Rocket Propulsion

A Résumé of Theory with an Account of the Practical Experiments made to Date

By Willy Ley*

THOUGH rockets have aroused a good deal of public interest during the last few years and a great number of very interesting books and articles† have been published about the theoretical side of this new science, little is generally known about the experimental progress that has been made, especially in Germany and the U.S.A. In describing this science—the Americans call it "rocketry"—as "new," it is to be understood that this term applies only to the mathematics of it. The ordinary powder or "sky" rocket is by no means new, but has a long and very involved history, going back to Hassan Alrammah, called "nedshm-eddin" (The Faithful) in A.D. 1280, who designed the first rocket-driven torpedo. But though rockets in general (*i.e.* the powder rocket, which alone existed previous to 1929) have a history of almost a millennium and have even been of historical importance (Sir William Congreve's war-rockets), the manufacturers of powder rockets knew nothing about their mathematics. When, for example, in 1928 the German Verein für Raumschiffahrt discussed the problem of exhaust velocities and impulses, its president, Johannes Winkler, asked the largest rocket factories about this information and received the answer that they did not know it and had no way of determining it. Winkler was therefore obliged to take the thrust-diagram of a powder rocket himself (Fig. 1). This diagram revealed that the thrust of a sky-rocket lasts for only two-tenths of a second; this result was really amazing and the most amazed were the manufacturers of these rockets.

The fundamental mathematics of rockets are comparatively simple. They are based on Sir Isaac Newton's third law of motion that "every action must have an opposite and equal reaction." The basic formula is $MV = mv$. It has become customary, however, to use other letters for the designation of the different velocities and to call the velocity of the rocket itself v, the velocity of the exhaust gases (relative to the rocket) c, the thrust P and the ratio of fuel weight and rocket weight m_0/m_1.

(The method by which the formulæ governing rockets and rocket flights are derived is not shown here, as it has been done very thoroughly by Oberth, Ziolkovsky, Robert Esnault-Pelterie, Rynin, Sänger and others. Only a few of the principal formulæ, especially those that are of practical value in judging the experiments already made, are given.)

The Principal Formulæ

From the differential equation

$$m \, . \, dv + c \, . \, dm = 0 \quad \ldots\ldots\ldots (1)$$

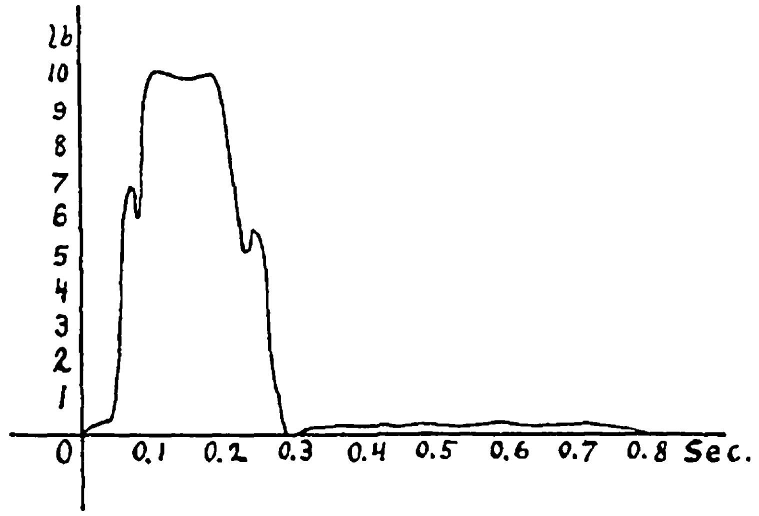

FIG. 1.—*Thrust diagram of a standard powder rocket*

we arrive easily at the expression

$$m_0 = m_1 \, . \, e^{\frac{v}{c}} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

e in this formula is 271828183 . . . the basic number of Napier's "natural" logarithms. In a more simple form the same formula looks as follows:

$$v = c \, . \, \text{lognat}\, m_0/m_1 \quad \ldots\ldots\ldots (3)$$

This formula gives at once the clue to the determination of what amount of fuel a rocket has to carry when the condition $v = c$ is to be fulfilled. In this case $m_0/m_1 = e$, so that the general rule runs as follows:

$v = c$ when $m_0/m_1 = e$
$v = 2c$,, ,, $= e^2$
$v = 3c$,, ,, $= e^3$ etc.

$e^3 \approx 20{\cdot}1$ represents a rocket capable of carrying over twenty times its own weight in fuels, which may be very difficult to construct. But $e^2 \approx 7{\cdot}4$ is doubtless possible (as has been indicated by practical experience), so that we might expect rocket velocities of double the exhaust velocity. The probable altitude is governed by the well-known formula for projectiles

$$h = \frac{v^2}{2g} \, . \, \sin^3 \alpha \quad \ldots\ldots\ldots\ldots (4)$$

where h means the altitude, g the (retarding) acceleration of the earth's gravitation and α the angle of elevation. It must be remembered, of course, that this formula is not valid as long as the rocket is burning. The value of v is determined most simply by

$$v = a \, . \, t \quad \ldots\ldots\ldots\ldots\ldots (5)$$

where a refers to the acceleration and t to the time of burning. The altitude s of the powered flight is

$$s = \frac{a}{2} \, . \, t^2 \quad \ldots\ldots\ldots\ldots\ldots (6)$$

The factor a in the formulæ (5) and (6) is the so-called "effective acceleration" (upwards), *i.e.* the "absolute acceleration" minus one gravity (32 ft. per sec. per sec., or 9·81 m./sec./sec.), the force of earth's gravitation.

As the formula (3) shows, in order to attain the high speeds which are the "raison d'être" of rockets, it is much more important to have high exhaust velocities than to eject large quantities of mass (gases) in the time unit. This obvious conclusion finds its confirmation in the table below for m_0/m_1, given by Professor Oberth in my book, *Die Möglichkeit der Weltraumfahrt* (1928).

Experiment, therefore, cannot be expected to yield satisfactory results with fuels of low exhaust velocities. Only fuels with a high c should be used, even if they are comparatively unknown. The question of fuels is consequently the most vital one in the practical development of rocketry.

The Problem of Fuels

Many writers have expressed their doubts whether rocket experiments will ever lead to the ultimate result—space travelling—before new and much more powerful fuels have been discovered. It is, of course, too early to discuss the problems of space-travelling from other than a purely academic standpoint. But from this standpoint it may be said that there is no reason why we should wait for the possibly distant discovery of new and ultra powerful fuels. Oberth, von Pirquet and others proved that (provided ample financial help to solve the purely technical problems) the present day fuels are powerful enough to overcome the gravitation of our mother planet which happens to be the largest in the inner

TABLE FOR $\frac{m_0}{m_1}$

V		500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000	12,000	13,000	14,000	15,000
c: 1,000	..	1·64	2·72	7·39	20·0	54·5	148	405	1,089	2,982	8,060	22,070	60,000	163,100	444,000	1,200,000	3,290,000
2,000	..	1·29	1·64	2·72	4·48	7·39	12·2	20·0	33·0	54·5	89·6	148·7	243·5	402	662	1,091	1,805
3,000	..	1·18	1·39	1·94	2·72	3·78	5·29	7·39	10·25	14·35	20·0	27·95	39·0	54·6	76·1	106·3	148·7
4,000	..	1·13	1·29	1·64	2·11	2·72	3·49	4·48	5·76	7·39	9·50	12·20	15·75	20·0	25·8	33·2	42·7
5,000	..	1·10	1·22	1·49	1·92	2·22	2·72	3·32	4·06	4·95	6·06	7·39	9·02	11·0	13·47	16·42	20·0

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* The author has been concerned in experiments in rocket propulsion both in Germany and the United States.

† *See* List of References to Literature on p. 230.

solar system. The formula for the necessary velocity to reach $h = \infty$ is simply

$$v_{(\infty)} = \sqrt{2gr} \quad \ldots\ldots\ldots\ldots(8)$$

g is 9·81 m./sec.² and r, the radius of the earth, 6,370 km., therefore

$$v_{par} \text{ or } v_{(\infty)} = 11{\cdot}180 \text{ m./sec.}$$

Assuming $c = 5{,}000$ m./sec., which is possible, a ratio $m_0/m_1 = 9{\cdot}04$ would be needed—in actual flights, of course, it would be somewhat higher for various reasons. How the many difficulties an actual flight would meet could be overcome—by means of step-rockets and other ingenious and feasible methods—has been shown by Oberth and von Pirquet. It would be a waste of time and space to discuss these questions here.

Only one very common mistake of the antagonists of the rocket will be mentioned. The argument, which has misled even physicists, maintains that the power to overcome the gravitational influence of the earth amounts to about 6 million kilogram/metres (mkg.) for every kg. of weight involved. It is of no consequence how great the acceleration is or whether the ascent is made on a straight line or not. The most powerful known fuel is a mixture of liquid oxygen and liquid hydrogen,* which gives about 1,700,000 mkg. per kg. Therefore it has been argued that it must be impossible to lift a body out of the earth's influence because the fuel could not even lift itself, let alone the machine and its passengers and provisions. But all the fuel is *not* lifted out of the earth's gravitational influence: it is the machine and the energy of the fuels; in the state of kinetic energy, or momentum, of the machine. Necessarily the fuel consumption is largest in the immediate vicinity of the earth, as long as there is much other fuel to lift. The energy has no weight, even from the standpoint of relativity.†

Abandoning these future questions we shall progress to the known fuels to select those which are most promising. Fuels are generally divided into "self-supporting" and "not self-supporting," the latter being those which need oxygen for their combustion. Self-supporting fuels for the purpose of rocket propelling can only be powders, some of them having been specially investigated:

Name	c (theor.)	c (measured)	Measured by:
Powder from ordinary sky-rockets	1,800 m./sec.	600-800 m./sec.	Winkler and Raketenflugplatz
Powder from coastguard life-saving rockets..	2,350 ,,	1,600 ,,	Dr. R. H. Goddard
Dupont Pistol powder No. 3..	2,860 ,,	2,290 ,,	,, ,,
Hercules Comp. powder Infallible	3,220 ,,	2,434 ,,	,, ,,

The commonest powders have the lowest exhaust velocity, and most designers dread the use of powder, which is apt to explode without visible reasons. Furthermore, powders have many other disadvantages when compared with liquid fuels, which are much easier to handle and to control.

No liquid fuel (except nitroglycerine) is "self-supporting"; they need oxygen for combustion, and for this reason we have to pay attention to the "oxygen-carriers." They are the following:

	Containing weight per cent of oxygen
$KClO_4$ (Potassiumperchlorate)	46·2
KNO_3 (Saltpetre)	48·5
$HClO_4$	64·0
N_2O_5 (Nitrogenpentoxide)	74·2
HNO_3 (Nitric acid)	76·3
H_2O_2 (Hydrogenperoxide)	94·2
O_2 (liquid Oxygen)	100
O_3 (liquid Ozone)..	100

Some of these oxygen-carriers cannot be used, either because of the chemical reactions they cause (HNO_3), or because of the reactions of their products (HCl for example). Others are poisonous (N_2O_5) or explosive or they need too much energy before releasing their oxygen content. All these reasons combined restrict the list for practical use to O_2 and O_3. Dr. Eugen Sänger gives in his book *Raketenflugtechnik*, tables of all possible combinations of fuels and oxygen-carriers. The most promising are the following combinations. All the figures are theoretical values, assuming combustion without losses, which is in practice, of course, impossible. The real values will be between 60 and 80 per cent of these, according to the usually high efficiency of the rocket motor.

		E in 10^6 mkg. per kg.	c in m/sec.
	1 kg. H_2 + 8 kg. O_2 = 9 kg. H_2O	1·36	5,170
	1 kg. H_2 + 8 kg. O_3 = 9 kg. H_2O	1·63	5,670
(Methan)	1 kg. CH_4 + 4 kg. O_2 = 5 kg. CO_2 and H_2O	1·03	4,490
,,	1 kg. CH_4 + 4 kg. O_3 = 5 kg. CO_2 and H_2O	1·27	5,000
(Octan)	1 kg. C_8H_{18} + 3·5 kg. O_2 = 4·5 kg. CO_2 and H_2O	1·01	4,450
,,	1 kg. C_8H_{18} + 3·5 kg. O_3 = 4·5 kg. CO_2 and H_2O	1·25	4,960
(Benzol)	1 kg. C_6H_6 + 3·4 kg. O_2 = 4·4 kg. CO_2 and H_2O	0·93	4,270
,,	1 kg. C_6H_6 + 3·4 kg. O_3 = 4·4 kg. CO_2 and H_2O	1·17	4,800
(Alcohol)	1 kg. C_2H_6O + 2·08 kg. O_2 = 3·08 kg. CO_2 and H_2O	0·89	4,180
,,	1 kg. C_2H_6O + 2·08 kg. O_3 = 3·08 kg. CO_2 and H_2O	1·09	4,630
	1 kg. C + 2·67 kg. O_2 = 3·67 kg. CO_2	0·95	4,320
	1 kg. C + 2·67 kg. O_3 = 3·67 kg. CO_2	1·17	4,800

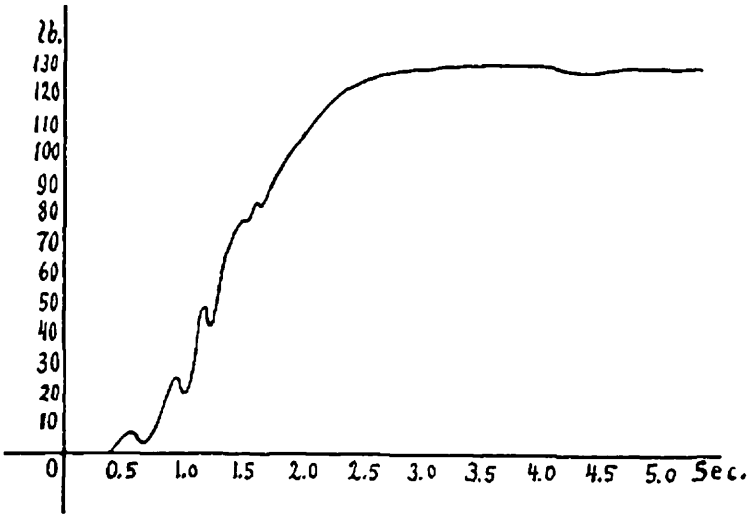

FIG. 2.—*Thrust diagram of Verein für Raumschiffahrt experimental rocket*

Materials for Construction

The question which material should be regarded as most efficient for rocket construction cannot be answered in general. The rocket consists of various parts, all of them having different conditions to withstand and different functions; the rocket, as well as all other vehicles, will have to be constructed of different materials. The supreme consideration is, of course, light weight, combined with sufficient strength. This leads us to consider chiefly the light metal alloys, aluminium and its alloys (duralumin) and the magnesium alloys like the American Dow-metal and the German Elektron. The fuel tanks are the main weight of the rocket; both magnesium alloys serve for this purpose. But duralumin may also be used for tanks; it has sufficient strength to form the framework and is still very good even at the low temperatures of liquid oxygen. The great difficulties are in the construction of the combustion chamber and the nozzle, called for short the "rocket-motor."

The flame of the rocket-motor is almost as hot as (sometimes even hotter than) the flame of the oxy-hydrogen torch. The lowest limit of temperature of the flame can be estimated at 1,200 deg. C.—usually it will be around 2,000 deg. C. at minimum.

There are not many metals that have a higher melting point, but it must be remembered that a rocket motor is used only for short times. Even the motors of a hypothetical space-machine would have to burn only 8 minutes until the velocity of liberation is reached, when working with an acceleration of 4 g. It is quite possible to put a greater strain on the materials of a rocket-motor than on those of any other motor without endangering them. *Astronautics*, the official publication of the American Rocket Society, recently published the very interesting table, reproduced below, of possible metals for the construction of rocket motors, compiled by Mr. Bernard Smith:

Metal	Spec. Weight	Thermal Conductivity (Copper—100)	Hardness	Melting Point Centigrade	Tensile strength 1,000lb. per sq. inch at 15° C.	1,000° C.
Aluminium	2·7	55	2·9	658	10	liquid
Duralumin	2·8	30	3·5	550	65	,,
Copper	8·9	100	3·5	1,083	30	low
Iron	7·9	15	4·5	1,525	40	,,
Steel	7·8	5	5·5	1,250	175	6
Molybdenum	10·2	40	6	2,620	300	50
Tungsten	19·3	45	7	3,370	560	15
Beryllium	1·84	10	6·5	1,280	—	—
Titanium	4·8	40	7	1,795	—	—
Ber.-Copper	8·2	40	5	864	193.	liquid

The use of graphite has been suggested because it has an extremely high melting point, but all its other features, such as thermal conductivity and tensile strength, are very poor. In fact, a graphite test motor of the American Rocket Society exploded during the first second of firing. Obviously high melting point and tensile strength of a metal are not sufficient proof that it might be used for the construction of an efficient rocket motor; the thermal conductivity is a factor of almost greater value.

Practical Experimental Work

Actual rocket experiments have been performed in the following countries: Germany, Austria and U.S.A. For a long time Germany was the only country in the world where experiments were made, most of them under

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* Possibly Ozone (O_3) and Hyzone (H_3) or monatomic hydrogen will be more powerful, but these fuels are scarcely known to-day.

† This argument is the same as calculating the possible altitude of an arrow shot on the assumption that bow and arrow are tied together. Analogously no bow could shoot higher than 20 metres. The bow weighs about 1 kg. and the energy stored in it (from the biceps of the archer) is about 20 m./kg., sufficient to lift bow and arrow a little less than 20 metres at the earth's surface. But the energy projects only the light arrow, its weight being about one-twentieth that of the bow. The altitude reached by the arrow would average 400 metres, if there were no air resistance.

Fig. 3.—*Tiling winged powder rocket*

the auspices of the Verein für Raumschiffahrt or the German Rocket Society. The next country following was U.S.A., after the president of the American Rocket Society, Mr. G. Edward Pendray, had visited (in 1931) the proving ground of the Verein für Raumschiffahrt, the famous Raketenflugplatz near Berlin.

The experiments are divided in two classes:

(1) Ground tests, motors alone on proving stands;

(2) Test shots of rockets.

Test shots have been made in Germany (Verein für Raumschiffahrt, Johannes Winkler, Reinhold Tiling, Gerhard Zucker, the latter two with powder rockets), in Austria (Fritz Schmiedl, powder rockets), in U.S.A. (American Rocket Society). Ground tests with liquid fuels were made in Germany (Verein für Raumschiffahrt, Johannes Winkler), in Austria (Dr. Eugen Sänger), Rumania (Prof. H. Oberth), and in U.S.A. (American Rocket Society and probably Prof. R. H. Goddard, though no reports have been published). Rumours about rocket-experiments in Soviet Russia were never verified, though the Russians contributed a large literature. All experimenters used liquid oxygen; the fuels tested were: Gasolene (Petrol) (Verein für Raumschiffahrt, American Rocket Society, Prof. Oberth, Dr. Sänger); Methane CH_4 (Johannes Winkler); Alcohol (Verein für Raumschiffahrt, American Rocket Society, Dr. Sänger); light oils (Dr. Sänger); liquid (or gaseous ?) hydrogen (Prof. Oberth); petroleum ether (American Rocket Society).

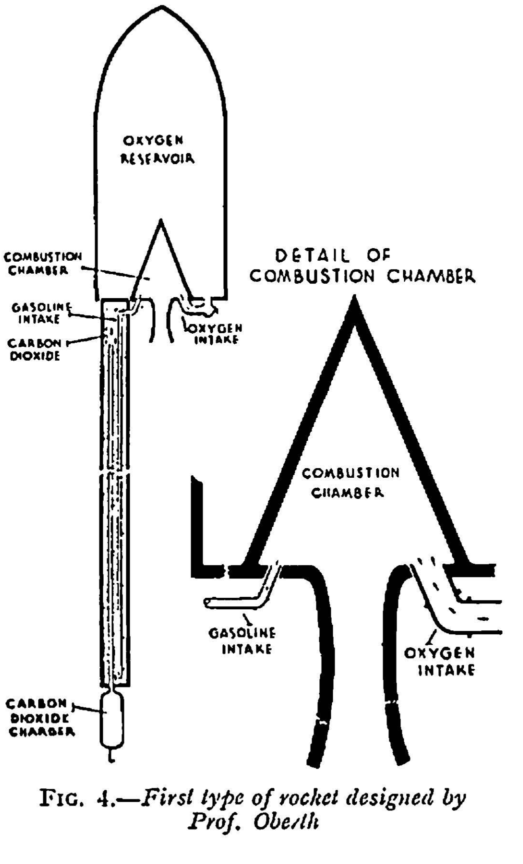

Fig. 4.—*First type of rocket designed by Prof. Oberth*

The *measured* values of c of some of these fuels were

Gasolene (petrol)	appr. 2,100 m./sec.	(Verein für Raumschiffahrt)
Alcohol	appr. 2,200 m./sec.	(American Rocket Society)
Hydrogen	appr. 4,200 m./sec.	(Prof. Oberth)

Dr. Sänger reports in the *Flug* (D. IV) that he had recorded values for $c = 3{,}500$ m/sec., Unfortunately he does not state for what fuel, but it is sure that it was not hydrogen.

These achievements are great enough to justify hopes of quick progress; though the results of the test shots do not look very overwhelming. Powder rockets—the famous Austrian post rockets of Eng. Fritz Schmiedl—have reached altitudes of about 3 km. and distances of about 5 km. (the rockets weighing loaded about 30 kg.); the corresponding data for liquid fuel rockets—the "repulsors" of the Verein für Raumschiffahrt—being 1½ km. and 3 km. The heaviest liquid fuel rocket weighed loaded about 70 kg.—that is, not much more than the largest powder rockets of the German Colonel Geissler in 1668; they were about 58 kg. heavy. But it should be remembered that these shots have been test shots.

Fig. 7.—*An American experimental rocket*

The construction of all rocket motors was almost identical, but it must be borne in mind that slight variations may mean much. There is certainly a great difference in the efficiency of the rocket motors of the designers mentioned, but the motors of the Verein für Raumschiffahrt, the American Rocket Society, the Cleveland Rocket Society, and Dr. Sänger look very much alike.

The German tests began with rocket motors shaped like cones, the first being designed by Professor Oberth and termed "Kegeldüse." Though it had naturally a few flaws in its design (for example, an inner lining with ceramic materials which proved to be utterly useless) it worked well, but the thrust did not exceed 7 kg. Iron and steel were the materials of these first motors. The next were made from copper; they were the ones designed to propel the first liquid fuel rockets, the so-called Miraks.* Their power, though it was great enough to lift the rockets, was still not satisfactory enough and in a long series of ground tests the light-metal motors were designed. Their fuel consumption was about 160 grams per second, the thrust P about 32 kg. From these recorded data c was easily computed:

$$P = c \,.\, dm/dt \quad\ldots\ldots\ldots\ldots(9)$$

equalling 2,000 m./sec. These motors were termed "type 16/32," the next step was the "type 32/64" (Fig. 2). The burning time in the ground tests was made to vary between 30 and 90 seconds. At the Raketenflugplatz, the characteristics of a motor were expressed in the type number alone; it gave fuel consumption, thrust and the value of c. The American Rocket Society prefers to give the impulse of the rocket motor in pound seconds. This method has the disadvantage that one has to know the time of burning, which is not necessary in the German terminology.

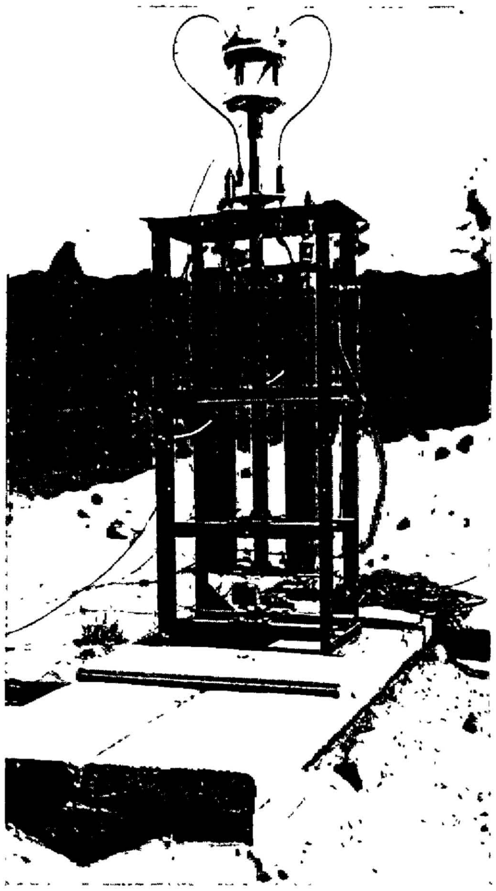

Fig. 6.—*Test stand of the American Rocket Society*

In the latest American tests John Shesta for the first time measured directly the pressure in the combustion chamber during the firing period, in the four tests of April 21, 1935. It

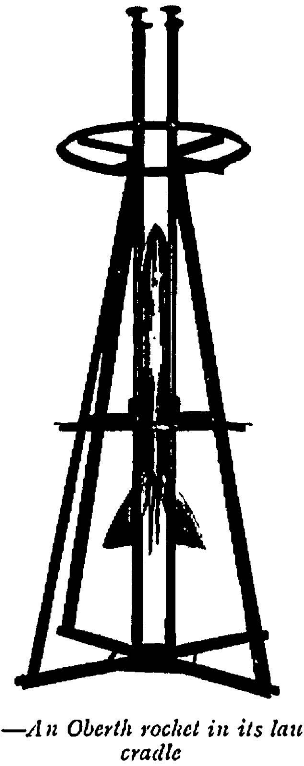

Fig. 5.—*An Oberth rocket in its launching cradle*

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* Abbreviation for *minimum rakete*, the smallest possible rocket to contain liquid fuels.

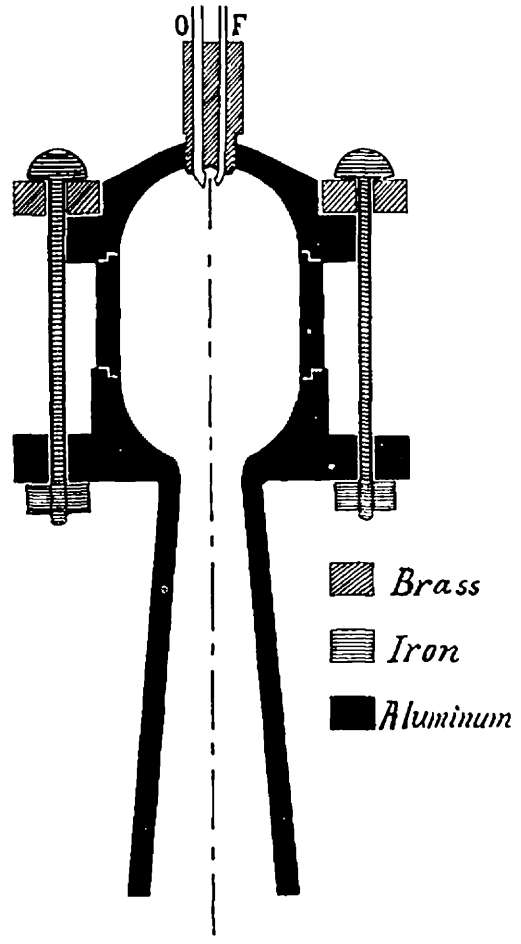

Fig. 8.—*Cross-section of the American rocket shown in Fig. 7. O, oxygen intake. F, fuel intake*

was always exactly three-quarters of the pressure in the tanks.

Cooling the Motor

There are two principal ways of solving the problem of cooling the rocket motor—external or internal. For outside cooling among the possibles three ways that suggest themselves most strongly have been tried in practice. The first is by radiation to the air from a motor not encased in the shell of the rocket. This has been done in the rockets of the American Rocket Society, also Winkler's first rocket met its cooling problems in this way. Of the other two methods one utilizes a special water jacket around the motor. Most of the German rockets were built on this system. The other method employs one of the liquids for cooling the motor. Here either the oxygen or the fuel may be used. The first and second Miraks had their combustion chambers in the oxygen tanks. Though the tank was equipped with a safety valve it burst from oxygen pressure, so that this method seems not safe enough. Cooling the motor by means of the fuel was tried at the Raketenflugplatz and by Dr. Sänger, in all cases with satisfactory results.

Internal cooling can also be managed in three ways: either by the injection of cooling water into the combustion chamber through a separate injection nozzle or by mixing it with the fuel. This, of course, demands a fuel such as alcohol that can be mixed with water. In the case of an oxygen-hydrogen rocket the fuel itself might serve to cool internally, by injecting the gases in such a proportion that a great surplus of hydrogen remains unburned. The alcohol-water mixture has been tried successfully both in Germany and in U.S.A., while the hydrogen cooling has been investigated theoretically by Professor Hermann Oberth.

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(23) David Lasser: *The Conquest of Space.* (New York, 1931.)

C. MODERN ARTICLES

(1) Lists of articles are given in: (B. V), (B. VI), (B. VIII), and in (B. XXI, vol. 7, *The Theory of Cosmic Flights*, also in vol. 9, *Astronavigation*).

D. PERIODICALS

(1) *Die Rakete,* 1927-1929, Zeitschrift des Vereins fur Raumschiffahrt. Since 1934 under the title *Das Neue Fahrzeug.*

(2) *Astronautics*, published by the American Rocket Society.

(3) *The Journal of the British Interplanetary Society*, Wallasey.

(4) Note: The December issue 1934 of the monthly *Der Flug* is devoted entirely to an essay by Dr. Eugen Sänger: "Neuere Ergebnisse der Raketenflugtechnik."

Injection of the Fuels

In all experiments made so far the injection of the fuels was made from tanks where the liquids were placed under a higher pressure than they met in the motor. But this method soon reaches a limit in larger rockets because the fuel tanks would become too heavy to withstand the necessary amount of pressure. In large rockets a pump or injector will become indispensable. The drawback of pumps of the existing types are that they are comparatively heavy and need another motor to move them. Moreover, their capacities are comparatively small. A new type of pump will have to be invented, a pump that combines large capacity with lightness, durability and simplicity. The only practical suggestion made so far is Oberth's pressure pump, which runs by the same fuels feeding the rocket motor. Though the means of injection needs still more investigation, the direction of injection has been explored experimentally. Generally the injection in the direction of the exhaust is unwise because the liquids have no time to vaporize and react thoroughly. In the experiments a long and brilliant flame indicates the fact that a part of the combustion takes place in the nozzle or even outside the nozzle. To avoid this the fuels have to be fed in at right angles to the longitudinal axis of the combustion chamber or even opposite to the direction of the blast. The problem has been investigated mathematically by Winkler (*Die Rakete,* March 1929 and December 1929).

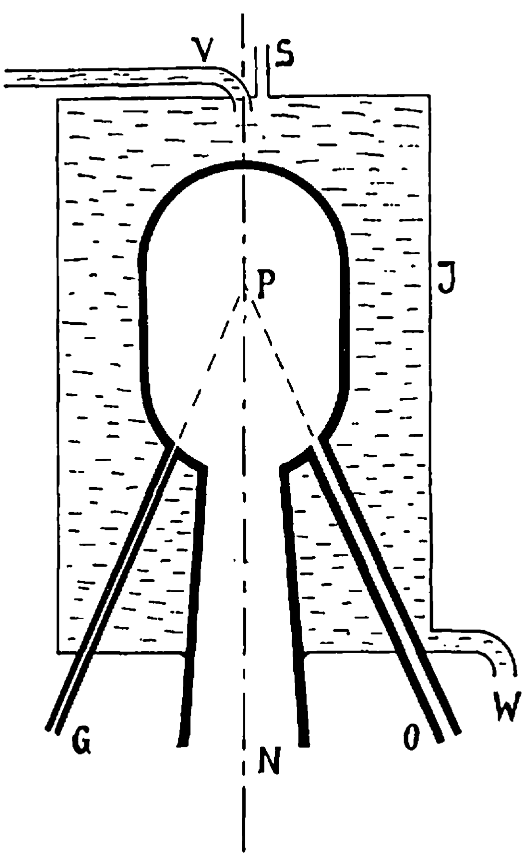

Fig. 9.—*Cross-section of a German rocket motor. G, fuel intake. N, nozzle. O, oxygen intake. P, combustion point. J, water-jacket. V, cooling water inlet. W, ccoling water outlet. S, air outlet*

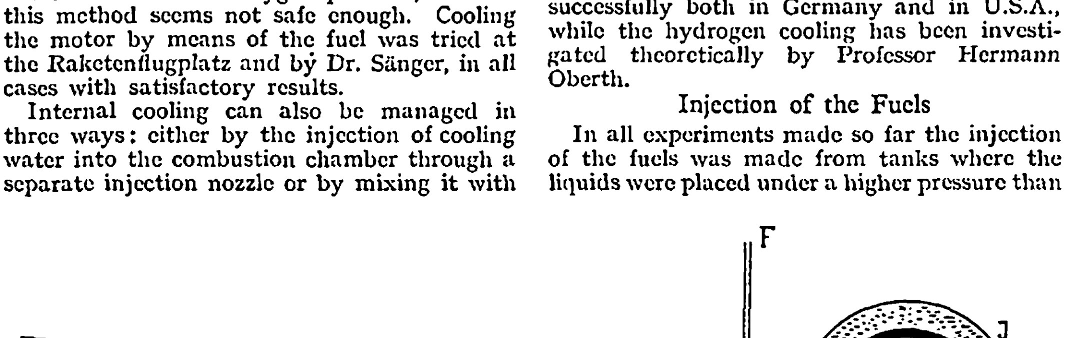

Fig. 10.—*Cross-section of rocket motor designed by Dr. Sänger. F, fuel pipe. J, fuel jacket. D, fuel injection. O, oxygen intake*

Additional Devices

In order to bring the rocket back and to locate it a few additional devices are necessary. For the latter small radio senders have been designed. They emit a single humming tone for long periods of time, thus allowing trace of the rocket by triangulation. Another method is a small smoke cartridge which leaves a thin line of smoke in the sky, showing the trajectory of the rocket.

To bring the rocket back parachutes are used. Tiling used folding wings. The parachute has proved superior so far, but it has to be released at or very near the apex of the trajectory, when the speed is lowest. To accomplish it in powder rockets is not very difficult, but the timing device for liquid fuel rockets is one of the knottiest and most characteristic of the minor problems. A time release suggests itself, but it demands an exact knowledge of the duration of powered and free flight. Time devices have been used in all rockets of the Verein für Raumschiffahrt but another method is desirable.

All devices working with pendulums and similar mechanisms depending on gravity are out of the question, because the rocket is in a state of "free fall." Next comes the plan to utilize the drop in air resistance at the top of the flight; this is practicable except that the rocket may swerve and follow a trajectory flat enough, so that speed and correspondingly air resistance never drop enough to actuate the mechanism. A modification of this plan, recently suggested by Peter van Dresser, may prove more practicable. His system depends on the fact that during a rocket flight there are two periods of increasing negative acceleration (due to the air resistance and independent of gravity acceleration); first, when the motor ceases firing, and, second, when the apex of the trajectory is crossed and the downward fall commences. A weight, suitably mounted on a spring, will respond to these two periods by successive movements towards the head of the rocket. Various devices, mechanical or electrical, could be designed to respond to the second of these movements, which by the nature of its cause can only take place just past the apex of the flight.

Efficiency

The efficiency of a rocket is determined by two factors, called thermic and ballistic efficiency. The latter varies according to the velocity. It is at its optimum when $v = c$.[*] The thermic efficiency ηth was found in experiments ranging from 57 per cent (powder) to 80·3 per cent (hydrogen). A thermic efficiency of 70 per cent is therefore guaranteed. Probably 80 per cent or even more will be reached, so that it becomes much higher than that of the internal combustion engine and approaches closely the high efficiency of electrical machinery.

Referring to the discussion of efficiency Professor Oberth asked the very interesting question: When will the proportion E/A be at its optimum? A means the thermic energy of the fuels before burning, E the kinetic energy of the rocket after burning. He found this optimum when $m_0 = 4{\cdot}94\ m_1$ or (which is the same) when $v = 1{,}593 . c$. E/A then becomes 64·7 per cent, which would be the highest possible efficiency under the assumption of a thermic efficiency of 100 per cent. Under the present conditions we may guess that a very good rocket converts about 50 per cent of the energy of its fuels into kinetic energy. But the proportion becomes better when c is not constant but increases with the velocity of the rocket, so that v and c are always equal or very nearly so.

Air Resistance

All questions of air resistance have been purposely omitted because our knowledge of this problem is still restricted. Because the thrust-efficiency of a rocket is best when $v = c$, and low speeds result in a heavy loss of power, it is essential for the designers of altitude rockets to give them a high acceleration in order to reach quickly speeds in the neighbourhood of the exhaust velocity. This is quickly done even with low accelerations of 3 or 4 g effective, but I believe that the future altitude rockets will average accelerations of 20 g—possibly after penetrating the troposphere with smaller acceleration. Thus the much feared limit of 333 m./sec. will be reached in a few seconds. Until future research in aerodynamics has provided more and better material it will be best to follow ballistic experience and to design altitude rockets in the shape of great gun-shells, in spite of the higher air resistance they may exist at less than sound velocities. Even here the accepted laws[†] might not be valid because the exhaust gases of the rocket motor add a new and as yet unknown factor.

For this reason it is desirable that not only rocket experimenting be continued on a larger scale than before, but that it be advanced by aerodynamical research.

The rocket, the simplest known prime mover—without any moving parts—has now reached a stage of development where experimentation will soon lead to the first practical application: the altitude rocket for the exploration of the upper layers of our atmosphere.

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[*] The Germans call the ballistic efficiency "Strahlwirkungsgrad," which may be translated as "blast-utilization." The expression should be introduced into English to avoid possible misinterpretations.

[†] It is, for example, very doubtful what becomes of the formula for the air resistance $L = F\beta\gamma v^2$. F is the area of the greatest cross section, β the density of the air, γ the "ballistic coefficient." γ is almost constant between 0 and 250 m./sec., rises between sound velocity and 400 m./sec. to 2·6 times its former value, and drops afterwards slowly to about 1·5 times its original value. This concerns shells, but not rockets without suction effect on their tails.

"THE RED FLAG REMOVED"

The Air Ministry is to free the manufacture and flying of light aeroplanes from official control. This decision will give to the British aircraft industry the biggest impetus it has received since the war and will revolutionise flying for the private owner.

It is understood that a general exemption cannot at present be given to all light aircraft, but that, pending the necessary legislation, special application will be necessary for each type and make of machine.

The first light aeroplane to receive exemption from Government inspection and control is the British Drone, the machine in which Mr. Robert Kronfeld recently made successful flights in Britain and to the Continent.

In a letter to B.A.C. Ltd., Hanworth, the manufacturers of the Drone, the Air Ministry specifies the conditions which will replace the official regulations. The new system will provide for reasonable conditions of efficiency and safety similar to those which govern the use of a motor car. One of the main conditions is that a machine must not fly outside Great Britain and Northern Ireland. This is because Great Britain has given freedom from control in advance of all other countries. Also, the aeroplane must not carry fare paying passengers. Third party insurance is compulsory as in the case of a motor car, and the machine must be maintained in good repair.

By its decision the Air Ministry has now given effect to the principal recommendations of the Gorell Committee on Civil Aviation and has placed the maker of light aircraft on the same basis as the motor-car manufacturer and the private owner on the same basis as the motorist. The Civil Aviation Department of the Air Ministry has co-operated wholeheartedly in devising the new code. It is significant that while exemptions so far granted are in respect of the ultra light single-seater aeroplane, the Ministry has not prescribed a maximum weight or power and it is anticipated that, in the reasonably near future, machines carrying from four or five passengers may be freed from official restrictions.

It is confidently anticipated the new system will inaugurate an era of low cost aviation and will bring flying within the reach of anyone who owns a car or a motor-cycle combination.

The new system should enable reductions in first cost of at least 25 per cent to be made with no sacrifice of safety or efficiency. How this saving will be possible may be instanced from the building of the Drone type of single-seater light plane. A good magneto can be fitted at a cost of 35s., but as soon as a similar magneto has to be certified by the Air Ministry the cost jumps to £6. A reliable compass can be obtained for £2, but the cheapest non-luminous type of certified compass cannot be purchased for less than £7 10s.

Even greater saving is reflected in the maintenance costs, which are a heavy item under present conditions. The owner of an exempted aeroplane will be allowed to overhaul his own machine instead of taking it to an approved factory and obtaining an official certificate of airworthiness when the work has been completed. For the types of light aeroplane at present exempted the cost of maintenance is reduced to motor-cycle prices. Such machines can in future be operated at an inclusive cost of 8s. 6d. per flying hour, a figure considerably less than half that of a similar machine if built and flown under full official control.

Further economy is effected by the decrease in insurance costs which in future will be at motor-car rates. . . . .

Mr. E. C. Gordon England, interviewed recently, stated, "The effect of the Air Ministry's decision is to remove the red flag from before the aeroplane as it was removed from before the motor car years ago. It is the most important aviation development since the war, and its full significance has yet to be appreciated even in aviation circles. Before the war the industry was developing normally and rapidly without Government control either in construction or operation. Quite rightly, the new science of aviation was used to its full extent in the service of the State in the war years, but in the view of some who, like myself, were associated with the pre-war developments, the aeroplane since the war has been regarded far too much as a potential instrument of destruction instead of as a new and valuable medium of civil transport, with the result that its true development has been atrophied.

"There is surely not more reason why a Government department should control a civil aeroplane throughout its construction and flight than that the Navy should supervise the building and voyages of a new merchant ship. Both can be of valuable service in time of national emergency, but the efficient civil aeroplane would not be a better fighting instrument than a merchantman.

"I should like to make it clear that in stating the case for the civil aeroplane I am not criticising the Air Ministry. On the contrary; I should like to pay tribute to the courage and foresight of the Director-General of Civil Aviation in taking this important step and co-operating wholeheartedly in drawing up the new code on a basis which will ensure reasonable conditions of safety and the minimum of maintenance costs for the private owner and will, at the same time, enable manufacturers to reduce prices to levels which will make flying comparable with motoring.

"I have no fear that builders of aircraft will be unmindful of the responsibility which the Air Ministry has placed upon them. The new freedom which has been given them comes at a moment of unprecedented interest in light aeroplanes and when the present five hundred private owners may be increased rapidly to ten times that number. The best interest of the industry will therefore be served by the design and production of better and more efficient machines worthy of the highest traditions of British skill and craftsmanship.

"New responsibility rests, too, upon the user of an exempted aeroplane and I would urge him in the exercise of his new freedom to have full regard to his social obligations towards others in the air and on the ground so that a bare minimum of essential restrictions may stand in the path of what I am certain will prove to be an era of unprecedented development in British aviation."

[We disagree violently with the whole tenor of the above, which has been widely circulated to the press. It is dealt with on page 211.—Editor.