ASTRONAUTICS

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Courtesy of Science Service

Number One Man of Rockets—A biographical sketch of Dr. Robert H. Goddard. **Rocket Motor Efficiency**—What can we expect of the motor?

Astronautics **Journal of the American Rocket Society**

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Notes and News

DEMOCRACIES change leaders often, and so do democratically managed scientific and technical societies. In its six years of existence, the American Rocket Society has had four different presidents, and now has a fifth, Mr. Alfred Africano. It argues for the stability of the movement that so young a group, in so new a field, should be able to command such a variety of excellent leadership.

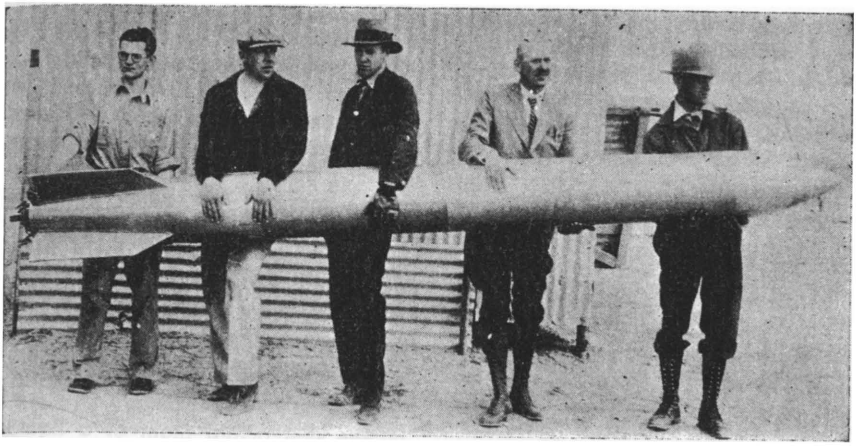
At the annual meeting in April a new Board of Directors was elected, and the Board, under the New York State Membership Corporation Law (the Society was incorporated in 1932), chooses the new officers. For the current year these are: President, Mr. Africano; Vice-president, John Shesta, Secretary, Max Krauss; Treasurer, Dr. Samuel Lichtenstein; Editor of Astronautics, G. Edward Pendray.

The Society also has new headquarters, in New York's well-known Graybar Building, 420 Lexington Avenue. The Assistant Secretary, Mr. James Rowlands, is on duty there to handle the Society's business and greet its members and callers. In its sixth year of life, the Society is strong, prosperous and growing, and has already to its credit a notable record of achievement.

LIKE WINGED SEEDS before the wind the rocket enthusiasts move about, sprouting into new groups of

(Continued on Page 16)

CONTENTS



Dr. Coddard (second from right) with one of his rockets

Astronautics herewith presents, in the first of a projected series about rocket experimenters, the first complete, authentic sketch of the sometimes mysterious, frequently uncommunicative experimenter—physicist of Worcester, Mass., whose early work launched modern rocketry.—Ed.

ROCKETRY'S NUMBER ONE MAN

Dr. Robert H. Goddard and His Achievement

IT is now twenty-eight years since Dr. Robert Hutchings Goddard began his investigation of rockets. A bald, spare, pleasant man, who will be fifty-five years old next October 5, he is at present on leave from Clark University, where he is Professor of Physics. Though he has made other contributions to science, notably in the electrical conductivity of powders, the performance of crystal rectifiers, and the presence of interference colors in clouds, his lifework is rocketry. Experimenters the world over recognize him as their Number One man.

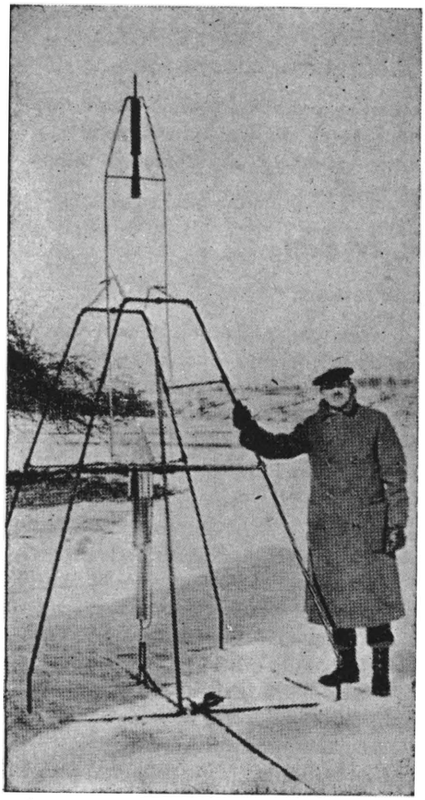
His first experiments were made while an instructor at Worcester Polytechnic Institute in 1909, during some studies of the upper atmosphere. He hoped, by building a huge skyrocket, to shoot self-recording instruments into the atmosphere beyond the reach of sounding balloons, and bring back information of value to science.

As new teaching appointments carried him to Princeton, and then to Clark University, the idea went with him.

Gradually he convinced colleagues that the rocket needs no air to push against; that it really could climb through the thin upper layers of the atmosphere propelled by nothing more than the recoil of its escaping gases. In 1914 he took out two basic patents on rockets, pertaining to combustion chambers and nozzles. He finally explained the scheme to Dr. Charles G. Abbot, Secretary of the Smithsonian Institution. Aided by a grant of funds from the Institution, he made a series of tests which convinced him that dry fuels must be abandoned in favor of more powerful, and more easily controlled liquid fuels.

Aided by further grants, Dr. Goddard then lanched a series of liquid fuel tests, carried on secretly near Auburn, Mass.

From 1920 to 1922, he made what are now known as proving-stand tests, with primitive liquid-fuel motors, trying liquid oxygen and various liquid hydro-carbons, including gasoline and liquid propane, also ether. As a result of these trials, he decided that liquid oxygen and gasoline was the most practical combination. Virtually all his experiments since have been made with these.



Courtesy Smithsonian Institution

Dr. Goddard and the first liquid-fuel rocket, as pictured in "Liquid Propellant Rocket Development".

He felt ready to try a liquid fuel rocket in 1923. On November 1 of that year a small rocket was tried out on the proving-stand, using liquid oxygen and gasoline supplied by pumps on the rocket. Two years later, in December, 1925, he completed and tested a rocket in which fuels were forced into the combustion chamber by means of inert gas (nitrogen) under pressure. Neither of these rockets was released from the proving stand.

First Liquid-Fuel Rocket

The first actual flight of a liquid fuel rocket in this country or anywhere in the world, so far as can be learned, occurred on March 16, 1926, at Auburn. Dr. Goddard first published photographs and details of this rocket in 1936, but it was fully reported to the Smithsonian Institution ten years earlier on May 5, 1926.

In appearance the first liquid fuel rocket was not unlike the later German **Repulsors.** The motor, a thin, long-nozzled affair, was carried well ahead of the fuel tanks on tubes, which also served as braces. The whole rocket was abo[illegible] feet long, but more than half of this length was accounted for by the distance from the end of the motor nozzle to the fuel tanks. Pressure to force the fuels into the combustion chamber was furnished by an outside pressure tank, and after launching, by an alcohol heater carried on the rocket.

Dr. Goddard reported that this first rocket traveled 184 feet, in 2.5 seconds, as timed by a stop watch, "making the speed along the trajectory about 60 miles per hour".

Placing the motor ahead of the tanks added nothing to the stability of flight, he noted. It made for difficulty of construction without compensating advantages. He therefore abandoned this arrangement in favor of rockets with motors at the rear. Between 1926 and 1927 several small rear motor rockets were fired at Auburn, and on July 17, 1929, a fairly large one was sent up, carrying a small barometer and a camera.

This last rocket broke into the newspapers. For a few weeks Dr. Goddard enjoyed the doubtful glory of being a front-page and feature-section hero. Imaginative and not too well informed writers scribbled of projected flights to the moon and published the kind of absurdities that often make conservative scientists squirm. The notoriety came about through no fault of the experimenter. It happened that the rocket of 1929, being large enough to carry instruments, also made a great deal of noise. Neighbors telephoned the police that an airplane had crashed in flames. A few excited Auburnites were certain a meteor had fallen. When fire and police department equipment arrived, they found only a rocket experimenter, examining the remains of his rocket, pleased at the notable fact that his instruments, parachute-carried, had landed from the flight intact and undamaged.

It was possibly as a result of this flight that Colonel Lindbergh became interested in rockets. At any rate, he presently discussed the new art with Dr. Goddard, and brought the research to the attention of the late Daniel Guggenheim. From this conference resulted a grant which made possible the present establishment in New Mexico, under conditions which the Worcester scientist believes practically ideal for rocket experiment.

Results

It should be noted that up to the time of the Guggenheim grants, Dr. Goddard had made notable strides in the development of rockets, on the relatively meagre funds available, and against the difficulties that irk a lone experimenter.

He had (1) demonstrated that rockets could be useful, (2) that dry fuels are inadequate; (3) developed a suitable fuel combination; (4) developed the method of forcing fuels into the chamber with inert gas pressure; (5) produced a workable liquid fuel motor; (6) shot the first liquid fuel rocket; (7) shot the first instrument-carrying rocket; (8) determined the "best location" for the motor; and (9)

Goddard On Rockets

Fuel: "Although oxygen and hydrogen - - - possess the greatest heat energy per unit mass, it seems likely that liquid oxygen and liquid methane would afford the greatest heat value of the combinations which could be used without considerable difficulty. The most practical combination, however, appears to be liquid oxygen and gasoline."

Motor Placement: "The combustion chamber was located at the rear of the rocket, which is, incidentally, the best location, inasmuch as no part of the rocket is in the high velocity stream of ejected gases, and none of the gases are directed at an angle with the rocket axis."

Direction Vanes: "Fixed air vanes, especially those of large size, are worse than useless, as they increase the deviations due to the wind. - - - Fixed air vanes should preferably be small, or dispensed with entirely, if automatic stablization is employed, to minimize air resistance."

—Quotations from "Liquid-Propellant Rocket Development".

brought the rocket forcibly to the attention of reputable scientists and engineers as a possible instrument for reaching high altitudes.

All of this he had accomplished by the summer of 1929, though the full extent of these achievements was not generally known until last year, when, in his "Liquid-Propellant Rocket Development", a report published by the Smithsonian Institution, he dispelled some of the mystery that has surrounded his experiments, and revealed a few, but by no means all of the details of the work.

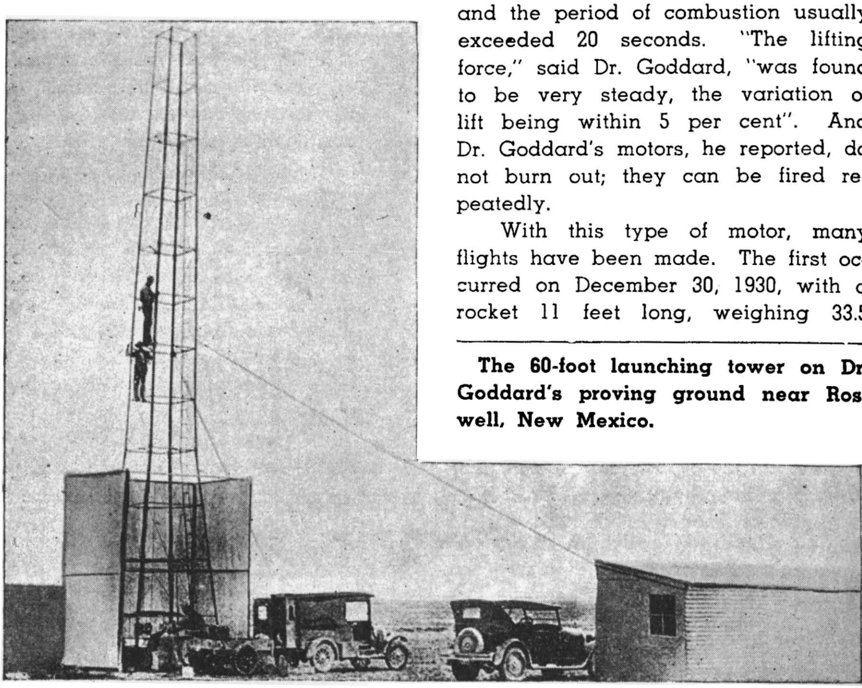
Since 1930, events have moved swiftly in the New Mexico laboratory. About three miles north of Roswell, a shop 30 by 55 feet was erected, and near it a 20-foot tower built for proving stand tests of motors and rockets. A 60-foot launching tower, from which actual rocket shots are made, was located fifteen miles farther north, on the plains.

During the first two years of experiment (1930-32), a number of static or ground tests were made, the chief object being to improve the motor. After the experimenter and his aides had tried many different shapes and materials, and various ways of introducing the fuel, they reached the conclusion that "satisfactory operation of the combustion chambers could be obtained with considerable variations of conditions, and that larger chambers afforded better operation than those of smaller size".

Motor Details

Full details of the Goddard rocket motor are not yet available. He has reported, however, that the combustion chamber decided upon for use in flights "was 5¾ inches in diameter and weighed five pounds". The maximum thrust obtained was 289 pounds, and the period of combustion usually exceeded 20 seconds. "The lifting force," said Dr. Goddard, "was found to be very steady, the variation of lift being within 5 per cent". And Dr. Goddard's motors, he reported, do not burn out; they can be fired repeatedly.

With this type of motor, many flights have been made. The first occurred on December 30, 1930, with a rocket 11 feet long, weighing 33.5



The 60-foot launching tower on Dr. Goddard's proving ground near Roswell, New Mexico.

pounds without fuel. The rocket reached an altitude of 2,000 feet; the maximum speed was about 500 m.p.h.

From 1930 until the summer of 1932, a number of shots were made to study the regulation of nitrogen pressure in the rocket during flight.

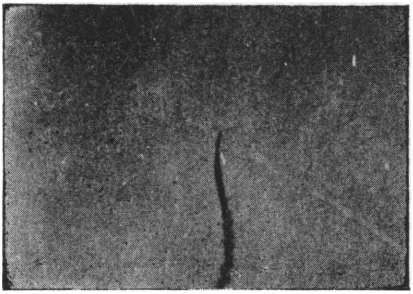
Dr. Goddard, considering that he now had a suitable motor, a practical system of fuel pressure feed and sufficient experience with rocket flight, decided that the problem of stabilization was the next to be tackled.

On April 19, 1932, occurred the first flight of a rocket with gyroscopically controlled vanes for stabilization. In this model small vanes were forced by gas pressure into the path of the rocket exhaust when the projectile deviated from a true vertical course. The system did not work as well as expected. The performance led the physicist to suspect that the vanes were too small, and he resolved later to try the system with larger ones. Accordingly, he improved his gyroscopic device, enlarged the flame vanes of his rockets, and in August, 1934 began a series of controlled shots to obtain vertical flight.

Pendulum Stabilizer

In the beginning of this series, he tried a device to which many an experimenter has given thought — the pendulum stabilizer. In the beginning of the flight some stabilization effect was obtained, but as the rocket increased its velocity, the pendulum became less effective, because the direction of the pendulum becomes a resultant between the acceleration of gravity and the acceleration of the rocket. His pendulum-controlled rocket rose about 1,000 feet, then turned and flew in a horizontal direction for 11,000 feet, landing a little over two miles from the launching tower. At one point the velocity exceeded the speed of sound, about 700 miles an hour.

The improved gyroscope stabilizer



Courtesy of Science Service

"— — — the flight reminded one of a fish swimming in a vertical direction".

worked better, since a gyro is independent of gravity or the course of the rocket. The gyro-stabilizer in Dr. Goddard's present rockets is set to apply controlling force, by means of gas-activated vanes in the rocket exhaust, when the axis of the projectile deviates 10 degrees or more from the vertical. The finest shot so far reported was that of May 31, 1935, when the rocket rose 7,500 feet. Rising slowly from the launching tower, it undulated from side to side as the gyro continually corrected the course. "The first few hundred feet of the flight", reported the experimenter, "reminded one of a fish swimming in a vertical direction".

Pleased with his control mechanism, the experimenter believes that the next step is reduction of the weight of the rocket, and progress on that problem is now being made. A few weeks ago he announced that an improved parachute release mechanism had been devised.

With these improvements, it may be that Dr. Goddard at last is within hailing distance of his goal of twenty-eight years ago: to explore the upper atmosphere by means of rockets. One wonders whether he would have undertaken so long and treacherous a quest had he foreseen the difficulties.

—G. E. P.

LINDBERGH ON ROCKETS

"The Rocket Offers Freedom From The Air"

Col. Charles A. Lindbergh was one of the earliest rocket enthusiasts. Through him, in 1929, Daniel Guggenheim became interested in aiding the experiments of Dr. Goddard. Recently, he did rocketry another good turn by writing a letter, since made public, to the President of Clark University, stating his views on rockets. These remarks, reprinted here in part, deserve a permanent place in the bibliography of rocketry—Ed.

THE rocket is now in that most interesting period of discovery where the shorelines are unplotted and the future limited only by imagination. We cannot state what speeds or ranges the rocket may attain, but it is not restricted by the rotation of an engine or by dependence on the atmosphere. As the airplane gave man freedom from the earth, the rocket offers him freedom from the air.

"From the standpoint of science the rocket offers the only known possibility of sending instruments to altitudes above those reached by sounding balloons. - - -

"From the standpoint of commerce we must look to the rocket if we hope to attain speeds of transport above a few hundred miles an hour. It is a significant fact that the efficiency of the jet is greatest at velocities which the propeller can never reach.

"From the standpoint of war we must consider the fact that rockets may carry explosives faster than the airplane, farther than the projectile.

Whether instruments, mail or explosives can be carried advantageously by rockets is a question for future research to decide. Sometimes the problems of carrying capacity and control seem almost unsurmountable. However, one need be only 41 years of age to have been born when Langley's model first demonstrated the practicability of mechanical flight in 1896.

"A child born in that year would have been old enough to remember the discussions of his parents over the flights of Wilbur and Orville Wright. He may have been bombed during the World War, have transacted business by air mail a few years after the Armistice, and have celebrated his fortieth birthday by crossing the Pacific Ocean on a 20-ton flying boat. The first half of his lifetime would have spanned the transition from the 26-pound 'aerodrome' of Langley to the transoceanic air liner.

And In The Future?

"Such a man - - - today could witness rocket ascents which would make him wonder whether the second half of his lifetime would see a similar development in wingless flight.

"And if conservatism - - - should point out the problems of carrying capacity, cost and control, his vision might well recall the articles he has read on the impracticability of the airplane. - - -

"In an unguarded moment he might prophesy that we will eventually travel at speeds governed only by the acceleration which the human body can stand, and that in rocketing between America and Europe we will accelerate half-way across the ocean and a decelerate during the other half. Or, he might even point his rocket toward another planet and, without regard to fuel supply, landing facilities, or Professor Goddard, lose himself in interstellar space."

TUBULAR MOTORS

Higher Pressures, Less Burning?

MOTORS that burn out too rapidly, that fail to deliver the realizable energy of the fuels, that refuse to produce complete, clean combustion, still plague rocket experimenters.

For this reason the recent experiments of Mr. H. F. Pierce, one of the Society's earliest members and designer of its first liquid-fuel rocket, are of especial interest. Mr. Pierce has undertaken to solve the motor problem by building tubular motors, equipped with a fuel-feed which he believes will permit higher temperatures and pressures, with less danger of burning out. A flight test of one of these new motors was witnessed by several Society members on May 9, 1937, at Old Ferris Point, the Bronx, New York.

Mr. Pierce writes to Astronautics:

"The motor employed in this rocket was developed after several tests of the type motor used by the Society in its first experiments.

Genesis of the Idea

"It was found that these first motors would burn out after short runs, giving evidence of improper fuel mixture and unequal pressure. The shape of the combustion chamber was then experimentally changed from an oval cross-section to a long, slender tube, the fuel being introduced at the upper end. (See Fig. 1).

"Introducing the fuel and oxygen was accomplished by placing a plate or disc slightly smaller than the inside circumference of the combustion chamber at the upper end, with a quarter-inch round port in the centre for the oxygen. The plate suspended in the centre formed an annular ring opening between the plate and the inside wall of the chamber.

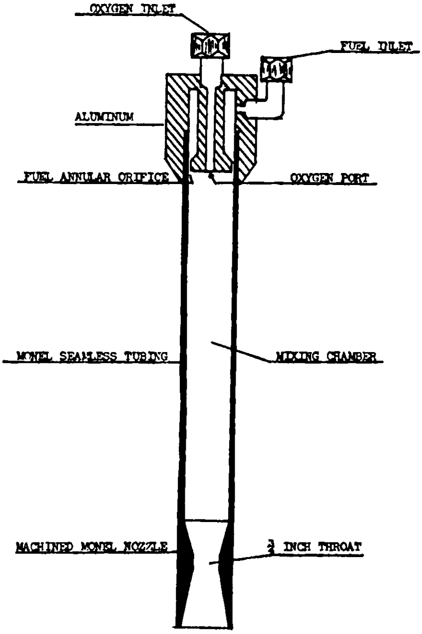


Fig. 1. The motor as Mr. Pierce used it in his recent test.

"This arrangement places the oxygen in the centre of the chamber with the fuel entering along the walls in a thin film completely surrounding the oxygen until thoroughly mixed. The oxygen, expanding from a liquid to a vapor, mixes with the fuel without being allowed to come into contact with the chamber walls.

"This motor is constructed of monel seamless tubing for the combustion chamber, the nozzle being machined from a solid monel round bar. The taper of the nozzle on the inside from the throat is 11 degrees while the outside taper is 7 degrees. The throat opening of the nozzle is three-fourths of an inch in diameter."

After proving stand tests, Mr. Pierce prepared one of his tubular motors for a test flight, in a rocket which itself contained some novel features, including a method for equaliz-

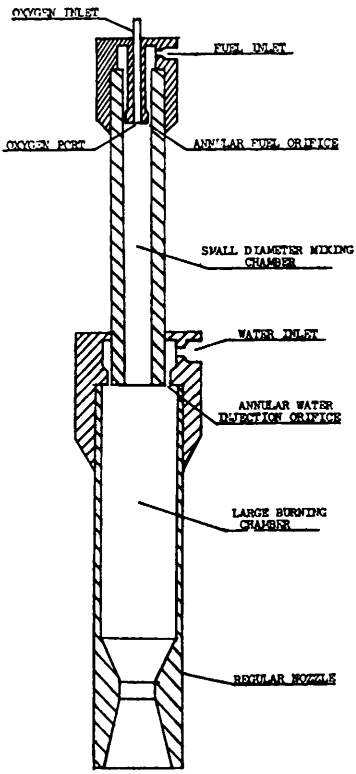


Fig. 2. Mr. Pierce's proposed rocket motor.

ing the fuel-feed pressures. His report continues:

"The rocket was of the two tank type, (two-stick) and the nitrogen pressure against both the fuel and oxygen was equalized through a connecting tube. Alcohol was used as the fuel.

"As described at a meeting of the Society on March 19th, a quick turn-on valve developed by John Shesta, somewhat altered in details, was installed in the fuel and oxygen lines, also in the equalizing tube to permit opening by remote control. A check valve placed in the equalizing connecting tube prevented oxygen vapors from entering the fuel tank and forming an explosive mixture there. In operation the nitrogen pressure was exerted against the alcohol in the fuel tank until a few seconds before firing, when it is released by the quick turn-on valve into the equalizing tube With but two tanks, the resuiting action is the same as for a three tank rocket, the space above the fuel being here used for nitrogen gas under 300 lbs. per. sq. in. pressure."

The rocket had not been designed for flights, but to be used as a test stand. Consequently its performance was not under test in the flight. On the first trials, a misunderstanding resulted in premature firing of the motor. Severe damage resulted to the parachute case, which was then removed.

Successful Shot

On the second attempt, the rocket rose rapidly, "Reaching an altitude of 250 feet," Mr. Pierce reported, "it turned off on a horizontal flight to the north, landing about 850 feet away on the ground."

So far as resistance to burning out goes, the rocket motor performed excellently. Fired several times previously, and twice on the day of the flight tests, it showed no scoring.

"It is my intention to devote a great deal of time this season to the further development of this motor," concludes Mr. Pierce. "The accompanying drawing (Fig. 2) will give some indication along what lines this development will procede.

"The object is to work with much higher chamber pressures. An attempt will be made to use some form of internal cooling system. For the present, water will be used to cool the outer chamber, and later nitrogen will be experimented with as a cooling agent."

"SPEAR" ROCKET

Mr. Lent Designs For Balance

NOT long ago, when the Society's experiments were tending toward head-drive rockets, and Mr. John Shesta was manufacturing four-nozzle motors to simplify the construction of tandemtank rockets, several experimenters foresaw that the logical development might be toward no nozzles at all; toward an annular orifice entirely encircling the rocket.

It remained for Mr. Constantine P. Lent to take this step in actual design. Members of the Society were particularly interested when he exhibited, at a recent meeting, the beginnings of a rocket and motor on this principle.

Mr. Lent calls his device a "spear rocket", principally because of its extreme length and small cross-section. More than twice as tall as a man, it has a tank diameter of 2½ inches, and is balanced like a throwing javelin. The balance, streamlining and nature of the jet thrust, Mr. Lent believes, will make the projectile fly true, like its namesake. The completed rocket will soon be ready for test.

New Features

The liquid oxygen tank is in the rear, the fuel tank (for either alcohol or gasoline) is just ahead. The principal new feature, however, is the motor. The fuels are to be brought into it through a central core, mixed and jetted into an annular blast chamber, where they will be fired initially by a spark plug.

At the lower end of the blast chamber is a circular constriction, below which the outer lip or skirt flares out, forming a circular or annular nozzle. The flame will spurt out in a cylindrical curtain about the upper part of the rocket.

Of the new motor Mr. Lent writes: "The cooling of the nozzle is accomplished by the air, over the large outside surface, when the rocket is in flight. The inside of the nozzle is cooled by the liquid oxygen . . .

"The main thought in this new rocket is (1) to construct a rocket which will fly like a spear, without stabilizing fins, and (2) to provide a nozzle that will not burn out. If these two features will be found by experiments to be up to my expectations, I believe this rocket will be able to fly to an altitude of five to eight miles."

Mr. Lent with the motor and upper tank of his rocket. Complete, it will be twice the length indicated here.

ROCKET SOCIETY AFFILIATES

Two Groups Join Under New Decentralizing Plan

WITH the growth of interest in rocketry, the Society has been repeatedly petitioned to establish "branches" in various localities, to enable local groups to carry on experimentation as a unit, at the same time having advantage of connection with the national organization. The need for such decentralization led, last spring, to the adoption of a plan for Affiliate Groups.

Of several applications, two Affiliates have been accepted, and others are under consideration. The honor of becoming the first Affiliate goes to the Yale Rocket Club, located at Yale University, New Haven, Conn.

Chairman of this unit is Franklin M. Gates; its treasurer is Merritt A. Williamson. It has seven members, and the address is 874 Yale Station, New Haven. Organized in 1935, it holds monthly meetings, and last May it provided a public meeting to which faculty members and the public were invited. An exhibit of historic ARS motors attracted considerable attention. Mr. Gates reports that the group is constructing a motor this summer, and hopes to begin experiments next fall, when the membership may be selectively increased to eight men.

The Society's second Affiliate is the Amateur Research Society, of Clifton, N. J., which has a membership of six, chiefly engineering students. This group has its own laboratory, and has conducted a series of experiments with powder rockets. The members are now engaged in building liquid fuel motors for further experiments. The president is Nicholas Swerduk; the treasurer, John Chocholak; the secretary, John Maluda, all of Clifton. The address is 12 East Russell Street.

Astronautics hereafter will regularly publish news of the activities of the Affiliates. Groups which desire information about affiliation should write to Max Krauss, Secretary of the Society, 420 Lexington Avenue, New York.

THE ROCKETOR'S LIBRARY

Word comes from Mr. Charles G. Philp, of England, that his interesting little volume, **"Stratosphere and Rocket Flight"**, is soon going into its third edition. The book, selling for 3 shillings sixpence (about $1) covers the problems of rocket flight and stratosphere exploration interestingly, giving historical information as well as discussing technical problems. In one chapter, Mr. Philp makes the regrettable error of repeating the famous hoax of the German man-carrying rocket, with the air of half-believing it. This may perhaps be pardoned, in view of the author's evident enthusiasm for his subject. The publishers are Sir Isaac Pitman and Sons, Ltd., London.

"Zero to Eighty" is the name of another new book on the interplanetary subject; this one by the well-known physicist Dr. E. F. Northrup, of Princeton, N. J. Dr. Northrup, writing under the name "Dr. Pseudoman", gives a fictional account of a trip around the moon in a projectile propelled by an ingenious "electric gun", with small prototypes of which he has made some promising experiments. Though one might well wish that the author had written a straightforward account of his subject, and tried less hard to color the tale with romance and adventure, the book presents an arresting idea. The publishers are the Scientific Publishing Company of Princeton, N. J.; the price is $3.

ROCKET MOTOR EFFICIENCY

What Performance Can Be Expected Of The Motor?

By ALFRED AFRICANO

PREDICTING the usefulness of a rocket motor in an actual flight requires an accurate knowledge of its real "overall" efficiency. It is my purpose in this article to trace the various losses in a rocket motor and to place tentative values on them based on the available data so that our conception of this phase of the science of rockets may become more concrete and perhaps lead to improvements in design and efficiency.

The Velocity-Ratio Efficiency

One of the most common conceptions of the rocket efficiency is that it is extremely high and in the neighborhood of 100%. While this is true in a special way, it is absolutely misleading if one concludes also that 100% of the fuel enegery is converted into useful forward thrust.

However, it does mean that 100% of whatever proportion of the fuel energy is being converted into the kinetic gas jet energy can be utilized in propulsion, **provided the forward rocket velocity is the same as the velocity of ejection of the gases rearward.**

We have now divided the general rocket efficiency into two of its major parts; first, the velocity-ratio efficiency (thus called because it depends only on the ratio of the rocket speed to the jet speed), and second, the "overall" rocket motor efficiency. There is no particular difficulty in understanding what to do about velocity-ratio efficiency—simply determine the jet speed, then drive the rocket at that constant speed for the greater part of the flight to obtain the greatest efficiency.

The Rocket Motor Efficiency

Increasing the rocket-motor efficiency is the more difficult problem and one of the principal objects of proving stand trials. Tests made by our Experimental Committee indicate that the average motor efficiency obtained was about 7%.

In a talk at one of our recent Society meetings I showed that this overall thermal efficiency was about half of the 14% maximum theoretical efficiency that could be expected under the circumstances. Some of the objections raised that this was too low were quite valid, and the following calculations will show that the theoretical motor efficiency is not fixed, but depends on the degree to which expansion of the escaping

About The Author

Alfred Africano, elected President of the American Rocket Society last April, became interested in rockets in 1931 and was one of the early members of the Society. He has participated in virtually all of the Society's experiments. In 1936 he was joint recipient, with the Society, of the Rep-Hirsch Award.

Graduated from Stevens Institute of Technology with the degree of M. E., he is an engineer of the Interborough Rapid Transit Company. He recently distinguished himself with researches in rail expansion which may result in widespread changes in railroad construction. Mr. Africano is thirty, married, and lives in New York City.

gases is effected, with the principal loss being the heat wasted in the white-hot exhaust gases.

Even before the efficiency of expansion can be calculated there is a loss factor which must be recognized. This may be called the combustion chamber efficiency and is the ratio of the actual heat generated (expressed in terms of the pressure, temperature, and volume of gases per second) to the heat generation theoretically possible if the fuel were completely burned as in a bomb-calorimeter.

Incomplete atomization of the liquid fuel and dissociation at the high temperatures of the combustion contribute to this loss. Data received from Dr. George V. Slottman on the dissociation in the oxy-acetylene welding flame shows that only about 50% of the fuel energy is generated as heat when the combustion takes place at atmospheric pressure. Combustion at a higher pressure is more efficient and more complete. We may assume 75% combustion efficiency as being fairly close to the actual condition in a chamber operating at about 200 lbs. per sq. inch pressure.

Thermodynamic Cycle Efficiency

It is a fundamental principle in thermodynamics that the availability of energy in any type of heat engine is measured by the ratio of the temperature drop during the cycle to the initial temperature. In our case the initial temperature is that existing in the combustion chamber and the final temperature that existing at the outlet of the nozzle.

Expressed as a formula, the cycle or highest possible efficiency is:

$$E_C = \frac{T_1 - T_2}{T_1} \quad \text{.....(1)}$$

where

E_C = the cycle efficiency

T_1 = initial temperature of the cycle

T_2 = final temperature of the cycle

While we have several reasons for believing that the temperature of the combustion is in the neighborhood of 3000° F., it is extremely difficult to measure the chamber and exhaust temperature so a more convenient way to express the cycle efficiency must be found in terms of the initial and final pressures, which can be easily measured.

To do this, start with the important relation in thermodynamics which combines Boyle's and Charles' laws of ideal gases:

$$\left.\begin{aligned} P_1V_1 &= MRT_1 \\ P_2V_2 &= MRT_2 \end{aligned}\right\} \quad \text{.....(2)}$$

etc, where P, V, and T are the pressure, volume per second, and the temperature; M is the weight of gas flowing per second; R is the gas constant equal to **1540** divided by the molecular weight of the gas; the subscript $_1$ denotes the initial position or state of the gas considered (in the chamber) and the subscript $_2$ denotes the second position considered (in the nozzle).

Substituting the values of T_1 and T_2 found from Equations (2) into Equation (1), and canceling the constant term MR gives:

$$E_C = \frac{P_1V_1 - P_2V_2}{P_1V_1} = 1 - \left(\frac{P_2}{P_1}\right)\left(\frac{V_2}{V_1}\right) \quad \text{..(3)}$$

To simplify Equation (3) further, we can eliminate the unknown volumes by assuming that there is no appreciable heat loss through the nozzle walls so that the logarthmic equation for adiabatic expansion can be applied, or

$$P_1V_1^{\ 1.3} = P_2V_2^{\ 1.3} \quad \text{--------(4)}$$

The exponent varies for different gases but for practical purposes may be taken constant as given.

Substituting the value of the ratio $\left(\frac{V_2}{V_1}\right)$ derived from Equation (4) into Equation (3) gives, finally

$$E_C = 1 - \left(\frac{P_2}{P_1}\right)^{.23} \quad \text{----------(5)}$$

At last we are able to predict the cycle efficiency for whatever expansion ratio we may obtain. If the pressure at the throat (the narrowest part of the nozzle) is considered the final or exit pressure as it would be in the case of a simple orifice where there is a smooth rounded approach to a short cylindrical section we can proceed in finding this efficiency immediately with only a knowledge of the initial or chamber pressure. It is my opinion based on many observations that our divergent nozzles did not work as well as they should have, theoretically, so that we had approximately the condition of the simple orifice.

In this case the exit pressure is the same as the throat pressure which reaches a certain critical pressure for maximum discharge entirely independent of the back pressure at the mouth of the nozzle, and is dependent only on the initial pressure and the exponent of adiabatic expansion, $k = 1.3$ for carbon dioxide and superheated steam. Expressed as a formula:

$$P_C = P_1\left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = .55\ P_1 \quad \text{---------------------(6)}$$

where P_C equals the critical pressure at the throat.

Now we can substitute the average chamber pressures used in our proving stand experiments to find the theoretical cycle efficiency. Most of our feed tank pressures began at 315 lbs. per sq. inch (300 lbs. per sq. inch gage—add 15 for the absolute pressure) and ended at about half that, or 157 lbs. per sq. inch, making an average feed pressure of 236 lbs. per sq. in. There was about 25% pressure drop in the feed pipes so that the chamber pressure averaged 177 lbs. per sq. in.

The critical pressure in the throat from Equation (6) is found to be 97 lbs. per sq. in. Now substitute $P_2 = P_C = 97$ and $P_1 = 177$ in Equation (5) which gives for E_C a value of 13% cycle efficiency. Therefore the best efficiency we could expect was the product of the combustion efficiency times this maximum cycle efficiency or .75 X .31 equals about 10%, and since our measured overall motor efficiency was 7% the mechanical eficiency of these nozzles (i. e. the percent of transformation of available energy into kinetic jet energy) must have been about 70%.

Future Development

Naturally the cycle efficiency can be increased above the 13% if the jet gases are expanded below the critical pressure. The correct theoretical design of the nozzle required to do this is enough of a problem to require a separate article at a future date. It is obvious that if the nozzle were flared and extended far enough, the final pressure might, theoretically at least, be made to approach zero when Equation (5) would indicate nearly 100% cycle efficiency. However, it is also obvious that this has the disadvantage of adding more weight to the rocket motor. There is some definite back pressure which would give the maximum practical cycle efficiency.

For expansion with a diverging nozzle to atmospheric pressure, say 15 lbs. per sq. in., the cycle efficiency from Equation (5) would be equal to 43%. This is encouraging because it shows that eventually a properly designed nozzle giving about 90% mechanical nozzle efficiency together with a maximum cycle efficiency of perhaps 50% and a combustion efficiency of 75% will give us an overall rocket motor efficiency of .90 x .50 x .75 or 34%. Once we have attained this objective, we will have a new type of motor with twice the thermal efficiency of the ordinary gasoline engine. The cost of liquid-oxygen and the work required to lift it would have to be considered in a comparison of the actual relative economy.

For the purpose of carrying a scientific expedition to an altitude of say 50 miles, nowever, there is no comparison whatsoever, since air would be too rarefied to support combustion or create lift in an ordinary airplane. The rocket plane, having practically no air resistance or nozzle back pressure to contend with would then be in its element.

News and Notes

(Continued from Page 2)

enthusiasts and experimenters. Latest of the rocket missionaries is Mr. Peter van Dresser, member of the Society's Board of Directors, who has moved from New York to Ft. Lauderdale, Florida. Mr. van Dresser writes that he is organizing a rocket group in Florida which may soon undertake active experimentation.

ALL ROCKET SHOOTERS have their troubles, but few can write of them so amusingly as Mr. Cleve F. Shaffer, of San Francisco, whose experiments recently came to an abrupt end when Army officials interfered. Mr. Shaffer writes to **Astronautics:**

"When the U. S. Army fired my apparatus off of their Marin County Reservation for making too much noise they snuffed the light of my particular rocket motor research.

"Anyway, the roar they complained of was as nothing to mine at paying $5.00 per litre for liquid oxygen when you lost three quarters of it at every pour.

"While I had many exciting experiences such as explosions, and once dodging an oxygen tank hose afire with 150 pounds pressure whipping about its long flames, and tried both liquid and gaseous oxygen with gasoline, alcohol, butane, acetylene in many combinations of pressure, size and placing of orifices, various metals, etc., the material gained was not sufficiently conclusive to publish as scientific memoranda due to the rather rough apparatus for measurement.

"Am still a member of the Society and my interest is still with you and the rocket subject."

OUR BROTHERS ABROAD are active this season, and we may expect to hear of some interesting rocket experiments there before the end of summer. The British Interplanetary Society, which was originally located in Liverpool, now has its headquarters in London. Its new president is the scientist, editor and writer, Prof. A. M. Low; its vice-presidents P. E. Cleator, founder of the society, and L. J. Johnson. The address is 92, Larkswood Road, South Chingford, London, E. 4.

Another British group, the Paisley Rocketeers, led by Mr. John D. Stewart, a member of the British Interplanetary Society, is doing valiant work with experimental dry fuel rockets, studying especially the problems of landing apparatus and stability.