relationship between the time, velocity and height is simply computed as the ordinary formulas for accelerated motion suffice. But in the 2.72 rocket, the rate of rocket acceleration is augmented each unit of time, as some fraction of the .72 fuel mass is discarded, introducing a variation in the usual calculation for uniform acceleration.

The first step in solving the accelerated part of the flight in the case of Fig. 2, with jet velocity rated at 3000 f.p.s., is accomplished by dividing the final rocket velocity of 3000 ft. by the 12 firing periods for an average acceleration of 250 ft. per discharge period. The altitude attainable by the rocket under power is then simply calculated from the customary altitude formula of one-half the acceleration times the time squared, or 18,000 ft. (3½ miles).*

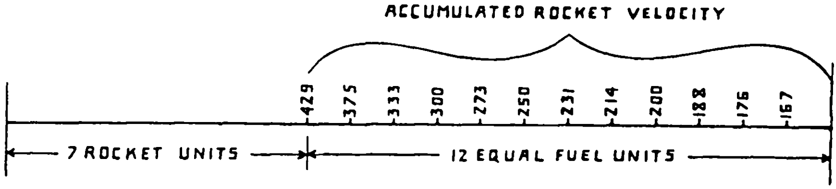


Fig. 2. Scale shows increase in rocket velocity due to discharges of fuel portions for a 7-12 rocket-fuel combination.

This height is naturally only the altitude the rocket reaches while in powered flight as the rocket will continue to climb in projectile flight against gravity under the applied momentum force. By the equation

$$H = \frac{v^2}{2g}$$

some extra 140,500 ft. (about 27 miles) will be gained for a theoretical total ascent of 158,500 ft. or approximately 30 miles. Air resistance will reduce the rocket velocity and consequently the maximum altitude by some 50 or more percent.

Velocity Curve

The plotted curve in Fig. 3 shows the low velocity of the 2.72 rocket in the initial increments of time and its rapid rate of speed increase as it nears the velocity of the gases. This acceleration of the rocket is due, as explained previously, to the constant expenditure of the fuel from the 1.72 figure until dissipated. The velocity path of the rocket can be considered fairly standard for all cases where the net rocket weight to fuel weight is 1 : 1.72.

Thus for a rocket to attain its jet velocity nearly ⅔ of the entire weight must be fuel. This rule holds true as long as the 2.72 ratio is used. The overall rocket weight may be 2.72, 27.2, 272, etc., providing the unfueled rocket weighs 1.0, 10, 100, etc., while the fuel weighs 1.72, 17.2, or 172.

Higher Ratios

The possibility of carrying a greater fuel payload enabling the rocket to exceed its exhaust velocity has been calculated numerous times. The ratio values of fuel and rocket weights in Table II for M_0/M_1, worked out by Oberth, has been reproduced in various forms. Examination of the table will reveal that 7.39 is the square of 2.72, and 20 is the square of 4.48. If the speed of the rocket or the gases is doubled the ratio is squared. Likewise, if the rocket velocity is tripled from 1000 to 3000 ft. per sec. the ratio is cubed, 2.72 to 20.

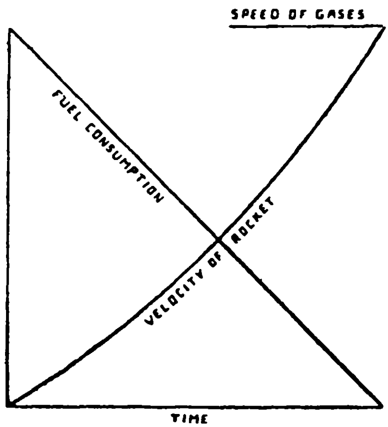


Fig. 3. Velocity curve of rocket attaining speed of exhaust gases.

Present-day rocket construction and jet velocities tend to place a limit on the practical use of this table for the higher ratios. Building a rocket to a 20 to 1 ratio becomes extremely difficult and higher weight-ratios appear well-nigh impossible. On a 20 to 1 basis a 1000 lb. rocket requires 750 lbs. of fuel to propel the 250 lbs. of rocket and payload. This is equivalent to 95 per cent of fuel to 5 per cent net rocket weight.

Tables on theoretical exhaust velocities of fuel often are misleading as in attaining mechanical energy by the conversion of heat a large percentage is wasted due to incomplete combustion and heat loss. With the present best fuels providing exhaust velocities under 1000 ft. per sec., higher velocities appear possible only through more efficient conversion methods or the employing of higher velocity fuels when available.

Conclusion

In concluding, it may be well to emphasize that the exponential law of motion applies only to rocket propulsion, where all fuel is carried along, and cannot be considered for the air-stream type of jet engine that utilizes the atmosphere for fuel combustion. In relation to rockets, it is a theoretical approach only and should not be construed as being attainable in practice where many contingent factors enter into the final result. With air resistance and other agents largely ignored, the weight-ratio becomes a general yard-stick on which to base calculation in the mathematics of rockets.

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Pendray, G. Edward, The Coming Age of Rocket Power, 1945.
Zim, Herbert S., Rockets and Jets, 1945.

TABLE II

Jet Velocity of Gases (c)

Velocity of Rocket (v)	1,000	2,000	3,000	4,000	5,000
500	1.64	1.29	1.18	1.13	1.10
1,000	2.72	1.64	1.39	1.29	1.22
2,000	7.39	2.72	1.94	1.64	1.49
3,000	20.0	4.48	2.72	2.11	1.92
4,000	54.5	7.39	3.78	2.72	2.22
5,000	148	12.2	5.29	3.49	2.72
6,000	405	20.0	7.39	4.48	3.32
7,000	1,089	33.0	10.25	5.76	4.06
8,000	2,982	54.5	14.35	7.39	4.95
9,000	8,060	89.6	20.00	9.50	6.06
10,000	22,070	148.7	27.95	12.20	7.39
11,000	60,000	243.5	39.0	15.75	9.02
12,000	163,100	402	54.6	20.0	11.00
13,000	444,000	662	76.1	25.8	13.47
14,000	1,200,000	1,091	106.3	33.2	16.42
15,000	3,290,000	1,805	148.7	42.7	20.0

Jet Aircraft in the United States

By JOHN McLEOD

Though the United States was not the first country to engage in experimenting and construction of jet-propelled aircraft, this country has become the proving ground of numerous types of such craft. Since the awakening of interest in rockets and jet planes in the United States, aircraft manufacturing concerns have turned out more models than is generally known.

The first flight of a jet-propelled plane in this country took place in October, 1942; and the craft in question, the Bell XP-59, now rests in Washington's Smithsonian Institute. Bell P-59 A's and B's are now used as transitional trainers by the AAF.

From the P-59 stemmed the larger Bell P-83, which utilized two General Electric jet engines with a 4200-lb. thrust.

Lockheed's original "Shooting Star", the XP-80, was designed, built, and flown in less than five months. P-80A's are now standard equipment of the AAF. Two P-80's have been tested (in England) using Rolls Royce jet engines. Reports state that performance was improved greatly.

Douglas Aircraft has produced the XB-42A, which uses two Allison reciprocating engines as well as two jet engines. This plane was developed from the Douglas B-42 "Mixmaster"

The XP-81, built by Consolidated-Vultee primarily for research work, was the first fighter plane to have a jet engine and a propeller driven by a gas turbine.

Ryan's FR-1 "Fireball", built for the navy, was the first craft to employ both a jet engine and a reciprocating engine. The jet is a General Electric J-31 (or a J-33 for the FR-2) and the engine driving the propeller is a Wright R-1820. The "Fireball" will fly on either or both engines.

Republic Aircraft has constructed the first jet plane in the U.S. to have the air intake in the nose (similar to Italy's Caproni-Campini). It's the P-84 "Thunderjet", with a speed of about 600 m.p.h.

The FD-1 "Phantom" has two Westinghouse jet engines and was designed for operation from aircraft carriers. It was built by McDonnell Aircraft.

A newer plane is the XF15C-1, by Curtiss. It utilizes a reciprocating engine and liquid fuel rocket in the tail.

North American Aircraft also enters the field with the XP-86; Northrop, builders of the new XB-35 flying wing bomber, also experimented with a jet-type flying wing, the XP-79; jet propelled bombers are also under construction by the Martin and Boeing companies.

The above planes are in the 475-600 plus m.p.h. class, considerably better performance than conventional fighter planes.

New models are being developed constantly, and with improvement in the fuels, engines, and in construction, the field will be wide open.

UNITED STATES PATENTS

The following patents are compiled from issues of the Official Gazette of U. S. Patent Office. Copies of patents may be obtained from the Commissioner of Patents, Washington, D. C., at 25 cents each.

No. 2,179,404, "Rocket Projectile"; Peter V. Fabionar, Norwalk, Calif.

No. 2,395,435, "Emergency Control Mechanism for Aircraft"; Louis T. E. Thompson, Dahigren, Va., and Robert H. Goddard, Roswell, New Mexico.

No. 2,397,654, "Propulsion Means"; Archibald G. Forsyth, Cheam, England, assignor to The Fairey Aviation Company Limited, Hayes, Middlesex, County, England.

No. 2,397,657, "Control Mechanism for Rocket Apparatus"; Robert H. Goddard, Roswell, N. Mex., assignor of one-half to The Daniel and Florence Guggenheim Foundation, New York, N. Y.

No. 2,397,658, "Combusion Appartus"; Robert H. Goddard, Roswell, N. Mex., assignor of one-half to The Daniel and Florence Guggenheim Foundation, New York, N. Y.

No. 2,397,659, "Control Mechanism for Rocket Apparatus; Robert H. Goddard, Roswell, N. Mex., assignor of one-half to The Daniel and Florence Guggenheim Foundation, New York, N. Y.

No. 2,397,834, "Rocket Motor"; Andrew L. Bowman, Detroit, Mich., assignor of one-half to Mabel J. Bowman and one-half to William Bowman.

No. 2,397,998, "Propelling Apparatus for Aircraft"; Robert H. Goddard, Roswell, N. Mex., assignor of one-half to The Daniel and Florence Guggenheim Foundation, New York, N. Y.

No. 2,397,999, "Propelling Apparatus for Aircraft"; Robert H. Goddard, Roswell, N. Mex., assignor of one-half to The Daniel and Florence Guggenheim Foundation, New York, N. Y.

No. 2,398,125, "Motor"; Martin Summerfield, Pasadena, and David A. Young, Arcadia, Calif., assignors to Aerojet Engineering Corporation, Azusa, Calif.

No. 2,398,201, "Motor"; David A. Young, Pasadena, and Martin Summerfield, Arcadia, Calif., assignors to Aerojet Engineering Corporation, Azusa, Calif.

No. 2,398,871, "Rocket Firing Tube"; William J. Turnbull, Towson, and Werner Buchal, Parkwill, Md., assignors to The Glenn L. Martin Company, Middle River, Md.

No. 2,398,927, "Sell-Propelling Projectile"; William W. Farr, Grosse Pointe Park, Mich., assignor by mesne assignments, to United States of America.

No. 2,398,928, "Reaction Propulsion Device"; William W. Farr, Grosse Pointe Farms, Mich., assignor, by mesne assignments, to the United States of America.

No. 2,400,242, "Motor"; Frank J. Malina and Mark M. Mills, Pasadena, Calif., assignor to Aerojet Engineering Corporation, Azusa, Calif.

No. 2,400,248, "Motor Mounting"; Harry W. Morgan, Pasadena, Calif., assignor to Aerojet Engineering Corporation, Azusa, Calif.

No. 2,400,714, "Jet Propulsion Power Unit"; Arthur J. Rowledge, Derby, and Thomas Shelley, Breaston, England.

Compiled by Cedric Giles

CONTAINED IN DR. GODDARD'S BOOK

From An American Rocket Society News Release:

The two fundamental technical reports, with which the late Dr. Robert H. Goddard launched the whole modern era of jet propulsion during the period of his pioneering researches in Massachusetts and New Mexico, are published for the first time in book form by the American Rocket Society, the national association of jet propulsion and rocket engineers. The book is entitled ROCKETS, by Robert H. Goddard.

"It is a tribute to the fundamental nature of Dr. Goddard's work", says the foreword to ROCKETS, "that these reports, though now several years old, are filled with data of vital importance to all jet propulsion and rocket engineers. These reports form one of the most important technical contributions of our time."

The first of the Goddard reports, only 80 pages in length, was originally published in pamphlet form by the Smithsonian Institution, in 1919. In it Dr. Goddard, who died last August, set forth the fundamental theory of jet propulsion, showed how the rocket could be used to reach extreme altitudes ("A Method of Reaching Extreme Altitudes" was its title), recounted his experiments proving that rockets will work as well in a vacuum as in air, and made some preliminary calculations which showed clearly that it will someday be possible to shoot a rocket to the moon.

For this paper, now a classic of modern science, Dr. Goddard was so severely ridiculed by other scientists and the public in the early 20's that he made no further report until 1936. He continued his work, however, under grants of funds from the Smithsonian Institution and the Guggenheim family. His second report, also issued as a small pamphlet by the Smithsonian Institution, was entitled "Liquid Propellant Rocket Development" In it, Dr. Goddard described his first liquid fuel rocket experiments, in which he was the world pioneer; told how he shot the first rocket to reach the speed of sound, and projected many other developments that have since come to pass.

These two important papers, as fresh and technically important today as they were when first written, are both included in ROCKETS. The book also contains more than fifty pictures of Dr. Goddard's experiments, a new foreword by Dr. Goddard written shortly before his death, and a biographical sketch of the scientist by G. Edward Pendray, nationally known authority on rockets and jet propulsion.

ROCKETS is now available through the American Rocket Society, Engineering Societies Building, 29 West 39th Street, New York City. Publication of the book is by special arrangement with the Smithsonian Institution and the estate of Dr. Goddard. The price is $3.50.

New Officers of the American Rocket Society

The American Rocket Society, national association of rocket and jet propulsion engineers, announces the election of Lovell Lawrence Jr., as its president for the 1946-47 term.

Mr. Lawrence, pioneer rocket engineer and long a member of the Society, is president of Reaction Motors, Inc., of Dover, N. J., now heavily engaged in the development of liquid-fuel rocket motors in connection with Navy and Army jet propulsion and guided missile program.

The new vice-president of the Society is Roy Healy, jet propulsion project engineer of the Air Technical Service Command (a division of the Engineering Section of the Army Air Forces.) Mr. Healy was until recently engaged in military rocket development at the Rocket Experimental Station, Dover, Delaware. Active in rocket development since before the War, he has been a member of the Society for more than ten years.

Other officers are:

G. Edward Pendray, secretary, pioneer rocket engineer and co-designer with H. F. Pierce of the Society's first liquid fuel rocket, in 1932. Mr. Pendray is nationally known as an authority on jet propulsion and rockets. He is author of "The Coming Age of Rocket Power" and was one of the founders of the Society, in 1930. He is a consultant on public relations and management to large industrial companies, including Westinghouse.

Louis Bruchiss, editor of the Journal of the American Rocket Society. Mr Bruchiss, armament and aeronautical project engineer and aviation writer, is associate editor of Aerosphere, and author of "Aircraft Armament" and other technical works, many of which relate to jet propulsion.

The Journal of the American Rocket Society, formerly known as "Astronautics," is the oldest technical publication on jet propulsion and rocketry in the world, having been published continuously since 1931.

Dr. Samuel Lichtenstein, of New York, was elected treasurer. Dr. Lichtenstein has been a member of the Society for more than ten years, and is now serving his fifth consecutive year as the organization's treasurer.

New Directors named for the coming year are Mr. Lawrence, Mr. Healy, Mr. Pendray, Mr. Bruchiss, Cedric Giles, of the New York Telephone Company, Alfred Africano, senior project engineer in jet propulsion research of the Curtiss Wright Corporation, Caldwell, N. J.; and H. F. Pierce, pioneer rocket engineer and a member of the engineering staff of Reaction Motors, Inc.

The American Rocket Society, founded in 1930 in New York, was one of the first organized groups of engineers and experimenters in the world devoted to the development of jet propulsion in all its forms, including rockets. For many years it sponsored experimental work carried on by members, and thus was able to develop and train many young engineers who have become key men in the various military and aviation jet propulsion and rocket programs now in existence.

For many years this work lacked both popular support and conservative engineering acceptance, and had to be carried on in the face of much discouraging opposition. During the War, however, proponents of jet propulsion and rocketry were enabled to demonstrate the unique values of this new field of engineering. As a result, the programs of research and development in jet propulsion now are very large, and jet propulsion is a recognized branch of engineering.

The American Rocket Society last fall (1945) became affiliated with the American Society of Mechanical Engineers, the largest engineering society in the world, and now has its headquarters in the Engineering Societies Building, 29 West 39th Street, New York.

The Society is now developing plans for an annual national convention of rocket and jet propulsion engineers, slated to be held early in December in connection with the annual meeting of the American Society of Mechanical Engineers in New York. It recently announced a program for publishing important technical material on rockets and jet propulsion. The first of these Society publications is "Rockets" by the late Dr. Robert H. Goddard.

Tentative Program for the American Rocket Society's Participation in the Annual American Society of Mechanical Engineers Convention

December 5, 1946 Joint ASME-ARS Dinner Hotel Pennsylvania

Introduction by MR. ALFRED AFRICANO

"Rocket Projectile Development" by Dr. C. N. Hickman, Bell Telephone Laboratories, wartime chief of Section H, Division 3 (Rockets) of N.D.R.C.

December 6, 1946 Morning Session 9 A.M. to 12 Noon

Chairman: MR. LOVELL LAWRENCE, Jr. — President ARS

"Long Range Rocket Bombs" by Major H. L. Karsch, Ordnance Department, Chief Proof Officer, White Sands Proving Ground. With films.

"Rocket Powerplants for Aircraft" by a representative of Reaction Motors, Inc. Dover, N. J. With films.

"Testing Naval Pilotless Aircraft" by Commander Grayson Merrill, USN, Technical Director, U.S. Navy Pilotless Aircraft Unit, Mojave, Cal. With films.

"Commercial Applications of Rocket Power" by a representative of Aerojet Engineering Corporation, Azusa, Cal. Possibly with films.

Luncheon 12:15 to 2 P.M. Hotel Pennsylvania

Introduction by DR. G. E. PENDRAY, Secretary ARS

"Possibilities of Atomic Rocket Powerplants" by Dr. E. U. Condon, Director, National Bureau of Standards.

Afternoon Session - 2:15 to 5:30 P.M.

Chairman: MR. ROY HEALY, Vice-President, ARS

"Problems of Supersonic Aircraft Flight" by Col. C. E. Reichert, Chief Armament Laboratory, Engineering Div. AMC, AAF, Wright Field. With slides and films.

"The Rocket Research of Dr. R. H. Goddard" by Mr. Alfred Africano, Curtiss-Wright Corporation. With slides and films.

"Ramjet and Pulsejet Propulsion" by a representative from N.A.C.A. Aeronautical Research Laboratory, Langley Field, Va.

"Design Trends in Turbo-jet Engines" by a representative from N.A.C.A. Engine Research Laboratory at Cleveland.

Alternate papers will be prepared should conditions prevent the presence of the above named speakers.