THE ROCKET MOTOR
——How and Why it Works

By LESTER D. WOODFORD, '33.

This is the second of a series of articles on Rocket Motors by Mr. Woodford. The first article of the series told of the early history of the rocket. The third, which will appear in the February issue of the Engineer, will relate some predictions that noted scientists have made of the future of the Rocket Motor and the Rocket Interplanetary Ship.
The Editor

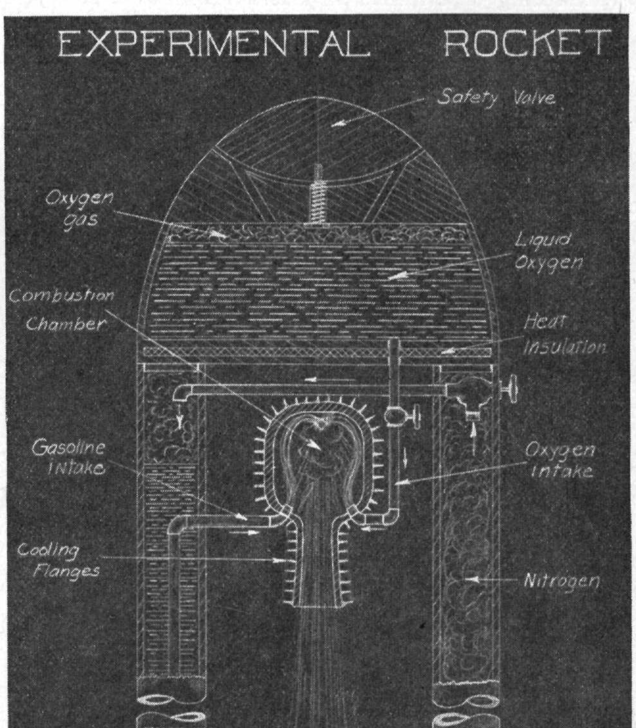
Any person who has fired a gun will remember how he experienced a "kick" against the shoulder as the cartridge was exploded. This is commonly known as the "recoil" of the gun, and is explained by Newton's Third Law of Motoin, "Every action has an equal and opposite reaction." That is, the amount of force that propels the projectile forward is transmitted with equal force back against the breech of the gun, and hence the "kick."

Let us take another example, that of the cubical box, constructed of sufficient strength to withstand the explosive forces, and made air-tight. We will then explode a charge of powder within the box. The exploding gases will act with equal forces on all sides of the box and it will not move in any direction. Now if one side of the box is removed, and the explosion repeated, the whole box will then tend to move in a direction opposite to the opened end, even though the exhaust gasses will rush out through the opening.

The above principle is the one that is being used by the scientists working on the rocket motor. They use a simple chamber, or cylinder, with one end open. The fuels are injected into the chamber from opposite sides, near the closed end, where they mix and are ignited. The resulting explosion forms a gas that suddenly increases in volume, exerting a pressure against all parts of the inner walls of the chamber. The exhaust gasses are forced through the open end. Then (remembering our analogy of the box) the chamber tends to move in the direction opposite to the open end. The whole structure built around the chamber is, of course, also given motion with the chamber. It must be remembered also that the motion given to the chamber is due to the action of the explosion and consequent gas pressure within the chamber, and not from the rushing forth of the exhaust material.

This then, is the simple medium by which aircraft in the future will be propelled, at terrific speeds, through the atmosphere around the earth, and eventually, through the vacuum of space. To this motor, which will work equally as well in the absence of air pressure as it does in the atmosphere, future aviation and its ultimate development, interplanetary travel, will owe its existence. Free from all moving mechanism and complicated equipment, this newest of developments, yet oldest of motive forces, seems to be the answer and solution to man's quest for "more worlds to conquer."

The greater majority of the people that I talk with today seem to think it impossible that this motor will work in a vacuum. They believe that as the gasses rush forth from the chamber, they must have some resisting force upon which to press, in order that the motor may be given motion. They base this deduction upon analogies similar to that of the rowboat which must have some medium against which its oars may press to secure forward motion. Any comparison of this sort is erroneous, for it has been definitely proved, in more than one experiment, that the



rocket motor will work not only as well in a vacuum, but considerably better. It must be remembered, as I have attempted to explain above, that all of the work is done within the cylinder, before the gasses are expelled, and the motor is given forward motion before the gasses are exhausted.

It may be understood then, that the presence of an outside medium (air, or atmosphere) will only serve to retard the forward motion of the rocket. The first reason for this statement, is that the presence of the medium creates a state of "air resistance," through which the rocket must force a path. If this were absent, it is apparent that the rocket would travel much faster. Another disadvantage that the rocket woud have in the atmosphere, is that the air pressure would tend to retard the action of the explosion within the chamber. Reverting once more to our box example, we discovered that if the box were completely closed, the explosion would not give the box motion in any direction, and if one side were opened, the box would be given motion in the opposite direction from the open end. Therefore, the existing air pressure at the rocket motor's open end, would tend to act similarly to partially closing the side of the box, it would decrease the amount of forward motion given the rocket. Then, in the absence of this air pressure, more motion would be given the rocket by the explosion within, and operation in a vacuum would be much more efficient than in the atmosphere.

Construction of the Motor

The heart of the rocket is the combustion chamber, it is in this section of the "ship," that we term the motor. In any rocket plane, all of the motive force is supplied by this motor. It is here that the fuels are collected and ignited, the explosion carried out, and the forward motion received from the gas action. I have found through experience, that the design of this chamber is of the utmost importance to efficient operation. The fuels must be introduced at a proper pressure to enable the combustion to be complete and the consequent gas action to furnish all possible speed.

Fuels for the rocket motor can be divided into two classes; the solid, as exemplified by gunpowder, and the liquid combination, such as oxygen and hydrogen (liquified), or liquid oxygen and gasolene. Engineers have discovered that solid fuels would be completely inadequate for use in rocket motors. In one experiment where carbon and oxygen were used only 4,000 BTUs of heat were evolved, as compared with the higher figure of the oxygen and hydrogen combination which gives off 6,900 BTUs. (Liquid oxygen and alcohol will produce approximately the same amount.)

Then, too, the solid fuel cannot be fed into the chamber to produce continuous combustion, as can the liquids. Although the liquids offer greater possibilities, they also present greater problems. Dr. Robert H. Goddard, of Clark University, was the first to use liquid fuel in connection with the rocket motor experiment in 1929. In 1930, the late Max Valier, of Germany, used liquid fuel in a rocket motor which was installed in a motor car. This motor weighed but seven pounds and developed fifty horsepower, giving the car a speed of sixty miles per hour. The pound-per-horsepower ratio in this case was seven times smaller than the ratio of the most efficient airplane motor in use today. This rating approximated 2.3 ounces per horsepower.

At the present time, I am working on a design which is expected to improve on Valier's model. My motor will have a ratio of one pound to weight horsepower, or exactly two ounces per horsepower.

Several designs have been tried, and it has been found that the best position for the injection of the fuel into the combustion chamber is near the open end, or "nozzle," of the motor. The fuels, upon entrance, are forced to the rear of the chamber where they are ignited. My earlier designs placed the intake ports at the closed end, or "head," but it was found that the pressure of the incoming fuel forced the gasses almost completely out of the chamber before they were ignited and thereby decreased the efficiency of the motor.

Research, to date, has shown that an egg-shaped cylinder is the best for all motors of this type. The experimental cylinder that was used produced a queer phenomenon. Although the pressure within the chamber ranged from 200 to 280 pounds per square inch it was discovered that it was only necessary to compress the fuels to a pressure of 90 pounds per square inch, to inject them into the cylinder. This is explained by the fact that the exploding gasses, upon rushing from the chamber, set up a partial vacuum, and the fuels are readily injected.

I fully believe that in the last analysis, the size and shape of the combustion chamber depends on the nature of the fuel used, its heat and its pressure. Any time spent on this part of the work will no doubt be repaid in increased efficiency in operation.

Another factor that must be kept in mind is the heat of combustion. In the combustion of liquid hydrogen and oxygen, the temperature reaches a point several thousand degrees above zero Fahrenheit. Because of this heat factor, construction of the walls of the combustion chamber should be made with extreme care and study. It is apparent that any failure in the strength of the chamber walls during the ignition of the gasses would cause a sudden rupture. This, of course, would have serious results. The oxidation point of the metal used must be considered to be above the temperature of the igniting gasses, for this relationship is one of the most important in the construction. The cooling system that is used is of the water-jacket type, with cooling fins covering the exterior of the cylinder.

Several alloys of steel and other metals have been considered for their high oxidation points and general tensile strengths. Alloys of beryllium, molybdenum, cobalt, chromium, and tungsten, are recommended.

The size of the combustion chamber is another factor of considerable importance. Dr. Goddard has discovered

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that the large chamber is much more effective than is the small one, for although the heat and friction losses increase according to the square of the dimensions, its fuel capacity, and consequent efficiency, increases with the cube.

Upon first thought it is hard to believe that the size of the nozzle, or open end of the cylinder, would have any effect on the operation of the rocket, but conditions exist on the contrary. It is at this point that we can call on one of our few established principles, for most of the others must be discovered through future experimentation. Experience with the gas turbine, whose principle of operations is practically the same as the rocket, shows that the size and shape of the nozzle is directly responsible for the reaction of the unit.

The above factors not only increase the pressure of the gasses in the chamber, but utilize the energy of the exhaust gasses. Dr. Goddard found that the size of the nozzle depends on the medium that the motor is to be used in (vacuum or atmosphere), and also upon the velocity of the gasses. In other words, if the nozzle opening is too wide (in high velocity ejection) the gasses will expand too rapidly and set up retarding currents within the chamber. If a higher pressure is used, a nozzle of greater length must be employed. Therefore, it is apparent that the design of the nozzle will vary with the type of fuel used, the pressure, and the ejection velocity.

Another discovery, through actual experimentation, is that in many cases the heat developed in the nozzle was much greater than the heat within the combustion chamber itself. Consequently, the walls of the nozzle must be constructed of superior metal.

Fuel Containers

In the construction of the fuel containers, it is quite obvious that their location within the rocket ship is of no little importance. If they are incorrectly positioned, consumption of the fuel will tend to disturb the balance of the whole craft. Two methods have been suggested for maintaining balance; to place them at the gravitational axis, or in position around the circumference of the rocket. I believe that the first of these methods has more possibilities.

In my experiments, I have discovered that it takes three litres of oxygen to utilize all of the combustible energy in one litre of gasolene. Therefore, with this ratio of consumption of three to one, even greater care must be taken in placing the fuel tanks. In their construction, a metal must be used that is strong, and at the same time light in weight. This strength is necessary in maintaining the high pressure for injection into the combustion chamber. The oxygen tank must have a high tensile strength at minus 182 degrees Centigrade, the temperature of liquid oxygen. The use of copper alloy in this project, would be permissible, but the metals that are most commonly employed are duraluminum, and aluminum. If hydrogen is to be used, the tanks should be built of a copper-lead alloy, which has a tensile strength of 64,500 pounds per square inch at minus 253 degrees Centigrade (the temperature of liquid hydrogen). In the use of gasolene, alcohol, or hydrocarbons, the problem of the metal's capability to hold its strength at low temperatures, is not so important and the requirements are primarily general strength and resistance to corrosion.

In the use of liquid oxygen and hydrogen, the fuel containers must be well-insulated, for at temperatures above minus 182 degrees C., oxygen vaporizes rapidly, and above minus 253 degrees C., hydrogen becomes a gas. The reason for the insulation is explained by the low vaporizing point of the liquids and one other significant fact, that the distance between the fuel tanks and the combustion chamber (which attains a temperature of approximately 2,500 degrees above zero Centigrade) is small, and a considerable amount of heat would reach these fuel tanks. In order to maintain these fuels in a liquid state, a vacuum-walled container may be used. Pressure would be kept constant by installing safety valves on each tank, for constant temperature and pressure are necessary to keep the fuels flowing into the combustion chamber at a steady rate of speed.