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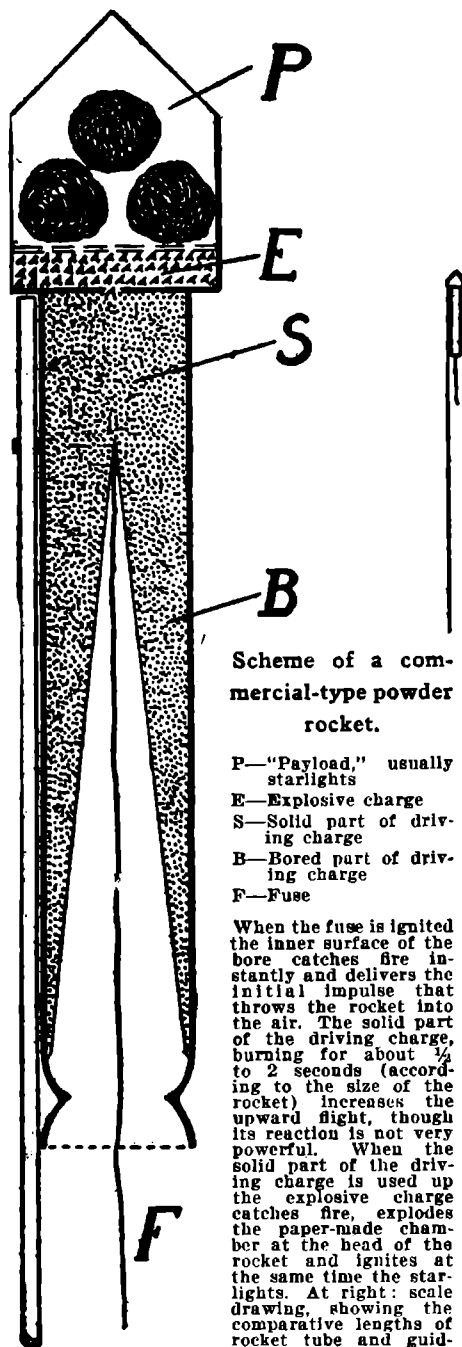
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The Dawn of the



Scheme of a commercial-type powder rocket.

- P—"Payload," usually starlights
- E—Explosive charge
- S—Solid part of driving charge
- B—Bored part of driving charge
- F—Fuse

When the fuse is ignited the inner surface of the bore catches fire instantly and delivers the initial impulse that throws the rocket into the air. The solid part of the driving charge, burning for about $\frac{1}{2}$ to 2 seconds (according to the size of the rocket), increases the upward flight, though its reaction is not very powerful. When the solid part of the driving charge is used up the explosive charge catches fire, explodes the paper-made chamber at the head of the rocket and ignites at the same time the starlights. At right: scale drawing, showing the comparative lengths of rocket tube and guiding stick.

THE CASE of the rocket ship is a peculiar one.

It does not yet exist, but many thousands of people feel certain that there will be a day when the first rocket ship leaves the Earth in an attempt to reach interplanetary space, later to soar to the Moon and to the other planets.

Thus we have—with the possible exception of flying machines—for the first time in history a machine that is popular even before its actual invention. This is an extremely rare case. Normally a machine has to be invented first and has to be brought to a comparatively high degree of perfection before the fight for general recognition and—if suited for it—for general use can be started.

Rocket ships, however, are popular even before they exist. They occur in the movies; they are comparatively abundant in the daily and periodical press and on the radio, and they are an every-issue event in a good many magazines. I do not dare to prophecy exactly when the first rocket ship will be built. But it is safe to prophecy that at that time there will be a great many people who will declare emphatically that it should have been done a long time ago.

In spite of this wide and constant interest, it has to be stated that the conceptions of very many enthusiasts are somewhat hazy or slightly out of focus. And it is for this reason that any discussion of rockets and rocket ships still has to be started with the basic principles, as they are incorporated in the ordinary commercial skyrocket. A skyrocket shows all the essential parts of more elaborate liquid-fuel rockets in rudimentary or embryonic state. It consists of fuel supply, pay load and

Conquest of Space

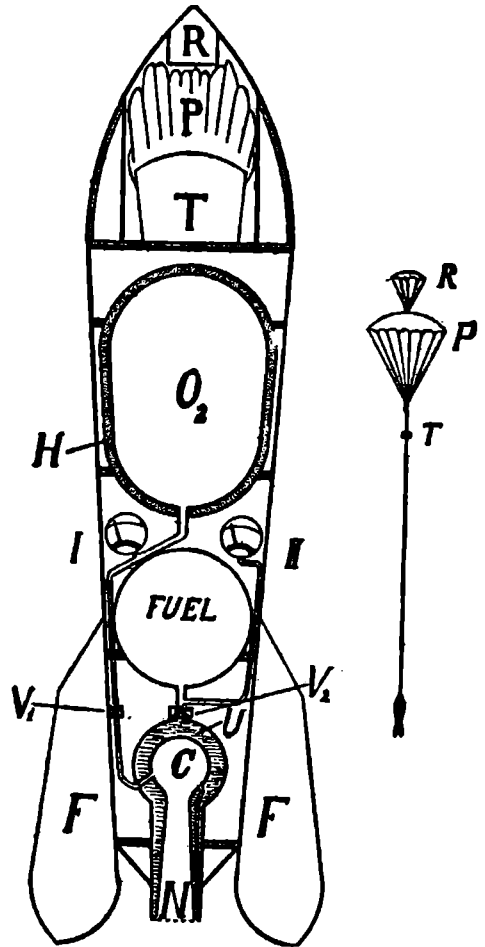
An outstanding article on rockets.

by WILLEY LEY

guiding device; it even shows a primitive exhaust nozzle, the main part, or one of the main parts, of a rocket motor, and it is sometimes equipped with a parachute, which is still the best landing device ever devised for rockets.

That the assembly of all these parts is pitifully inefficient is mainly due to the fact that skyrockets were invented before scientific designs were heard of, and that they have hardly changed in shape, size or method of manufacture since then. We have an Arab manuscript preserved which was written around the year 1280 A. D., the uncertainty factor in this date being about five years. Its author was an Arab scientist, the hunchback Hassan Alrammah. This man, who appears to have been of extraordinary brilliance, was called "Nedshim-Eddin—Star of Faith"—by his contemporaries. In his manuscript he described at length everything known about rockets in his time and country. The invention was then new in the Mohammedan west, so new that Hassan did not even have an Arab word for rocket, and had to call rockets *al-sichem alkahatai*—Chinese arrows—but there is hardly a difference between Hassan's powder rockets and those of the nineteenth century.

IT TOOK about four hundred years until it was discovered why a rocket moves. The discoverer of the natural law underlying the principle of the rocket was Sir Isaac Newton, who termed it his Third Law of Motion.



Scheme of an instrument-carrying, liquid-fuel rocket.

- R—Parachute releasing mechanism that pushes the pilot parachute out of the rocket in a given instant
- P—Parachute, folded up
- T—Compartment of instruments
- O₂—Liquid oxygen
- H—Heat insulation of the oxygen tank
- I—Oxygen pressure gauge
- II—Fuel pressure gauge
- V₁—Oxygen valve
- V₂—Fuel valve
- FF—Fins
- C—Combustion chamber
- N—Exhaust nozzle
- U—Fuel jacket around the rocket motor for cooling.

A few minor details, like infill and safety valves, reinforcing struts and similar things have been omitted for the sake of clarity. At right: How the rocket will return by parachute.

His definition says, in effect, that action and reaction are equal in power, but opposite in direction. This statement, for which any desired mathematical and experimental proof can be furnished—and *has been* furnished—includes a number of other unspoken statements, the most important of which are the following:

1. That reaction must occur independent of the surrounding medium, no matter whether the rocket is surrounded by air, by an inert gas like nitrogen or by nothing at all.

2. That any expelled mass creates a reaction, no matter what its nature. (This sounds perfectly obvious to us, but up to Newton's time it was believed that only gunpowder could produce the effect.)

3. That high exhaust speed is of greater importance than ejection of large masses.

4. That the velocity of rockets may surpass the velocities of their exhaust.

It has to be remembered, however, that these conclusions were not drawn at once; in fact, they were hardly known before rocket theory was evolved by the Russian scientist, Konstantin E. Ziolkovsky (1903), the American physicist, Dr. Robert H. Goddard (1919) and the German mathematician, Professor Hermann Oberth (1923).

The first of these four proven statements gives us the right to investigate the possibilities of rocket propulsion with a view to exploration of the stratosphere. The second allows us to select any fuel that seems promising, may it be gunpowder or dynamite, steam or monatomic hydrogen. The third statement urges us to find fuels with very high exhaust velocities; the choice among these is then only limited by considerations referring to practical points of view, such as safety, chemical stability, expense and similar questions. The fourth statement, finally, allows us to expect any velocity desired, if we can only manage to construct our rockets in a way that they are able to carry the necessary amount of fuels.

It can be said that these theoretical investigations are practically finished. The mathematical part of them has been treated most extensively, and, for the time being, conclusively by Oberth; the chemical part—mainly concerning fuels—was done to a good extent by chemists before liquid-fuel rockets were discussed at all, and had only to be adapted sensibly to the new requirements. The problems still to be solved are difficulties of actual construction. Others are not known to me, except—I am sorry to mention this point—a certain ridiculing attitude of certain people, and—*very* sorry now—the problem of financing the work.

After rocket theory had proved that there was something to be expected from a device which had been known but, at the same time, lying dormant for centuries, actual experimentation was begun. It started—aside from Dr. Goddard's work, which was kept in unnecessary secrecy for many years—in 1928 in Germany. Experimental progress, however, did not follow a single path. There were, seemingly, two ways to achieve results, and both found defenders. This soon resulted in the formation of two distinct parties, commonly referred to as the wet and the dry party.

These appellations do neither refer to the state of mind of the experimenters, nor to their political colorations with a view to prohibition, but to the nature of the fuels used by them in their experiments.

THE DRY PARTY, using powder for fuel, had a seeming advantage in the fact that actually flying powder rockets were manufactured commercially. They were admittedly inefficient, but the task of the experimenters was to increase the rockets in size, to find a more powerful powder for them, to eliminate as much of their dead weight as possible, and to make the combustion and the

handling of the comparatively large quantities of powder safe.

Considering all points, it can be said that these experimenters failed in their task. They succeeded in increasing the size of powder rockets, but it seems that they soon reached the possible limit. They also succeeded in using a more powerful powder as a fuel, but since the increased size implies a very great increase in the pressure necessary to compress the driving charge, a new danger factor in manufacture was created which could be overcome only with the best of equipment and the most experienced and most skilled labor. In fact, it is said—and probably rightly so—that only one man could make these large powder rockets and survive: Frederick William Sander in Wesermünde.

The dry party did not succeed in eliminating dead weight; in fact, they were forced to use heavier tubing, and in general heavier construction while increasing the size. And they failed utterly in making these large rockets safe. Approximately half of all rockets used in the so-called Opel experiments with rocket cars and rocket railroad cars, exploded. The dry party ceased to exist when, in October, 1933, Reinhold Tiling's* laboratory blew up, killing Tiling himself, his assistant Friedrich Kuhr and his secretary Angelika Buddenböhmer.

In order to understand the most important arguments of the wet party, which dominates rocketry entirely now, it is necessary to go back to theoretical considerations again.

It was mentioned that high exhaust speeds are more important than large exhaust masses. Liquid fuels happen to have higher exhaust velocities than solid fuels. The exhaust velocity of gases resulting from the rapid combustion of ordinary rocket powder amounts to little more than 2000 feet per second. The

exhaust velocity of the gases resulting from the combustion of gasoline and oxygen amounts to approximately 6000 feet per second. The exhaust velocities of marsh gas—which is liquefied, like oxygen always is, to facilitate the use of large quantities—is still somewhat higher. The exhaust velocity of alcohol and oxygen is about the same, while the exhaust velocity of liquid hydrogen and liquid oxygen approaches the theoretical limit of about 16,000 feet per second.

THE other advantages of liquid-fuel rockets are really obvious.

In powder rockets fuel tank and combustion chamber are the same; therefore, there is always the possibility that the supply of fuel explodes all at once. In liquid-fuel rockets fuel tanks and rocket motor—i. e. combustion chamber and exhaust nozzle—are separated. This allows a place to insert valves, preventing the flame from flashing into the fuel tanks. Even without such valves it is very unlikely that the flame from the combustion chamber could perform this trick, since the fuel lines are narrow and because there is only one of the two liquids present in each line. Naturally, alcohol or gasoline cannot burn without any oxygen, and oxygen alone is also harmless.

The rate of combustion cannot be regulated in powder rockets, or only to a very slight extent in using various kinds of powder. But it is very easy to regulate the rate of combustion in liquid-fuel rockets. It can be done either in changing the size of the fuel lines, in applying various rates of pressure in the fuel tanks, or in using regulating valves. It is also possible to stop combustion completely in liquid-fuel rockets, a problem which is practically unsolvable as far as powder rockets are concerned.

One of the greatest disadvantages of powder rockets is the short duration of thrust. In ordinary skyrockets it ranges—according to size—from one tenth of a

* Reinhold Tiling (the name is pronounced Teelink) invented the so-called winged powder rockets without parachute.

second to one and a half seconds, and only specially manufactured rockets burn for 20 or 25 seconds with comparatively low thrust. The duration of thrust in liquid-fuel rocket motors is dependent only upon two things: the amount of fuel available and the resistance of the combustion chamber. Both are problems of construction which can be solved and which have been solved already to a large extent.

A long duration of thrust is desirable to attain a high efficiency. A rocket is more efficient the faster it moves; the highest efficiency (100 per cent) occurs when the velocity of the rocket and the velocity of exhaust are equal. Since exhaust velocities are high—and have to be high—it is obvious that the rocket needs some time to attain a velocity somewhere near the velocity of exhaust. The longer the duration of thrust, the more efficient the rocket, generally speaking, and the lower the acceleration the rocket and its pay load—whether the pay load consists of instruments or of live beings—has to stand. Naturally, instruments that do not have to stand high accelerations do not have to be very massively constructed, which also helps to eliminate dead weight.

In addition to all this, it is desirable to keep the speed of the rocket comparatively low—in spite of bad efficiency—during the first 6 or 7 miles of its ascent. It is these first 6 miles above sea level that contain approximately 75 per cent of all air and which offer most of the air resistance to be overcome by the rocket on its flight. To keep air resistance low also necessitates a long duration of thrust. To make the rocket most efficient it is desirable to increase acceleration above this layer, which means a change in the rate of combustion. All this cannot possibly be done with powder rockets, while there is no reason why it could not be done with liquid-fuel rockets.

Practical rocket experimentation,

working along these lines of thought, has already achieved a good many results which may be summed up as follows: Professor Goddard, after investigating the possibilities of improved powder rockets finally turned to liquid fuels and made a long series of experiments of which, unfortunately, nothing is known. His very brief report, which was published by the Smithsonian Institution recently, only states that he made a number of flights with gasoline-fueled rockets, his altitude record being 7500 feet.

The American Rocket Society made two rocket flights and a series of very interesting ground tests with rocket motors on a proving stand, registering thrust, pressures, fuel consumption, etc. Similar ground tests were made by the Cleveland Rocket Society, but while the American Rocket Society published accurately the results obtained, the results of these other tests are not yet known.

JOHANNES WINKLER in Germany, who originally founded the German Rocket Society, of which Professor Oberth was president and myself vice president, built the first liquid-fuel rocket in Europe that actually flew, in March, 1931. It was propelled by liquefied marsh gas and liquid oxygen, and reached an altitude of approximately 2000 feet. His second and much larger rocket was less successful. A few feet above the launching rack, either a minor explosion occurred that ripped of one of the fuel lines, or one of the fuel lines broke, which resulted in a minor explosion. Due to this mishap the rocket motor ceased firing; the rocket fell back and was destroyed by the impact on the ground.

Dr. Eugen Sänger of the University of Vienna conducted a series of ground tests with rocket motors. This series was not meant to lead to the construction of a flying rocket, but was made for purely scientific reasons. Dr. Sänger

succeeded in obtaining extremely long durations of thrust. His best result was a thrust of approximately 55 pounds for a period of 20 minutes.

The credit for the most extensive research still belongs to the German Rocket Society, which worked experimentally from August, 1929, till June, 1933, on its own proving ground near Berlin, the so-called Raketensflugplatz. During this period we built: four proving stands, one for the Miraks—the first type of liquid-fuel rockets we built—one for rocket motors alone. This was the second or large proving stand; it served for most of the ground tests. Proving Stand No. 3 was also only for rocket motors, but portable. It was not often used. Stand No. 4 was for complete rockets of the heaviest type.

About 490 ground tests were made on these 4 proving stands, and about 95 rocket flights. To these flights, 6 flights of an especially heavy type of rockets, built for a demonstration contemplated by the city of Magdeburg, have to be added. These heavy "repulsors," as I had termed them, weighed more than 200 pounds. They reached altitudes up to about 2400 feet. The lighter repulsors still hold the records for liquid-fuel rockets. They ascended about two miles and covered, once, a distance of three miles. This was highly unwanted, since the proving ground was so near the city. For the same reason, we had to resist all temptations to prepare a real altitude shot.

Though rocket experimenters still have occasional trouble with minor nuisances like leaking valves, melting nozzles, and freezing feed lines, there can be no doubt that the main problems are solved. Rocketry is now about as far as aviation was some 30 years ago. There exists a pretty complete theory—much more complete than the theory of aerodynamics 30 years ago. There exists a comparatively large amount of practical experience, and there

are already quite a number of successes on record.

THE QUESTION now arises what should be done next.

I think that the first practical application of liquid-fuel rockets will be what is termed the "meteorological rocket." This term means a rocket able to reach altitudes of about 15 miles and capable of carrying scientific instruments to these layers of the stratosphere that have only occasionally been reached by unmanned, so-called "sounding balloons."

Meteorological rockets have to be constructed in a way that a timing device throws out a tiny parachute at the top of the flight. This parachute pulls a larger one from its container, which, in turn, brings the instruments in the open. Then the whole assembly will descend slowly by parachute, the empty and now comparatively light rocket first, then the instruments, and finally the parachute. During the descent, the instruments are busily taking their data and recording them, while a small and light radio device emits a shrill radio "scream," which allows one to trace the rocket during its drift by parachute. Such a device is necessary, because a rocket soon disappears in the sky. Even our heaviest repulsors were hardly visible to the naked eye at so low an altitude as 2000 feet.

The data taken by these rockets will probably aid very much in weather forecasting and will be very valuable for the study of certain problems of flying, especially stratospheric aviation, which is due to come in the near future.

The next application of rockets will probably be in the transportation of urgent messages and mail, first over short distances and later, when the necessary experience has been gathered, over long range. Such a long-distance mail rocket—if launched vertically—would be able to attain altitudes beyond the limits of our atmosphere.

This possibility now leads to the last question—that of interplanetary travel.

To state it bluntly: we do not know any reason why it should not be done. At the same time, we know very definitely how much practical experimentation is still necessary, and how much experience has still to be gathered before the construction of the first passenger-carrying rocket could be undertaken. And from the first passenger-carrying rocket it will still be a long way to the first space ship. But it is possible, definitely possible. We know from experiments undertaken in Germany that men are able to stand the accelerations involved. As far as air-purifying machinery is concerned, we have the necessary experience from the constructions of submarines. That the necessary amounts of fuel and of foodstuffs can be carried is proven mathematically.

THE WHOLE PROBLEM is a problem of speed. A stone, falling from a height of a hundred yards, attains a certain speed. It takes the same velocity to throw the stone a hundred yards high. The greater the height, the greater the velocities involved. But the velocity of a stone falling from an infinite height does not become infinite. It reaches a certain value which is dependent only on the mass of the planet and its radius. In the case of the Earth this value is 11.2 kilometers per second, or approximately 7 miles. This velocity has been termed the "parabolic velocity" or the "velocity of liberation."

Whether a rocket ship will be able to leave the Earth is therefore answered by the question of whether it is able to attain a speed of about 7 miles per second.

To answer this question needs higher

mathematics, but it is, nevertheless, possible to explain the answer in a simple way. There is a symbol called "e." Its exact value can only be expressed by means of a formula*, but for all practical purposes it is sufficiently accurate to use the approximate value, 2.718.

If a rocket is capable of carrying e times its dead weight in fuel, its velocity, after all fuel is consumed, will be equal to the velocity of its exhaust. If a velocity of twice the velocity of exhaust has to be reached, the amount of fuel to be consumed has to be e² times the dead weight. If thrice the velocity of exhaust is desired, the amount of fuel has to be e³ times the dead weight of the rocket. "Dead" weight in this connection means the weight of the rocket itself, plus passengers and all provisions. If a rocket, fully equipped and with passengers on board, but not yet fueled, weighs 10 tons, it has to carry about 27 tons of fuels to attain exhaust velocity, about 74 tons of fuels to attain double exhaust velocity, and about 201 tons of fuels to attain triple exhaust velocity.

Whether this can be actually constructed cannot be answered on purely theoretical grounds, though I put emphasis on the fact that theory, as far as it can answer the question asserts that it is possible.

For the time being, however, the attention of rocket engineers centers upon construction and design of the first meteorological rocket, which will introduce a new branch of engineering science in everyday life. We know that this new branch offers amazing possibilities, and we have every reason to believe that there will be no stop to the development of rocketry until all these possibilities are actual facts.

* The formula reads:

$$e = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \dots = \lim_{n \rightarrow \infty} \left(1 + \frac{1}{n} \right)^n$$

approximately 2.7182818284 . . .

(4! for example means 1x2x3x4)