N. A. Rynin

INTERPLANETARY FLIGHT AND COMMUNICATION

Volume II, No. 4

Rockets

TRANSLATED FROM RUSSIAN

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AUTHOR'S FOREWORD

The present book is one of the separate sections of a comprehensive work planned by the author, whose title is "Interplanetary Flight and Communication."

The first two sections, "Dreams, Legends and Early Fantasies" and "Spacecraft in Science Fiction" have already been published. The third section, "Radiant Energy, Science Fiction and Scientific Projects," is being printed and will appear in January 1929.

These three sections constitute the first volume of the work and comprise fantasies of interplanetary communications. Beginning with this section, projects of those scientists who took an interest in problems of interplanetary communications are explained, and experiments are described that were carried out in this connection. The following sections will appear:

Superaviation and Superartillery.

K. E. Tsiolkovskii: Life, Writings, and Rockets.

Theory of Space Flight. (Works by Goddard, Oberth, Hohmann, Lebedev, Esnault-Pelterie, Lorenz, Scherschevsky, and others.)

Theory of Rocket Propulsion (in print).

Astronavigation — Theory, Annals, Bibliography, Index [to the whole series].

Although the entire work is ready for print, it will be published in individual sections for financial reasons, and it is difficult to say when the subsequent sections will appear.

Readers are requested to address all comments on the present and the already published sections to the author, Nikolai Alekseevich Rynin, Leningrad, Kolomenskaya ul. 37, Apartment 25. Orders are to be sent to the author or to the Publisher, P. P. Soikin, Leningrad, Stremyannaya ul. 8.

N. Rynin

29 November, 1928

"It is necessary that everything be ready for the time when the physicists will put at mankind's disposal a powerful source of energy (intra-atomic).* Interplanetary communications will then take place."

R. Esnault-Pelterie

5 INTRODUCTION

Reaction engines are at present widely used in engineering. In fact, all modern airplanes, airships, helicopters, and autogiros are propelled by such engines. However, in these engines the force created by the explosion of the fuel does not directly supply the thrust, but is used to rotate a propeller which acts on the air and thus induces a reaction moving the aircraft. These aircraft thus use indirect-reaction engines; between the exploding substance and the thrust, there is an intermediate link in the form of a propeller which absorbs part of the energy. Besides, such engines can be used only where a surrounding medium (water or air) exists which can induce a reaction.

The idea of omitting the intermediate link in the form of a propeller and thus increasing the engine efficiency on the one hand, and, on the other, the tempting idea of traversing interplanetary space, where the propeller causes no reaction in the surrounding medium, induced many inventors to try to design a direct-reaction engine in which the energy of the explosion would be directly transformed into motion of the spacecraft through reaction or recoil.

History shows that in this case too the idea was first put into practice in the form of toy rockets for amusing people,** and was only later used for other purposes.

However, this raises the question why the direct-reaction engine — if it is so advantageous — is so far used only in rockets and has not found any application in other fields of engineering.†

The answer is that until recently the following obstacles were encountered.

1. The difficulties of building such an engine, since the explosions produce very high temperatures which have a detrimental effect on the material of
6 the engine; it is essential to develop methods of cooling the latter.

2. The combustion rate of strong explosives. It is necessary to invent devices reducing this rate.

3. The dangers involved in handling these substances. It is necessary to invent protective devices.

* [Now called nuclear energy.]

** The prototype of the balloon was the soap bubble, and that of the airplane the paper arrow and the kite.

† We do not refer here to reaction turbines.

4. The insufficient specific energy, i.e., the power developed per unit weight of the explosives. An ideal solution could be found if it were possible to use the intra-atomic [nuclear] energy of matter without special effort.

5. The difficulty of properly utilizing the energy liberated by the explosion in view of the rapidity of the latter. The special advantage of a direct-reaction engine is its ability to develop a high speed within a short time and thus propel the spacecraft over great distances. However, the concomitant high acceleration at the beginning of the motion and the high deceleration at its end are dangerous not only to man but also to the spacecraft itself. It is therefore necessary to study this problem as well.

Recent works by Tsiolkovskii, Valier, Oberth, Goddard, and Hohmann have clarified many of these problems theoretically and, in part, experimentally (Goddard, Winkler, Valier, and others).

Moreover, instructive experimental data has been accumulated over several centuries by inventors. We can therefore hope that modern engineering will pay more attention to engines employing the principle of direct reaction, and that a type will be designed which will ensure the fastest motion possible, especially for interplanetary flight.

In particular, we shall discuss direct-reaction engines, proceeding in the following order. We shall first explain the operating principle of the reaction engine, illustrating this by examples; we shall then give a brief survey of the history of rockets, since they are the forerunners of direct-reaction engines, and their principle will obviously be developed in similar future engines. The history of the development of direct-reaction engines in general then follows; we classify them:

1. according to the kind of the ejected substance (water, air, steam, gases, combustion products);
2. according to the place of motion (on water, air, land);
3. according to the type of vehicle (carriage, ship, train, airplane, airship, helicopter, jet craft);
4. according to the purpose (transportation of animals, of people, signaling, rescue, combat (impact, incendiary), illumination, photography, entertainment).

We shall then discuss some theoretical investigations proposed by various scientists for clarifying the operation of direct-reaction engines.

At the end we shall explain the fundamentals of interplanetary flight, details of which will be given in subsequent sections of this work.

7 *Chapter I*

THE PRINCIPLE OF REACTION

The operating principle of a rocket (Figure 1 a and b) is as follows: Let an explosion occur inside a vessel closed on all sides (Figure 1a). The gases formed will exert uniform pressure on all walls of the vessel. Let us now make a hole in the bottom of the vessel (Figure 1b). The gases will then flow toward this hole, and there will be a difference in the pressures acting on the lower and the upper walls of the vessel. The resultant force will be directed upward and will propel the vessel in the direction opposite to that in which the hole points. The smaller the resistance of the air to the ejected gases, and the higher their velocity, the stronger will be the recoil or reaction.

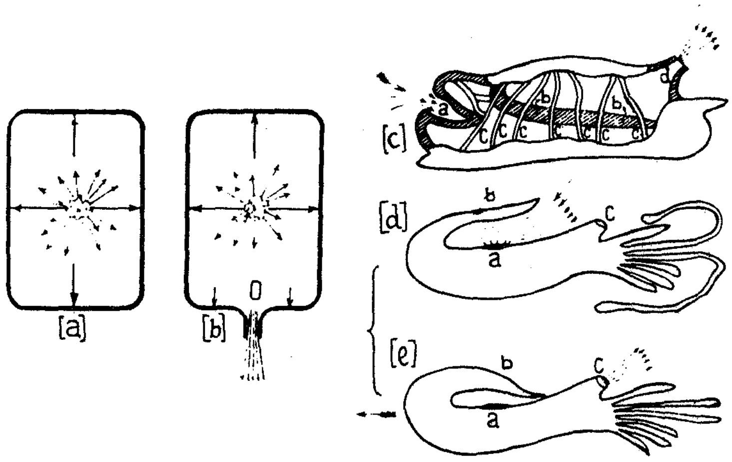


FIGURE 1:

a, b — schematic illustration of reaction effect; c — motion of the Salpa; d, e — motion of the cuttlefish.

a) Reaction engines in nature

In nature there are several examples of motion due to a reaction. Figure 1c shows a marine animal, the Salpa, at 1/4 of its real size, which moves as a result of the reaction created by the ejection of water from its body. The water is first taken in through a hole and then passes through

gills b; the body then contracts with the aid of muscles cc, and the water is
8 ejected through funnel-shaped hole d. The reaction thus created propels the Salpa through the water in the opposite direction.

Another animal moving through water by means of reaction is the cuttlefish (Figure 1 d, e). Around the body it has a fold shaped like a coat; water is aspirated through hole a into the space between the coat and the body, and is then ejected through funnel-shaped hole c.

Jellyfish and dragonfly larvae move in the same manner. The sturgeon, ascending rapids and water falls, jumps quite far by striking the water with its tail. A plant, the squirting cucumber (Figure 2), has fruits which drop from the branches when they are ripe; they open on one side, and the seeds are ejected through the hole thus formed, while the fruit itself flies in the opposite direction.

FIGURE 2. Squirting cucumber.

b) Reaction toys

The principle of reaction has been used to impart motion to children's toys. Figure 3a shows two sections of a reaction ship whose boiler consists of an eggshell filled with water. The narrow end of the shell has a hole. When the water in the shell is brought to the boil, the steam is ejected through the hole, and the reaction propels the ship through the water in the direction of the arrow. The firebox is a piece of eggshell containing kerosene or a piece of cotton wool soaked in alcohol.

Another toy is the swimming fish shown in Figure 3b. It is cut out of thin cardboard. If some drops of oil are put into the round hole, the oil tends to flow into the water and moves along channel mn, thus propelling the fish through the water in the direction of the arrow.

(9)

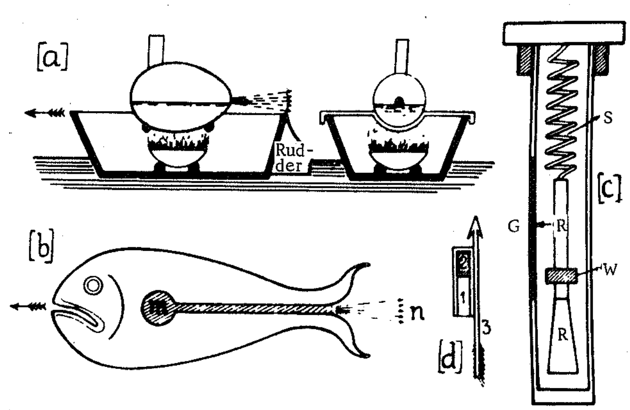


FIGURE 3:

a, b — reaction toys; c — Goddard's experiment; d — Chinese fiery arrow.

c) Experiments on the reaction effect

1. A person standing on a smooth floor on roller skates or balls will roll forward if he throws backward any load.
2. A person firing a rifle feels the recoil acting on his shoulder.
3. When a gun is fired, it kicks back because of the recoil unless it is fixed in position.

Interesting experiments, performed with rockets by Prof. Goddard in the USA, show that the recoil is stronger in vacuum than in air (Figure 3c).

The combustion chamber of a rocket was placed in a tank in which the pressure of the air was 1/1,500 of the atmospheric pressure. The combustion chamber of rocket R, shown in the illustration, was suspended from
9 coil spring S, being pulled downward by weight W. When the rocket was ignited, the gases were ejected downward and lifted the rocket; this was proved by the mark made by the combustion chamber on smoked glass G. The counterpressure of the gases was eliminated by leading them into a tubular reservoir in which they performed a translational motion along a circular path, gradually losing speed due to friction with the walls. The results of 50 experiments showed that in vacuum a rocket exerts a 20% higher thrust than in air at atmospheric pressure.

10 *Chapter II*

THE HISTORY OF ROCKET DEVELOPMENT

a) The first applications

A rocket is a heavier-than-air vehicle propelled by the recoil or reaction of gases or other matter ejected from it. A rocket thus is a reaction engine. The term rocket is derived from the Italian word "rocchetto" (pin, spindle, bar).

The first rockets date back to antiquity. They appeared in China around 3,000 B. C., where they were at first used for entertainment as fireworks, then for military purposes (for starting fires), and later, according to legends, for lifting people. One story relates that the Chinese mandarin Wan-Hu built two large parallel horizontal kites with a seat between them; beneath this machine there were 47 rockets which were ignited simultaneously by 47 servants. However, the rocket under the seat blew up, and the subsequent fire unfortunately also killed the inventor.

The Chinese knew the composition of gunpowder long before it was invented in Europe, and they used it as rocket fuel; in wartime they attacked the enemy with "fiery arrows" (see Figure 3d). Such projectiles consisted of paper case (1) filled with powder (2) and tied to an arrow (3). Rockets were launched by hand or with a bow (11th century).

Rockets later appeared in Europe. The Roman poet Claudianus, who lived at the time of Emperor Honorius, described a festival held in 399 A. D. in Milan, at which rockets were launched. Marcus Graecus used rockets in 843, and Leo the Philosopher made them in his secret laboratory. However, in all these rockets the explosive was poor, and their real development began only in the 14th century after gunpowder had been invented in Europe.

The Chinese used rockets in combat in 1225 A. D. (arrows), as did the Chinese Emperor Pen-King.

In 1249 the Arabs used rockets in the siege of Damietta.

Albertus Magnus mentions them in his work "De mirabilibus mundi" in 1265.

The Arab writer Hassan-al-Rammah-Nejm-Eddin* described them in 1285 as "Chinese arrows" and mentioned their use in driving mines.

11 Jaime, King of Aragon, used "flying fire" in 1288.

Muratori [1672 – 1750] states that rockets were known in Western Europe in 1379.

* [Ed. note: given as Nejd-id-din Hassan Alrammah in "Small Arms of the World," by W.H.B. Smith, Military Service Publ. Co., Harrisburg, Pa., 1955, p. 4,218. All other corrections of names, etc., are in accordance with this book.]

In 1405 Konrad Keyser von Eichstadt mentioned a rocket with a stick.

J. de-Fontana in 1420 described rockets for throwing mines and torpedoes in the form of pigeons, hares, and fish (Figure 4).

The Hussites launched rockets in the form of pigeons in order to set the enemy camp on fire when they besieged Saaz in 1421.

Works on rockets appeared in Germany by Hans Hartlieb (1437), Johann Schmidlap (1501), Franz Helm (1530), Reinhard Solms (1547), who mentioned rockets with wings, Linhard Fronsprenger (1557), and Kazimir Simenovich (1650). Christopher Heisler experimented in Berlin with comparatively large rockets in 1668.

His rockets weighed between 50 and 100 pounds and were intended for lifting bombs.

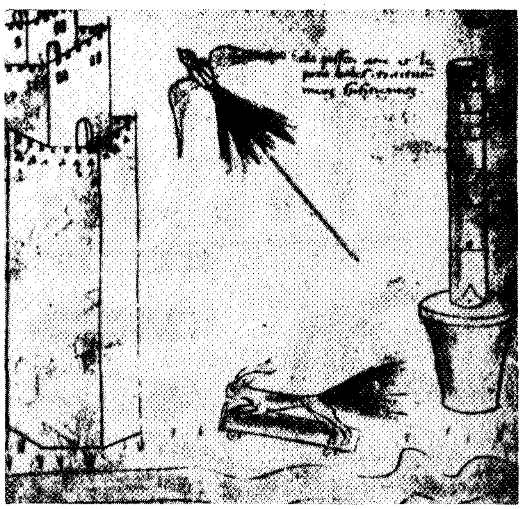


FIGURE 4. J.de-Fontana's rocket pigeons and hares

In India Prince (Rajah) Gandar-Ali of Mysore in 1766 formed a 1,200-man strong corps of rocketeers. His son Tipu (also spelled Tippu or Tippoo) Sahib increased their number to 5,000 in 1782. The weapons were bamboo pipes weighing 3 to 6 kg, tied to 8 foot long sticks. These rockets were used in the siege of Seringapatam in 1799, where the British Colonel Congreve became acquainted with them.

In Europe a strong impetus was given to the development of rockets by Congreve, who used them at the end of the 18th century against the American Indians.

He obtained a range of 4,500 feet with his rockets at the beginning of his experiments in 1804; in 1805 the range was already 8,000 feet. Later the range increased to 3,000 yards (2.7 km) (8 lbs), 2,500 yards (2.3 km) (12 lbs), and 2,000 yards (1.8 km) (28 lbs).*

* [Ed. note: the "Safety at Sea" supplement of "Shipping World and Shipbuilder" (June 1967) states that "lbs" in fact refers to the weight of a lead ball fitting into the mold from which the rocket was made.]

12 In 1806 the British launched about 200 incendiary rockets from ships during the siege of Boulogne.

In 1807 they also used 12, 24, 32, and 48-lb rockets to set Copenhagen on fire.

The use of rockets spread rapidly in Europe: in 1848 the Austrians used them against the Italians and Hungarians, and in 1870 the Germans against the French.

In 1885 the British used 9-lb rockets with a range of 1,200 yards during operations in the colonies [Ed. note: this apparently refers to the Sudan campaign.].

The diameter of the rockets was usually 5 to 8 cm; Congreve built rockets with diameters of up to 12 cm.

After Congreve the Danish captain Schumacher suggested drilling a hole through the explosive compound in the rocket in order to improve burning.

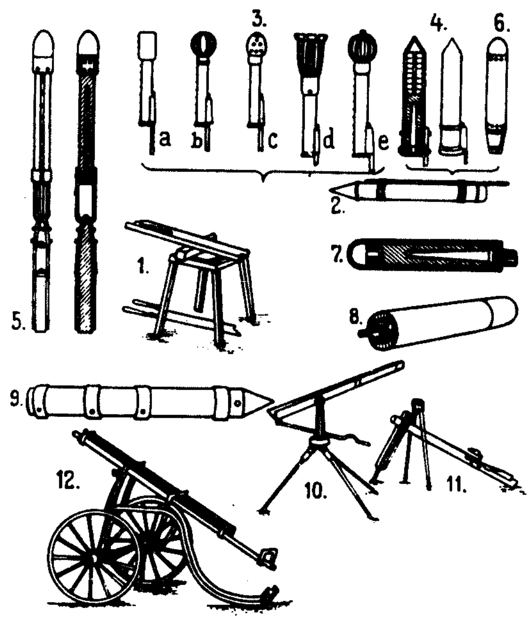


FIGURE 5. Rockets of the 16th to 19th centuries

Figure 5 shows rockets used between the 16th and the 19th century. These are:

1 and 2. Launching stand and rocket, 16th century.
3. Congreve rockets of 1804.
4. Signal rocket, 19th century.
5. German rocket, 19th century.
6 and 7. Hale's rocket (1846).
8. Hale's rocket weighing 73 lbs (1861).
9. Large Congreve rocket.

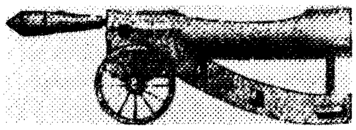


FIGURE 6. Rocket launcher

10. French stand for launching rockets.
11. Hale's launcher.
12. Another of Hale's launchers.

Figure 6 shows another rocket launcher built by Congreve around 1805.

b) **Types of rockets**

Rockets have now attained a considerable development, variety, and degree of perfection, and are used for different purposes. Besides, many engineers hope to employ the reaction principle, on which rocket flight is based, to propel artillery shells and to enable people to fly.

13 All rockets can be classified as follows:

According to purpose:

1. For fireworks:
   a) signal rockets which ascend, burst, and make a loud noise;
   b) flares — for illuminating an area;
   c) with stars;
   d) whirling;
   e) Hermes staff.
2. For combat:
   a) impact;
   b) incendiary;
   c) flares.
3. Rescue or coastal — to carry a thin line from shore to ship.
4. For scientific investigations of the upper layers of the atmosphere.
5. Photographic rockets.
6. Passenger-carrying rockets (planned).

According to design:

1. Simple.
2. Compound — Auxiliary (for lifting) or two-stage.
3. Parachute.
4. Revolving.
5. Helical.

According to the kind of propellant: solid fuel (gunpowder, etc.) or liquid fuel (oxygen with hydrogen or alcohol).

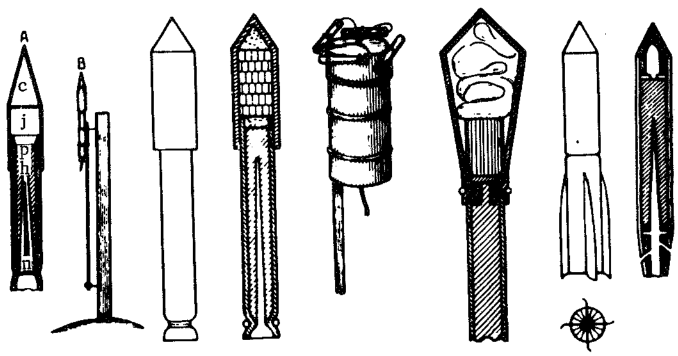
We shall now describe the various types of rockets in more detail.

1. Fireworks rockets can rise to a height of 1,500 m. The initial speed may be up to 100 m/sec, in exceptional cases up to 210 m/sec.

2. Signal rockets have the following arrangement (Figure 7): the lower part consists of a case having a neck at the bottom. The case is filled with powder in such a way that a conical space remains free above neck (n); this accelerates burning. This space is called the bore and
14 reaches to the solid part (h) of the charge (the heading). The charge is then covered by a percussion plate (p) with a hole in the center.

A cardboard cap (c) is directly fitted to the upper part of the rocket if the latter is only intended to rise. An intermediate cylinder (jacket) (j), filled with percussion powder (to cause an explosion) or a colored compound, is placed between them. A primer, i.e., a rapidly burning fuse in a thin case glued to the rocket, is inserted in the throat. The tail is then attached to the rocket (Figure 7); it consists of a thin stick. The weight and length of the tail are such that the center of gravity of the rocket with the tail is at a distance of 1–3 cm from the lower end of the rocket, where the throat is. The diameter and length of small rockets are 1.6 and 27.5 cm respectively; the corresponding values for large rockets are 2.5 and 35 cm respectively.

(13)



7. 8. 9. 10. 11. 12.

FIGURES 7–12. Various types of rockets:

7 – signal rocket; 8 – fireworks rocket with stars; 9 – whirling rocket; 10 – parachute; 11 – revolving rocket with fins; 12 – ditto, with grooves.

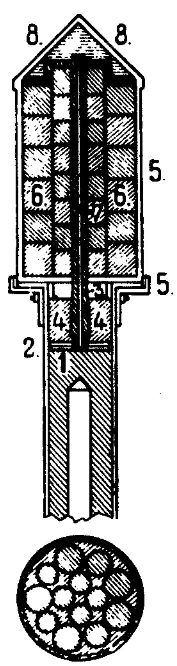


FIGURE 13. Flare

3. Flares (Figure 13) have a diameter of 3" and differ from combat rockets by the head in which copper ring (2) with copper tube (3) soldered to it is located above heading (1). The tube is filled with a slowly burning powder and held by sulfur coating (4). Tin cap (5) filled with pieces (6) of a luminous substance (saltpeter + sulfur + antimony) in the form of small cylinders pressed into paper cartridges is attached to the front of the case; at the end of each small cylinder there is a recess filled with gunpowder paste. Quickmatch (7) is inserted in the space between the small cylinders; one of its ends passes through the hole in the bottom of the tin cap and is inserted into copper tube (3), while the other end is located above the small cylinders. The free space above the small cylinders is filled with felt before cap lid (8) is attached. The rocket weighs about 16 kg and can illuminate an area of about 0.5 km diameter. Its range is 1 km. The duration of illumination is 1/4 minute.

A simple military signal rocket, 8 cm in diameter and 50 cm long, is filled with ordinary granular gunpowder; it lifts a load of 4 kg in 5 seconds to a height of 1,500 m, i. e., it develops about 10 hp. [Ed. note: $\frac{4\,\text{kg}\cdot 1{,}500\,\text{m}}{5\,\text{sec}} = 1{,}200\,\text{kgm/sec}$; average $= \frac{1{,}200}{75} \cong 15\,\text{hp}$.]

German flares weigh up to 15 kg; their tails are 2.4 m long, while the overall length is 3.45 m. Such a rocket attains a height of 300 m in 3 seconds when launched at an angle of 45°. It develops a power of 1,500 kgm/sec [≅ 20 hp]. Its charge consists of 76 parts pure saltpeter, 10 parts sulfur, and 16 parts 25% charcoal.

Figures 8 and 15 show various fireworks rockets filled with colored stars. They are similar in design to flares. The upper cone contains a paper or felt charge carrying a cardboard ring and, above the latter, colored stars interspersed with gunpowder pulp. Behind this there is the cracker. The powder charge with bore and the tail, whose length is 7 to 8 times the length of the cartridge, are at the end.

The whirling rocket (Figure 9) consists of a large rocket carrying several small rockets on its top in a horizontal plane. The large rocket is ignited first; the small rockets are ignited at a certain altitude and produce a beautiful spiral wheel.

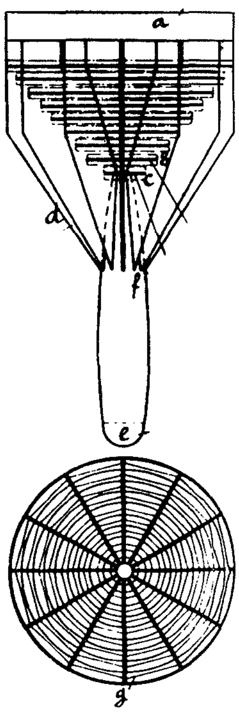


FIGURE 14. Scherschevsky rocket with parachute

The helical rocket is attached to the tail at an angle and thus describes a winding path when launched.

15 The Hermes staff is a modification of the helical rocket and consists of two rockets attached crosswise to a common tail; they have holes at the bottom and sides, so that the motion is both vertical and rotational.

Also used for fireworks is the parachute rocket (Figure 10) which ejects a paper or cloth parachute; at its maximum altitude; some inflammable substance suspended from the parachute then descends slowly.

Several parachutes are sometimes inserted into the rocket; the parachutes are detached from the rocket after it has ascended, and the cartridges carried by them create colored lights. The parachutes are lifted by a large percussion rocket whose cap has as many holes as there are parachutes. Fuses lead from these holes to the parachute cartridges (Figures 24 and 25).

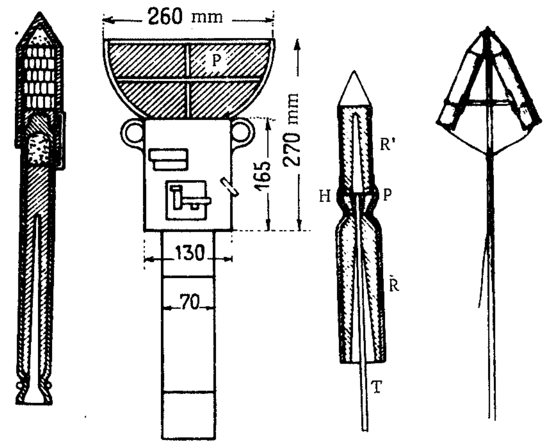
Figure 14 shows a recording rocket with parachutes, invented by Scherschevsky. Rocket (f) is provided with fins (d) between which vanes arranged in several layers can turn. During the ascent the vanes are pressed against the fins, so that their drag is small; during the descent they extend flat and thus increase the drag (top, and full lines at bottom).

A nice effect, namely a flying fiery kite, is obtained in America with rockets. This is achieved by tying a light cloth strip to the end of the tail stick. This strip is in flight illuminated by sparks and thus creates the desired impression.

The Künzer flare (Figure 16) invented by Künzer (Basel) is intended
16 for illuminating the landing site of an airplane; it is dropped at night by the pilot from the plane. Parachute (p) is placed at its top in a basket. A special catch, which acts when the parachute opens, detonates a primer

which in turn ignites the illuminating compound in the rocket. Ignition occurs at an altitude of 500 m above ground. The speed of descent is 2 m/sec. The duration of burning is [up to] 210 sec. The tare weight of the rocket is 2.5 kg. Such rockets are made in various sizes: 10 cm long for 25 sec [illumination], 15 cm (40 sec), 40 cm (120 sec), and 65 cm (210 sec).

(15)



15 16. 17. 18.

FIGURES 15 — 18. Various types of rockets:

15 — fireworks rocket with stars; 16 — Künzer flare; 17 — two-stage rocket; 18 — twin rocket.

The combat rocket (Figure 19a) consists of case (1) rolled from sheet iron and packed with composition (3) consisting of saltpeter (68% by weight), sulfur (13% by weight), and charcoal (19% by weight). Bore (2) is drilled in order to improve burning of the composition, above the bore the charge is solid (4). The warhead is secured to the case head. Copper tube (5) serving to ignite explosive charge (6) is located behind the warhead in sulfur layer (7). The sulfur layer is separated from the charge by iron or copper disk (8). Iron pan (9) is located beneath the rocket; it contains a socket for tube (10) which carries wooden tail (11). A number of holes are arranged in the pan so as to permit the composition to be ignited and the gases to escape. The tail is twice as long as the case. This combat rocket is 2" in diameter and weighs 10 lbs.

This combat rocket is launched from a stand (Figure 20) which carries tetrahedral tube (2) on tripod (1). The rocket is inserted into this tube which can be pivoted for sighting.

The range of Russian combat rockets is approximately 1,500 m. Figure 22 shows a different incendiary rocket. At its bottom there is a tube with holes arranged in such a way that the gases escaping from the rocket cause it to rotate about its longitudinal axis; this ensures its directional stability.

Combat rockets attained diameters of 12 cm with 20 kg charges in the fifties of the 19th century; they carried bombs 27 cm in diameter, weighing
17 49 kg, to a height of 2,700 m at a launching angle of 40°; the overall weight of this missile was 80 kg.

(16)

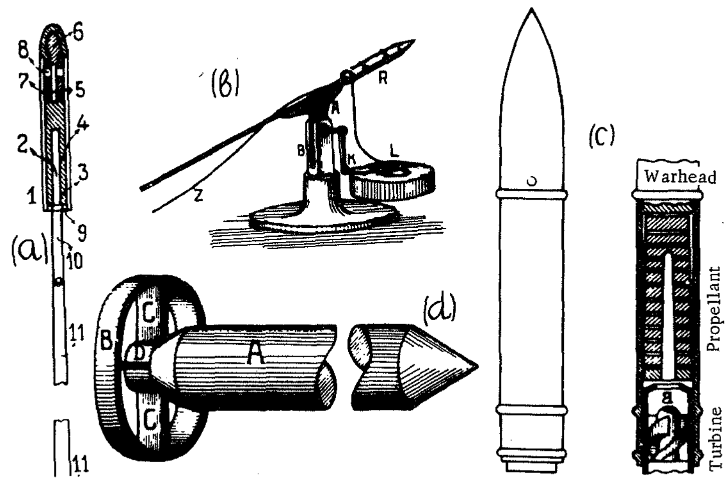


FIGURE 19. Various types of rockets:

a — combat rocket; b — launching stand for same; c — Unge rocket; d — Pomortsev rocket.

We shall now determine the efficiency of such a rocket. We assume, for the sake of simplicity, thus exaggerating the efficiency, that the rocket flies in vacuum to a height which is 10% greater, i.e., 3,000 m, and that the launching angle is 45°.

The final velocity will thus be $v = \sqrt{3{,}000 \cdot 9.8} = 172$ m/sec. [This value should be multiplied by 2.]

At a weight of 60 g after burnout the useful energy at sea level is

$$\frac{\frac{60}{9.8} \cdot 172^2}{2} = 88{,}752 \text{ kg} \cdot \text{m}$$

A black-powder charge of 20 kg has an energy of $20 \cdot 700 \cdot 430 = 6{,}020{,}000$ kg·m. The efficiency of this rocket thus cannot exceed

$$\frac{88{,}752}{6{,}020{,}000} = 1.47\%$$

If we require that this rocket develop 1 hp during one hour, the charge necessary would be

$$\frac{75 \cdot 3{,}600}{70.43 \cdot 1.47} = 60 \text{ kg black powder.}$$

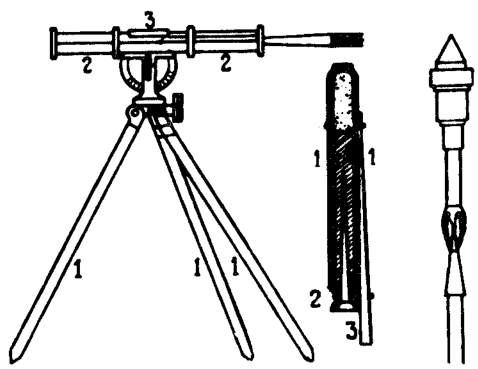
The "Death Rocket" designed by Ernest Welsh may also be considered as a combat weapon.

This rocket was invented in England in 1925 for shooting down airplanes attacking towns.

The lower part of the rocket includes a chamber in which repeated explosions occur; they give the rocket a translational motion. It is launched from a stand similar to that from which ordinary rockets are

launched. Ignition of a fuse causes the first charge to be exploded by the
18 detonator, so that the rocket is launched from the stand. Subsequent explosions occur at predetermined intervals, induced by a regulating mechanism, which propel the rocket further. The rocket can reach a height of 5 miles (8 km) and carries a warhead containing 700 bullets. Such rocket batteries firing into the air form a kind of curtain which cannot be penetrated by airplanes. The bullets themselves burn rapidly and create no danger to the town.

(17)



20. 21. 22.

FIGURES 20—22. Various types of rockets:

20 — launching stand for rockets; 21 — rescue (distress) rocket; 22 — revolving rocket.

A novel type of aircraft appeared in Italy in 1918. This was a winged bomb (torpedo), which according to one source only glided after being released by an airplane at an altitude of approximately 1,000 m, the range exceeding 15 km (Figure 23). The bomb weighed 10 kg; its length was 1.5 m, and its diameter, 0.25 m. Other sources state that the bomb was self-propelled in air, using a reaction engine. This is more probable, since signs of the explosive substance are visible in photographs of this "telebomb."

(19)

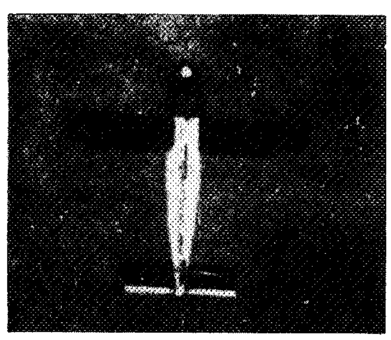
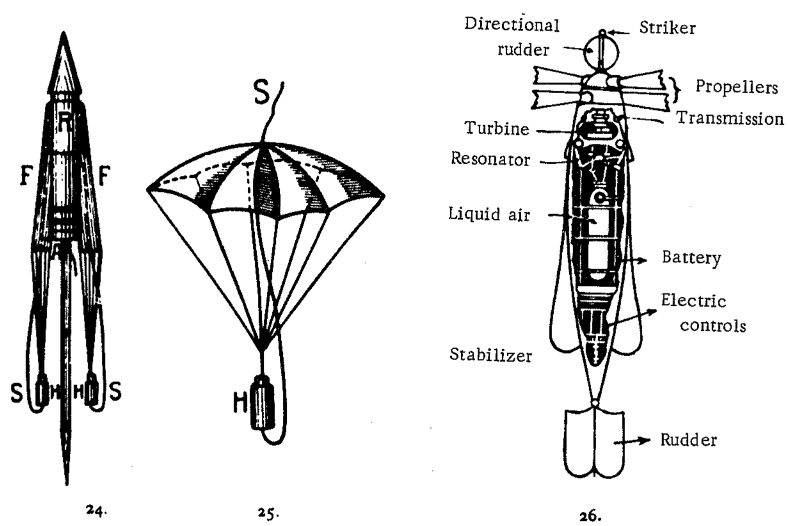


FIGURE 23. Italian winged rocket bomb

Boruch's Aerial Reaction Torpedo. Sidney Marton Boruch designed and successfully used aerial reaction torpedoes whose propellers were driven by compressed air. Such a torpedo is shown schematically in Figure 26.

Coastal or Rescue (Distress) Rockets. Rockets were first used for rescue from ships in 1807, when Captain Trengrouse of Helston, Cornwall, suggested throwing a line from shore to ship by means of a rocket. Denney in Newport carried out similar experiments in 1824, as did Steiler in Memel in 1828 (at a range of 300 feet). The range (with line) had increased to 1,300 feet in 1854. Rockets in use in 1867 had these dimensions: diameter, 8 cm; length, 55 cm; length of staff, 5'7.5"; gunpowder charge, 7.5 lbs; overall weight with staff, 38.5 lbs; weight without staff, 31 lbs; empty weight, 2.5 lbs; weight of head, 16 lbs (the head was made heavy in order to prevent it being diverted from its path by the wind). The range was 3,000 feet without line, and 1,440 feet with a line of 1" circumference, consisting of 27 strands; a range of 1,300 feet was achieved at a weight of 42 lbs.

(20)



FIGURES 24—26. Various types of rockets:

24, 25 — parachute rockets; 26 — Boruch's aerial torpedo.

Figure 27 is a section of the British rescue rocket. J is the case, W are the walls, C is the charge, B is the conical bore, f is the fork, b is the wooden bar. Figure 21 shows a simpler type of rescue rocket. It is made from a metal cartridge having a diameter of 7 to 8 cm and a length of 70 to 80 cm. No jacket is provided. A line is attached to the bottom of the rocket, which is launched from a special carriage. It is used to throw (a line) from the shore to a sinking vessel. The history of the development of rescue rockets was recorded by Feldhaus in his book "Ruhmesblätter der Technik" which appeared in 1941.

Rescue rockets designed by Konstantinov are also known. Their range was approximately 145 fathoms. Boxer rockets had a range of 230 fathoms;

Nechaev rockets, 200 fathoms, Spandau rockets, 295 fathoms. A thin line was attached to the rocket head.

The two-stage rocket (Figure 17) consists of two separate rockets, a large one (R) and a small one (R'). The latter is mounted on the former in such a way that it replaces its jacket. Heading (H) carries a layer of granular gunpowder (P) on which the small rocket is placed. Tail (T) is common to both rockets. It passes through the entire lower (large) rocket and ends at the nozzle of the upper one.

The anti-hail rocket serves to prevent the formation of hail. Müller and Emmishof carried out experiments in Germany, in which they fired
19 rockets to heights of 1,100 m. The rockets were 3 to 4 cm in diameter and had a length of 25 to 35 cm. Figure 28 is a section of such a rocket. C is the cap; k is the charge which explodes upward; F is the fuel; S is the conical recess; P is the primer; b are bands; c is the staff; s — s indicates the position of the center of gravity.

A twin or multiple rocket (Figure 18) consists of two or more simple rockets secured to a common tail.

Revolving rockets. Various inventors tried to provide rockets with devices causing them to rotate during flight in order to make them maintain the desired direction, i. e., ensure their directional stability. Figure 11 shows one of these devices consisting of curved fins secured to the lower part of the rocket. Figure 12 shows the (British) Hale device which consists of helical grooves on the outside of the rocket; the gas escaping from them causes the rocket to rotate. Lastly, Figure 19c shows the rocket torpedo invented by the Swedish colonel Unge, in which the rotation is induced by a separate turbine fixed to the lower part of the rocket. Unge began his work on this torpedo in 1900. The first trials were carried out in Stockholm in March 1904. In 1908 he carried out experiments by firing torpedoes from two Swedish airships. The patent for this torpedo was acquired from Unge by Messrs. Krupp in 1908.

The torpedo consists of 3 parts, namely 1) the upper part containing the warhead, 2) the central part filled with an explosive, i. e., the fuel which propels the torpedo, and 3) the lower part, i. e., the turbine.

(21)

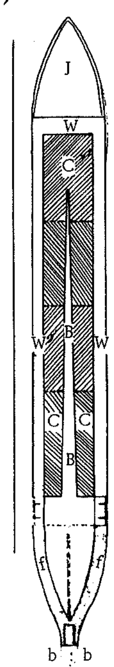


FIGURE 27. British rescue rocket

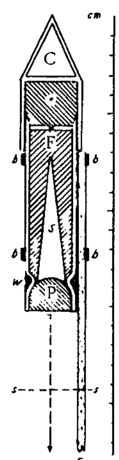


FIGURE 28. Müller's anti-hail rocket

The central part is filled with fuel charges sandwiched between disks of an insulating material, which also separate the fuel from the chamber bore. This is done in order to ensure uniform burning and prevent instantaneous explosion of the entire fuel. Channels inside the fuel charges facilitate propagation of the explosion and direct the gases downward.

20 The gases formed enter the turbine through holes in the casing of the small distribution chamber (a) and pass into helical ducts through which they escape downward, thus causing the torpedo to revolve.

The upper part of the torpedo can be removed and transported separately. The same is true for the turbine.

The torpedo is launched either from an aiming tube or from a gun. No charge is needed in the former case. The tube weighs only 64 kg. Lugs are provided inside the tube in order to prevent contact between the torpedo and the tube wall, which might interfere with its rotation.

The dimensions and weight of the torpedo and the aiming tube are as follows:

	Type		
	I	II	III
Diameter [of torpedo], cm	10	20	30
Length of torpedo, cm	90	155	245
Weight " " , kg	19	134	420
Weight of charge, kg	2	12	40
Diameter of tube, cm	25	37	50
Length " " , cm	250	460	700
Weight " " , kg	64*	235	710

The gun used was similar to an ordinary gun, but was considerably lighter. The charge needed was small, since it was only required to give
21 the torpedo a small velocity in a certain direction. About 100 torpedoes were built. At a weight of 50 kg the rocket flew at an altitude of 100 m and had a range of 5,000 m. The maximum speed in flight was 300 m/sec.

Experiments with rockets were carried out in vacuum by Prof. Birkeland in Norway between 1905 and 1907.

M. Pomortsev's rocket. M. Pomortsev published the results of his experiments on the range of rockets in 1912. He built a 3" rocket (A) (Figure 19d). Its base plug (D) had a central hole for the escape of the gases and carried a ring (B) made of 1 mm thick steel strip. The ring was secured to the base plug by radial struts (C) made of similar steel strip. Such rockets, weighing between 10 and 12 kg and launched at an inclination of 30 to 40° to the horizontal, had a range of 8 to 9 km. However, the range obtained was less than 1 km when ring (B) was moved much farther to the rear, so that part of the gases impinged on it, and the struts were lengthened.

D. Ryabushinskii in 1916 carried out a series of experiments on the flight of such rockets in his Aerodynamic Institute at Kuchino near Moscow. In 1910 he published the theory of these rockets in issue VI of the transactions of this institute (cf. Chapter V).

c) New rocket projects

Problems of interplanetary communication and the use of rocket engines for them caused many scientists to concern themselves with designs of new types of rockets, capable either of rising to great altitudes and returning to earth while automatically recording measurements in the upper layers of the atmosphere, or even of lifting passengers beyond the terrestrial atmosphere into space. Such projects were undertaken by Tsiolkovskii, Esnault-Pelterie, Goddard, Ganswindt, Valier, Oberth, Hohmann, and others.

* According to another source the type I [torpedo] weighed 35 kg with a 4 kg charge. The initial velocity was 50 m/sec, the speed in flight being 300 m/sec.

The work of most of these scientists will be considered in separate books so that we shall now only briefly discuss some of these projects.

Figure 29a shows a section of an ordinary fireworks rocket whose case is filled with gunpowder and to whose side a staff is fixed in order to ensure its stability in flight. The rocket is of cylindrical shape; the gases escape through a cylindrical hole. The altitude attained by such a rocket is small, due to its poor aerodynamic shape.

(22)

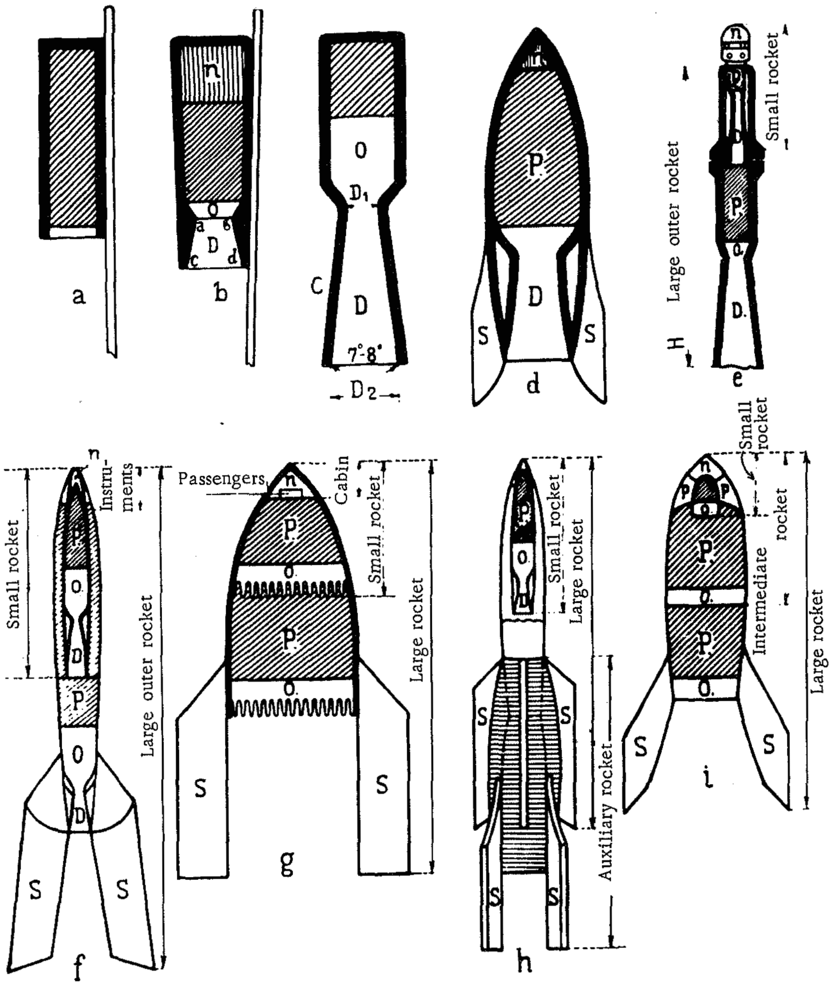


FIGURE 29. Various types of rockets:

a — ordinary fireworks rocket; b — ditto, of improved design; c — ditto; d — rocket with stabilizers; e — Goddard two-stage rocket; f—i — Oberth rockets.

Figure 29b shows a section of a slightly improved rocket. It contains,

22 besides the case, the fuel, and the stabilizer (staff), 1) the payload (n), i. e., a substance which explodes at a certain altitude, thus emitting a light (Bengal lights, Roman candles, etc.), and 2) a special end piece consisting of combustion chamber (O) and nozzle (D) with throat ab and exit section cd.

Nozzles are special bell mouths whose task is to convert the potential energy of the expanding gases into kinetic energy by reducing the turbulence of the particles. Furthermore, the rocket becomes narrower toward the nozzle; this reduces the drag.

23 Various means are employed in order to reduce the drag. The latter consists of 1) the resistance due to friction between the air and the rocket walls [skin-friction drag], 2) the drag of the frontal part, and 3) the drag of the rear part. All three drag components are observed when a body moves at subsonic speed. At supersonic speeds, however, the drag of the rear part decreases considerably or vanishes completely, so that the stern may have a blunt shape. In the former case the rocket should be smoothly streamlined and its surface polished.

Figure 29c shows a further rocket development. Nozzle (D) has been perfected, its angle of divergence being 7 to 8°.

Figure 29d shows a smoothly streamlined rocket with nozzle (D), fuel (P), payload (n), and stabilizers (S). These fins ensure stability during flight in the atmosphere.

The gradual reduction of the rocket weight during the flight is of great importance. Its mass is reduced, so that its velocity is increased. It has therefore been suggested in some projects that the rockets consist of 2 or 3 parts to be successively discarded when their fuel has burnt out. Such proposals were made by Goddard in the USA and by Oberth in Germany.

24 Figure 29e is a schematic section of a Goddard two-stage rocket. Each rocket consists of a chrome-nickel case containing fuel (P), combustion chamber (o), and nozzle (D), and a head which is caused by the explosions to revolve rapidly; it thus acts as gyroscope and ensures directional

(23)

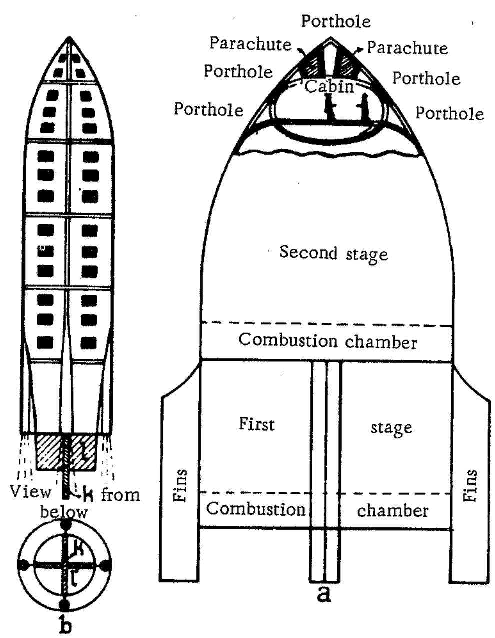


FIGURE 30. Oberth rockets:

a — two-stage passenger rocket; b — rocket with 4 nozzles.

stability of the rocket during flight. Payload (n) is carried on top of the small rocket; it consists of instruments and a parachute.

Figures 29 f–i, 30–32 show various rockets designed by Oberth. The fuel used in them is alcohol and liquid hydrogen, (the oxidizer being) liquid oxygen.

Figure 29f is a longitudinal section of a two-stage rocket. The small rocket (the second stage) is located inside the large one (the first stage) and carries payload (n) consisting of instruments and a parachute. The small rocket has nozzle (D), combustion chamber (O), and fuel (P). It also has folded fins around the nozzle. After burnout of the large rocket its tip opens and the small rocket leaves it under its own power.

Figure 29g shows a two-stage passenger-carrying rocket designed by Oberth (for one passenger n). Figure 29h is an overall view of the rocket shown in Figure 29g, to which a third, auxiliary rocket has been added, which separates first.

Figure 29i shows a three-stage rocket carrying payload (n). Figure 30a shows an Oberth two-stage rocket for 2 passengers. Lastly, Figure 30b is an overall view of an interplanetary spaceship with 4 nozzles at the stern and 2 rudders (k and l) for guiding it in the atmosphere.

(25)

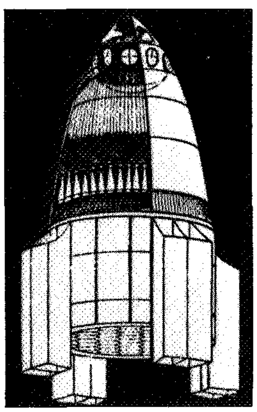


FIGURE 31. Oberth rocket

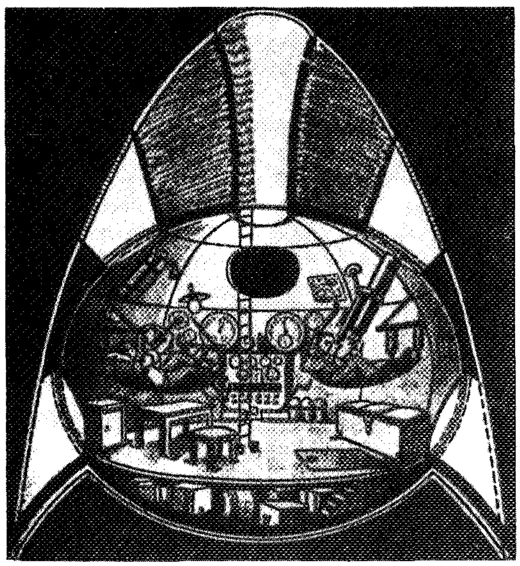


FIGURE 32. Cabin of Oberth rocket

Figure 31 is an overall view of a two-stage passenger-carrying rocket designed by Oberth (corresponding to Figure 30a). Figure 32 shows its cabin equipped for 2 passengers. The overall height of the rocket exceeds that of a four-storied house.

Figure 33 shows a future rocket with a single central nozzle. Figure 34 shows a rocket with 4 lateral nozzles, corresponding to Figure 30b.

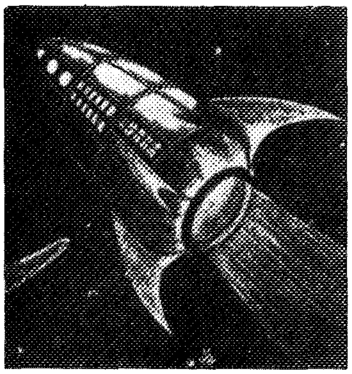
(25) 

FIGURE 33. Passenger - carrying rocket with single nozzle

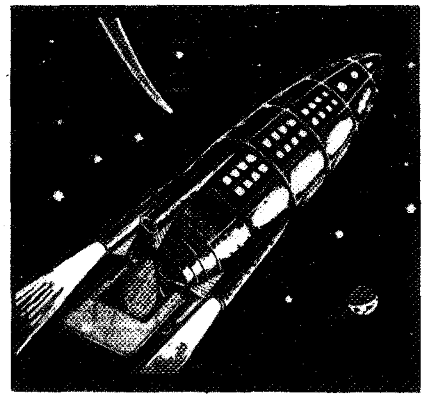
(26) 

FIGURE 34. Passenger-carrying rocket with 4 nozzles

Figure 35 shows schematically a very simple recording rocket designed by Oberth. Its case is made of copper sheet. Liquid oxygen (S) is carried on top with fuel (B) (gasoline, benzene, alcohol, or petroleum) below; liquid hydrogen may also be used. The oxygen flows into pipe (A), and is mixed with the fuel vapors and ignited at (G), the temperature attaining 700—900°C. The liquid fuel is injected through a large number of holes into space (Z) (Figure 35, center) and is ignited in combustion chamber (O), (the combustion products) escaping via throat Fm and nozzle exit Fd. Both the oxygen and the fuel are pressurized, the former at 20 atm and the latter at 50 atm. The walls of the tanks must therefore be strong and thus heavy. Such rockets can hardly rise higher than 50 km.

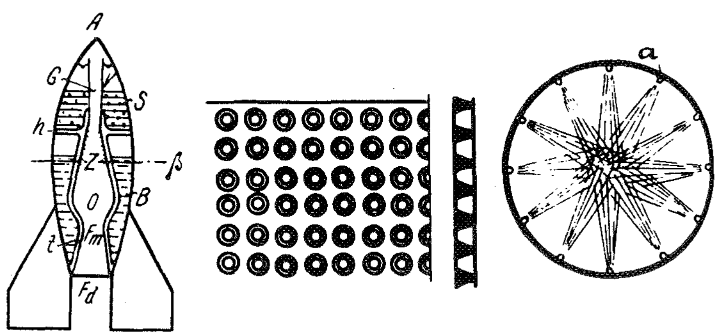
(26) 

FIGURE 35. Design of Oberth rocket

Figure 36 shows schematically an unmanned wingless rocket designed by Goddard: a is the fuel; b is the carburetor; c is the combustion-chamber
25 inlet; d are the stabilizers; f are the altitude rudders for flight in the atmosphere; e are the rudders for flight outside the atmosphere (which are acted upon by the outflowing gases).

(27)

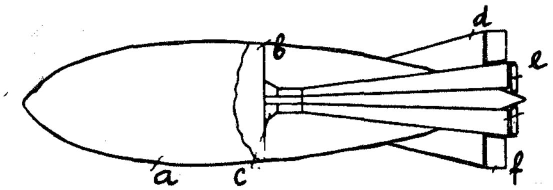


FIGURE 36. Goddard rocket

26 Figure 37 shows, half in side view and half in longitudinal section, a passenger-carrying rocket designed by Oberth and Valier with stabilizers, rudders, fuel, and mechanisms. Figure 38 is a schematic section of a rocket designed by K. Tsiolkovskii.* The various compartments from right to left are the cabins for the pilot and the passengers; behind them is a movable weight used for changing the direction in flight; this is followed by the fuel (hydrogen) and oxygen, the combustion chamber, the pumps, the reaction nozzle, and the rudder. Periscopes are seen at the sides.

27

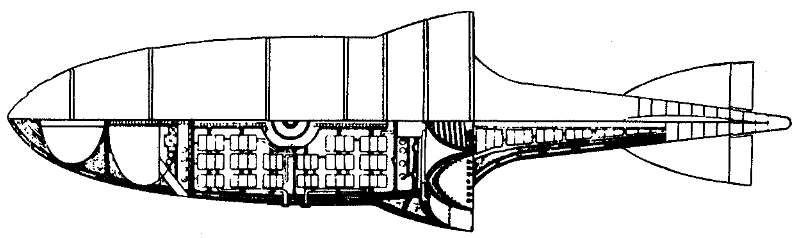


FIGURE 37. Passenger-carrying Oberth and Valier rocket

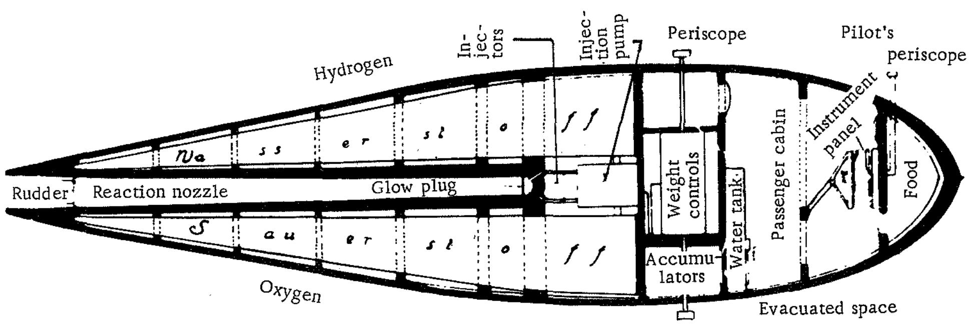


FIGURE 38. Tsiolkovskii rocket

Lademann's radio rocket. In 1928 Lademann in Germany published a project for a radio rocket which was to be launched to a height of 200 km. The aim was to determine whether the Heaviside layer, if it existed, was capable of transmitting radio waves. The rocket was to be launched

* Details on Tsiolkovskii's work will be given in a separate book.

from a mortar at an acceleration of approximately 5 g, a speed not dangerous for the recording instruments carried by it (Figure 39). At a height of about 20 m the reaction engine of the rocket was to be started (Figure 40); this was to lift the rocket to a height of 200 km. The exit velocity was to be up to 5,000 m/sec. The ratio of the fuel weight to the payload was approximately 0.8. The length of the rocket was between 5 and 10 m. The propellant was to consist of liquid hydrocarbons and (the oxidizer) nitric oxide.

(28)

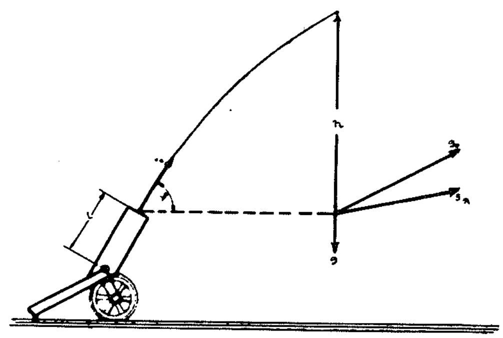


FIGURE 39. Launching of Lademann rocket

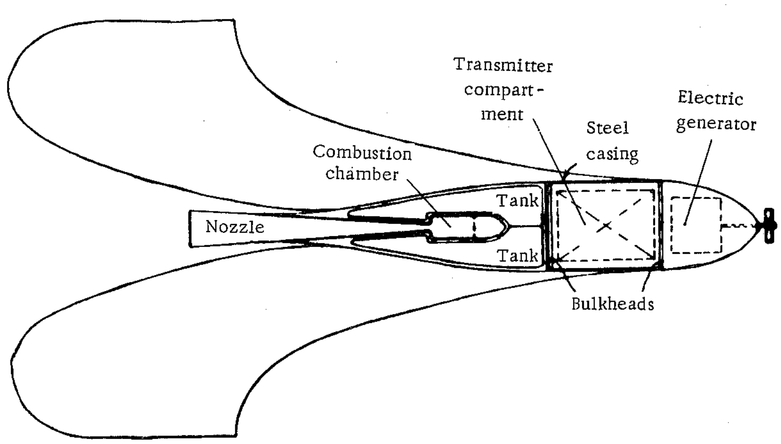


FIGURE 40. Winged Lademann radio rocket

The rocket (Figure 40) consists of the following parts (from right to left): a propeller rotated by virtue of the resistance of the air, an electric generator, and a radio transmitter in a closed compartment;
28 the rear section contained fuel tanks, pumps, combustion chamber, and nozzle. Stabilizers were fitted to the sides of the stern. The bow section served as antenna, while the central insulated section served as grounding. Both sections were waterproofed in order to prevent the rocket from sinking should it fall into water after its return to earth. In this case the design deceleration did not exceed 5 g.

d) **Use of rockets for photography**

Even before World War I (in 1900) Engineer Maule of the German Army tried to use rockets for taking photographs. The rocket with the photographic camera was placed on a stand (Figures 41 and 42), and the propellant ignited. The rocket was thus launched, trailing the photographic camera behind it. A parachute separated from the rocket at a predetermined instant and opened out, thus enabling the rocket and the photographic camera to descend gradually. The picture was taken at this instant. The length of the type 1 rocket was 1 m, its diameter was 8 — 10 cm, and the length of the staff, 4 — 5 m. Fins were fitted to the staff end. The lower part of the rocket contained the parachute which was released with the camera after the picture had been taken. The upper part of the rocket case contained a gyroscope serving to guide the camera to a predetermined area. The ceiling was 200 – 300 m. The type 2 rocket had a diameter of 21 cm, a 4 m long staff, weighed 6 kg, and had a ceiling of 600 m. The type 3 rocket had a diameter of 36 cm, a 4.6 m long staff, weighed 25 kg, and had a ceiling of 500 m. The type 4 rocket (1912) weighed 42 kg. It had a 6 m long staff and a ceiling of 800 m.

(29)

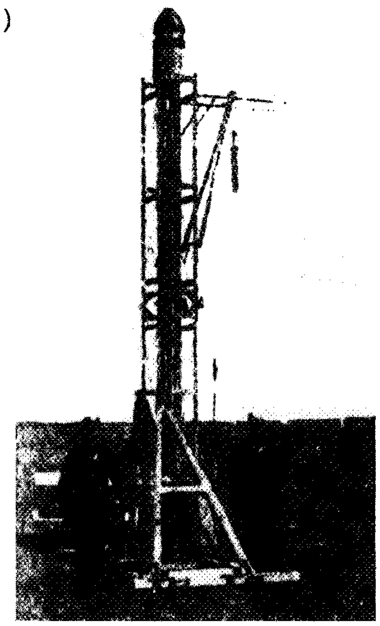


FIGURE 41. Maule photographic rocket

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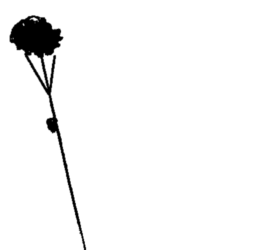

FIGURE 42. Maule photographic rocket

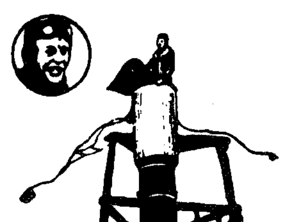

FIGURE 43. Low rocket

Furthermore, according to some sources, Forrest in the USA designed a device for photographing the earth from a height of 8—10 km. This device was a slowly rising rocket equipped with several photographic cameras. The objectives of the cameras were opened automatically at the instant when the rocket had attained its highest point, and its nose had
29 begun to point earthward. The objectives were shut automatically after a predetermined time interval. The rocket was provided with a parachute which was to act during the descent, slowing down the fall and thus preventing the rocket from being ignited by the heat generated as a result of friction with the air.*

In addition to the unsucccessful attempt at human flight by the Chinese mandarin, a notice appeared in a New York journal in 1913, stating that a Mr. Low had ascended to a certain altitude by means of a rocket from which he had then detached himself and smoothly descended by parachute, at the same time taking a film with a cinecamera. Figure 43 shows him before the launching. This flight apparently took place only in the imagination of the reporter.

* Cf. also Rohrmann's project below with regard to the photographic rocket.

Chapter III

THE HISTORY OF THE DEVELOPMENT OF DIRECT-REACTION ENGINES

a) First attempts

Hero of Alexandria was apparently the first to apply the principle of direct reaction to motion of a body. In 120 B. C. he built a small steam engine which employed the reaction principle (Figure 44). Fire caused water in kettle (A) to boil. The steam via pipe (abc) entered spherical vessel (B), which could rotate on the ends of supports c and d. The steam escaped from vessel (B) via bent tubes (e, e); the reaction force caused the vessel to rotate.

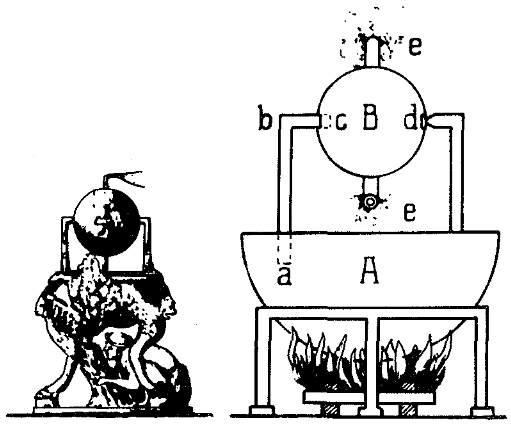

FIGURE 44. Hero's steam engine

In 1405 in Frankfurt-on-Main a kite balloon was apparently raised by means of a rocket employing Konrad Keyser von Eichstadt's system.

In 1420 Giovanni di Fontana proposed a reaction car (Figure 45).

The following example of the application of the reaction principle to motion is found in the works of the French writer Cyrano de Bergerac. In his "Voyage dans la lune" (1649) he describes how one could supposedly fly to the moon with the aid of a rocket.*

In Cyrano de Bergerac's time (around 1670) there lived in France a learned Jesuit called Fabri, who worked on the design of a huge flying machine propelled by compressed air contained in a pipe.

* See our book "Interplanetary Flight and Communication. Dreams, Legends and Early Fantasies."

In 1686 Newton established his so-called Third Law of Mechanics, which states that "to every action there is an equal and opposite reaction." Newton himself apparently proposed a reaction-propelled steam car
31 which is shown schematically in Figure 46. The boiler with the water was placed on wheels; the firebox was at the bottom. The steam escaped through a hole at the back and caused a reaction which was to propel the vehicle.

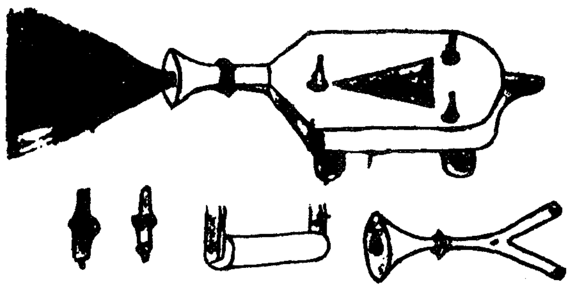

FIGURE 45. Giovanni de Fontana's reaction car

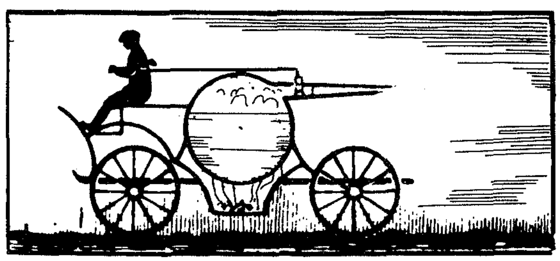

FIGURE 46. Newton's reaction-propelled steam car

In 1720 Gravesande studied the problem of propelling a vehicle by the reaction force of escaping steam, in accordance with Newton's law.

In 1730 Bernoulli, in his work on hydrodynamics, explained the effects of the reaction force of a jet issuing from a vessel. Applying the work of Newton and Bernoulli, Segner in 1750 used this principle to build a reaction wheel operated by water. The water flows from vessel (V), open on top to provide access for air, through two bent pipes (P); the reaction force causes the entire vessel to rotate about its vertical axis (Figure 47).

The Montgolfier Brothers also were interested in the principle of reaction flight and mentioned it in their memorandum presented to the Lyon Academy of Sciences. However, they encountered difficulties in this field and had to use a balloon filled with hot air (1783). Nevertheless,

(32)

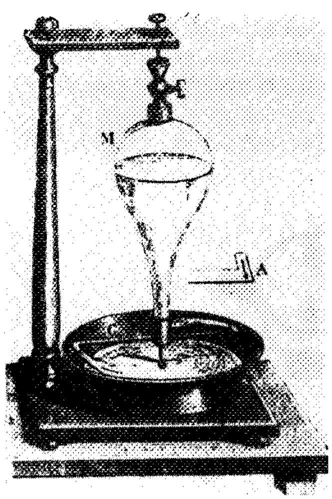

FIGURE 47. Segner wheel

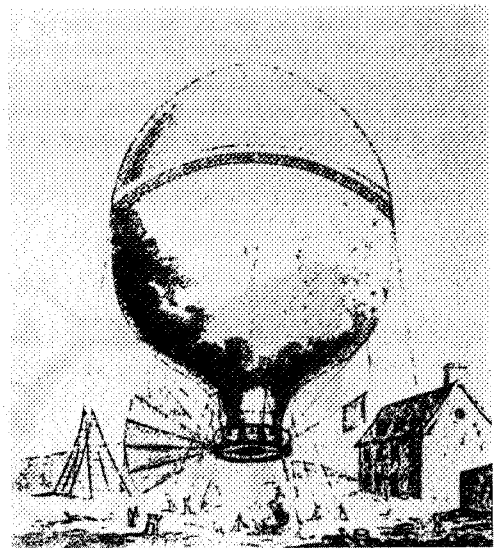

FIGURE 48. Mioland and Janiner's reaction balloon

in 1783 two Parisian inventors (the abbé Mioland and Janiner) planned to
32 use reaction force for guiding an air balloon. They hoped that a hole in the side of a Montgolfier balloon would cause the escaping hot air to propel the balloon in the opposite direction. They built a huge Montgolfier balloon to test this idea, but even the trial apparently did not take place; the strong draft induced by the hole in the side caused the balloon to catch fire while being filled, and it was burnt (Figure 48).

Gerard in 1784, in his book "Outline of Artificial Flight in Air", proposed the construction of an ornithopter with huge wings, propelled by a rocket. It was to have the shape of a ship with a vertical bow rudder and a horizontal rudder at the stern (Figure 49).

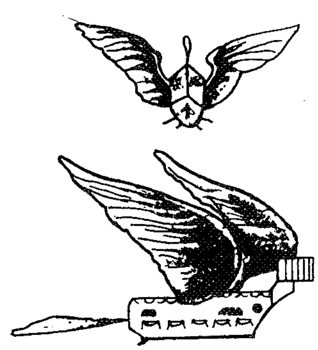

FIGURE 49. Gerard's rocket helicopter

In 1784 the American James Ramsay built a vessel propelled by the reaction force of a water jet issuing from a pipe.

33 In 1806 Claude Ruggieri in Marseilles managed to lift a living ram to a height of 200 m by means of a rocket and to bring it back to earth with the aid of a parachute.

In 1828 there appeared in Britain a cartoon on reaction flight by means of steam (Figure 50). Max Valier ascribes it to the year 1841 (patent granted to the Briton Charles Golightly). Wings can be seen on the sides of the boiler. The book

(32)

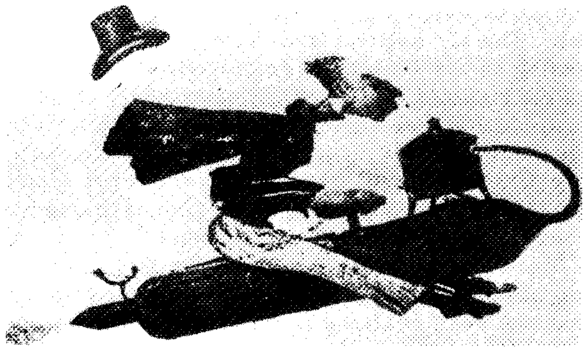

FIGURE 50. British cartoon on reaction flight

"Scoperta della direzione del globo aerastatico" was published in Venice by Molinari in 1831. The anonymous author describes in it the use of rockets suspended from a balloon. In his opinion their reaction might be sufficient to reach the moon. The direction of motion of this balloon could be changed by turning the rockets (Figure 51).

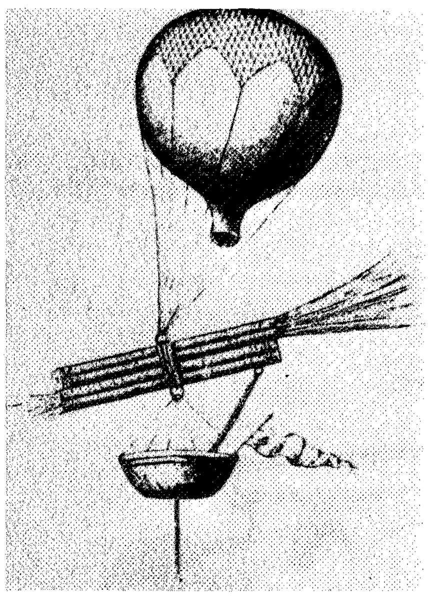

FIGURE 51. Italian reaction air balloon

In 1839 Rebenstein, a Nuremberg mechanic, proposed propelling an airplane of his own invention by jets of steam or compressed carbon dioxide. A drawing of this airplane appeared in 1837 (Figure 52).

In 1843 a Russian newspaper stated that a certain Emil Zhir had invented a method of guiding an air balloon in any desired direction by means of compressed air; the balloon could be raised or lowered with the aid of compressed gas contained in a tank beneath the gondola, from which it was extracted by means of a pump.

Around 1844 the French engineer Selligue suggested propelling a vessel by means of continuous explosions of
34 hydrogen and gaseous carbide. These explosions were to take place in metal pipes at the rear of the vessel. The expanding gas would give impact to the vessel; continuous expansion would rapidly propel the vessel forward.

In 1849 military engineer Tretesskii presented his book of 208 pages, called "O sposobakh upravlyat aerostatami" (On Methods of Guiding Air Balloons) to the Governor of the Caucasus, Prince Vorontsev, in Tiflis [Tbilisi]. In this book Tretesskii proposed, on the basis of computations, that the reaction force caused by water, vapors of alcohol, gas, or compressed air be employed. The air balloon was called steam plane, gas plane, or air plane, according to the substance employed.

Experiments carried out by Colonel Konstantinov in the fifties of the 19th century at the St. Petersburg Rocket Establishment showed that "man is incomparably more suitable than rockets for moving large masses for considerable time intervals over large distances, since rockets must also carry the forces propelling them; hence, human force is more suitable than rockets for propelling air balloons." Konstantinov wrote further: "The idea of putting floating fireships into motion by means of rockets has long since passed from a military-laboratory artifice into use in fireworks, and has been realized in certain firework pieces, namely ducks propelled on the water surface by rockets."

(33)

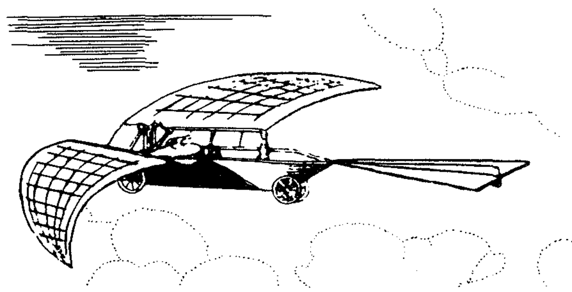

FIGURE 52. Rebenstein's jet plane

A drawing of a flying machine of the rocket type appeared in 1860. This machine was propelled by a jet of highly compressed gas (Figure 53).

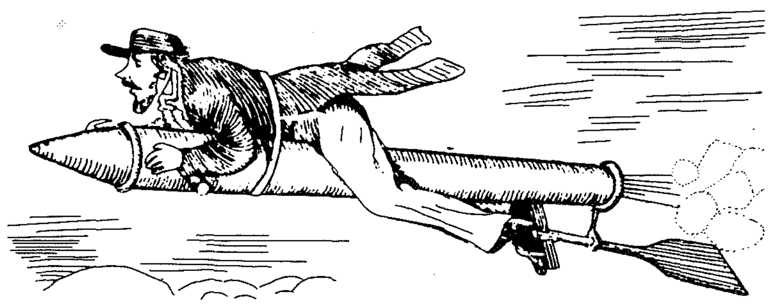

FIGURE 53. Rocket flight

35 A drawing showing a helicopter with special airscrews rotated by the reaction force of jets of compressed gas appeared in 1860 (Figure 54).

The novel "Achill Eyrand" was published in 1865. A rocket designed for flight from the earth into space is described in this book.

(34)

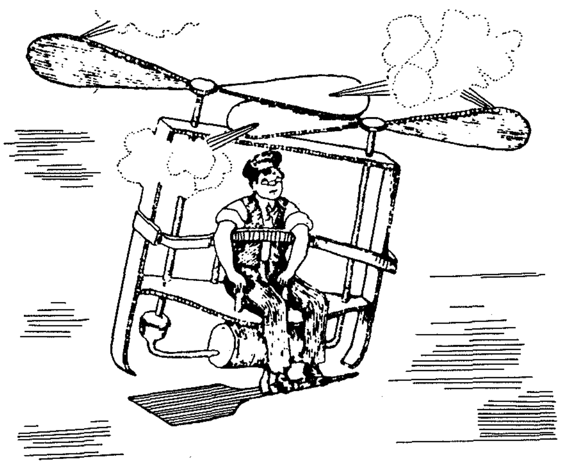

FIGURE 54. Reaction helicopter

b) **N. Sokovnin's reaction-propelled airship**

A small book called "Vozdushnyi Korabl'" (The Airship), written by N. Sokovnin, was published in 1866 in St. Petersburg. The author suggested in this book that a reaction engine be used in an airship.

The design of the airship and engine in this project were as follows (Figure 55):

36 The machine was to be a dirigible. It was kept aloft by ammonia contained in 12 balloons. The latter were located in spoon-shaped body (I) subdivided by one longitudinal and 5 transverse partitions into 12 chambers open at the bottom. The ammonia balloons were held in place by a series of cross beams below them between partitions (1-1,2-2,3-3,4-4,5-5). Two ammonia balloons (6) are shown in the cross section and in the view from below, between the second and the third partition. Platform (II) was suspended from the body by means of vertical bars. The platform carried the crew and the engine. Altitude and directional rudders were arranged ahead and behind the platform. The body and the platform were made of a special cardboard, bamboo, and steel tubes. The volume of the ammonia balloons was 2,535 m^3 when they filled only half the space between the partitions. The weight of the airship was 2,623 kg. Since the specific weight of ammonia is half that of air, the airship could only lift a weight of approximately 1,367 kg from the earth. The airship had therefore to start from the earth with full sections. Later, when a high speed had been attained and the airship was pointing with the nose upward, dynamic lift could be obtained from the air acting on the bottom of the platform. Part of the ammonia could then be compressed by the engine and forced into the balloons.

The airship was propelled by thé reaction force of air ejected through pipes (8). Engine (7) compressed atmospheric air and forced it into pipes (8). A bank of ready compressed air could also be carried.

The author referred to the successful operation of a similar water motor described by Fedorov in No. 9 of Marine Collections (1863). This

40 hp motor was built in Antwerp in 1862 and propelled a steamship quite rapidly through the water. Sokovnin assumed that a power of 2—3 hp would be sufficient for his airship.

(35)

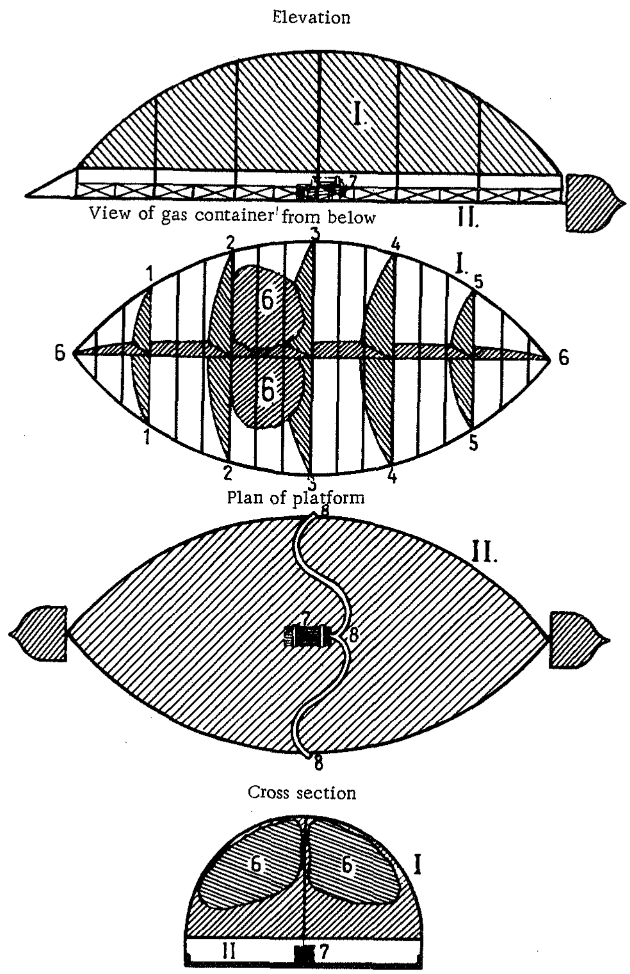

FIGURE 55. Sokovnin's reaction-propelled airship

Sokovnin suggested changing the volume of the ammonia in the balloons, as stated above, by putting the gas into contact with water which would absorb it, or again liberating the gas from the ammonia-saturated water by heating the latter.

Lastly, he envisaged the construction of hangars for airships, wind indicators, beacons, and similar structures, which are now widely used.

Conclusion. We shall not discuss this airship design, which is neither practicable nor useful, but note that the idea of employing reaction for its propulsion merits our attention. Sokovnin's project is accompanied by a computation of its engine, performed by the astronomer K. Kh. Knorre. The calculation is as follows:

Given: Airship speed = 19 m/sec.
Midsection area = 2,223 sq. ft.
Diameter of pipes (8) = 1 ft.
Sum of cross-section areas of both pipes =
= 1.5708 sq. ft.
Discharge velocity of air from pipes = v.

The fundamental equation for determining v is found by equating the resistance of the air to the motion of the airship to the resistance of the air discharged from the pipes, i. e.: $2{,}223 \cdot 19^2 = 1.5708 \cdot v^2$, whence
37 $v = 714.9$ m/sec. This value must be increased by 19 m/sec since the pipes move at the same speed [as the airship]. It is, however, impossible to achieve such a velocity.

To this the author replied that at first a speed of 9 m/sec might be sufficient, at which flight would be possible.

c) Later projects

Butler and Edwards were in 1867 granted a British patent for a jet plane whose shape resembled that of an arrow. A steam engine was to be the means of propulsion. The steam was to be discharged to the rear, propelling the machine both by the reaction of the engine itself and by the thrust of the jet against the air.

A rocket flying machine was proposed in 1870 by General Ivanin. The engine was to use gunpowder gases.

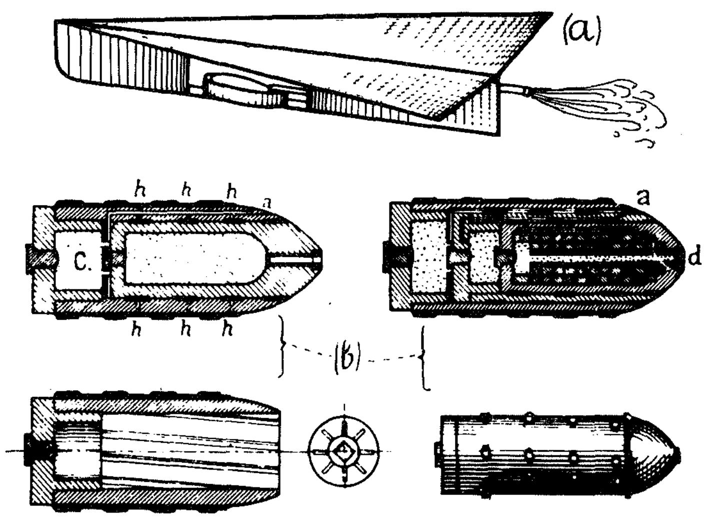

FIGURE 56:

a — Butler and Edwards' arrow; b — Gützler's rocket missile.

GÜTZLER'S COMPOUND ROCKET MISSILE

In 1878 German patent No. 2917 was granted to Gützler for his compound rocket missile (Figure 56b). The principle on which this rocket was based was as follows. A rifled missile is fired from a gun. An explosion occurs inside the missile when it reaches a certain point on its trajectory; the rear of the missile then separates, while the front part is ejected from the casing of the rear part and continues to fly toward its target where it explodes. For greater stability during flight this front part carries lugs so that it begins to rotate as soon as it leaves the casing. The inventor also produced a drawing of this missile, which consisted of three parts.

38 REACTION ENGINE OF A. VAN DE KERCHOVE AND T. SNYERRS JR.

August K. van de Kerchove and Theodore Snyerrs Jr. in Brussels were granted in 1881 a patent for a reaction engine operating on detonating gas and intended for propulsion on land, sea, and air (Figures 57—59). The engine consists of four main parts (Figure 57a).

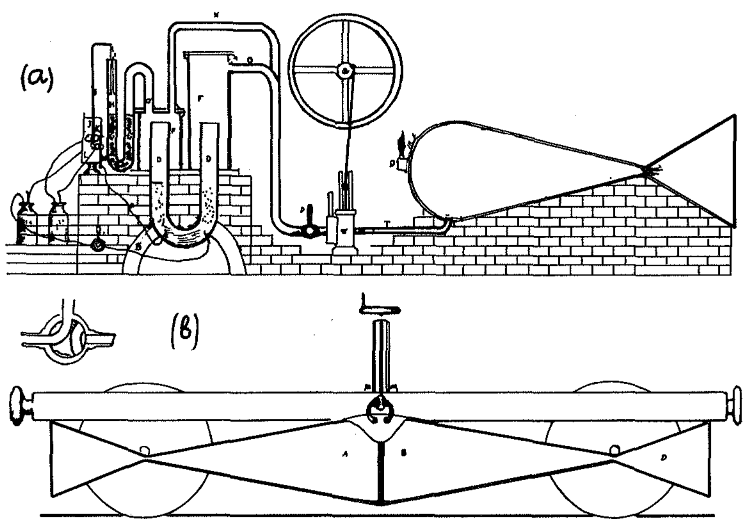

FIGURE 57. Reaction engine of van de Kerchove and Snyerrs

1. The gas generator. Water in bent pipe (D, D') is dissociated into oxygen (D) and hydrogen (D') by means of electric current supplied to poles (C, C') from batteries (A, A').

2. The gas-production regulator. The pressure of the gas introduced causes the level of the liquid in pipe (G, G') to fluctuate. This raises or lowers float (H) which entrains contact (K) and thus switches one of the batteries on or off; this increases or reduces the production of gas.

3. Mixture (detonating gas) supply regulator. This device is similar to the slide valve of a steam engine and consists of a flywheel and a cylinder with slide valve (W).

4. Explosion chamber with nozzle. The detonating gas enters into chamber (R), where it explodes, and escapes through hole (x) to nozzle (S). This creates a recoil which propels the machine. Figure 57b shows the arrangement of 2 explosion chambers (A) and (B), with 2 nozzles (C) and (D) for forward and backward motion, located beneath the platform of a wagon. The remainder of the mechanism is located on the platform.

39 Figure 58a shows a double-ended vessel propelled through water according to the same principle. (A) and (B) are the combustion chambers, and (x, x) the nozzles through which the gas escapes. Slides (D) have to be opened after the explosion in order to destroy the vacuum in the chamber.

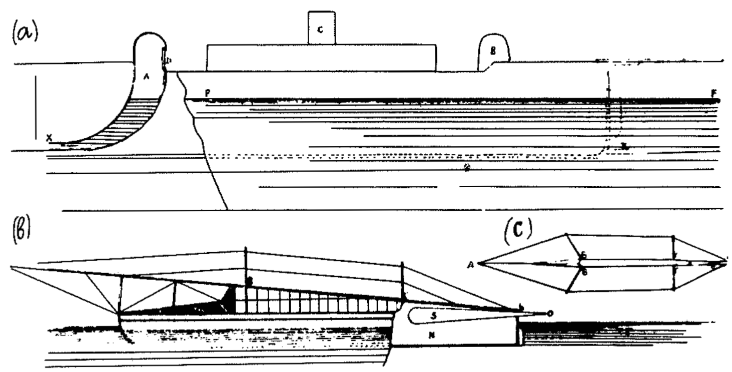

FIGURE 58. Reaction engine of van de Kerchove and Snyerrs

Figures 58b,c and 59b illustrate applications of this engine to a hydroplane (the combustion chamber is denoted by S).

Lastly, Figure 59a illustrates the application of this principle to a stationary engine. The explosion chambers are denoted by S, S', S''; P, P', P'' are the nozzles; the shaft is denoted by O; the hole through which the gas enters, by I; the igniter by C; and the openings of the gas ducts by L, L', L''.

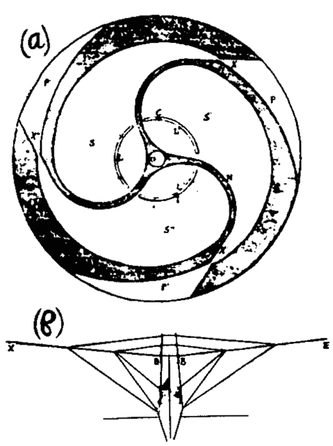

FIGURE 59. Reaction engine of van de Kerchove and Snyerrs

d) N. I. Kibal'chich's aeronautical machine

Nikolai Ivanovich Kibal'chich was a former student of the St. Petersburg Institute of Communication Engineers and a member of the Russian Social-Revolutionary Party. Between 23 March 1881 and his execution, to which he was condemned for his part in the assassination of Czar Alexander II, he presented to the prison authorities a design of an aeronautical machine and requested that it be given to experts for their evaluation. This project included a reaction engine. Kibal'chich was executed, and his project remained amongst the papers of the legal investigator without any action being taken on it.

40 On 23 March 1918, the author of this book received from the editors of the journal "Byloe" a typed copy of the original of Kibal'chich's work with the suggestion that he should review it. This review, together with Kibal'chich's work and an introduction written by P. Shchegolev, was printed in the "Byloe" (1918, Nos. 10 and 11, p. 112).

The introduction written by Shchegolev and Kibal'chich's work are given below in the form in which they were originally printed. Kibal'chich's work merits attention not only because it deals with the use of reaction engines for flight, but also because it proves the deep attachment of its author to new ways of investigating technical problems, an attachment which could not be suppressed by the harsh sentence already announced to him, an attachment which can overcome the fear of death and render people almost insensitive to earthly suffering...

THE LIFE OF N. I. KIBAL'CHICH

Nikolai Ivanovich Kibal'chich (Figure 60) was the son of a village priest. He was born in the Krolevets District of Chernigov Province in 1854. He received his primary education in the Novgorod-Severskii Theological Seminary, then entered high school, and upon graduation on 19 September 1871 he enrolled in the
(41) first course of the St. Petersburg Institute of Communication Engineers. At his request he was discharged from the third course of the Institute on 25 August 1873, enrolling the same year as a student in the Medico-Surgical Academy. During the whole time there he was active in student circles concerned with self-education. He took an interest in political and economic problems, on which subjects he even gave lectures. However, he kept out of politics, and became involved in them only through special circumstances about which much was said during the trial. Kibal'chich had spent the 1875 summer vacation with his brother in the Lipovets District of Kiev Province, where he gave a peasant the fairy tale "O Chetyrekh Brat'yakh" (The Four Brothers) to read. This booklet passed from hand to hand and finally reached the authorities who were angered by this educational activity. When he returned to St. Petersburg, they searched his apartment where two days earlier a girl friend had temporarily left two packages with illegal literature. Kibal'chich was arrested on 11 October 1875, spent 2 years and 8 months in various prisons, and on 1 May 1878 was condemned to one month's imprisonment. Kibal'chich referred to the effects of his arrest on him in the following

FIGURE 60. N.I. Kibal'chich

words: "In 1874 and 1875, when the predominant mood in the party was to go to the people, mingle with the masses, and reject the environment in which we had been educated, I also sympathized with and shared these opinions. It is true that I would have carried out my duty if my arrest had not interfered... If the authorities had not taken strict measures against (party) workers approaching the masses, I would have gone to the people and would still be there. The aims which I had set for myself were partly cultural and partly socialist. None of us was accused of murdering the Czar (Alexander II), but of mingling with the urban and peasant population. I would certainly have used the inventiveness, which I showed with regard to the missile, in order to investigate the domestic industry, improve methods of working the land, perfect agricultural machinery, etc."

Prison and terrorization by the government turned Nikolai Ivanovich into a revolutionary. Anticipating that the fight between the government and the party would become stronger and that the latter would be forced to employ resolute means, he seriously began to study literature on explosives
41 in Russian, German, French, and English, so that he came to know the properties of nitroglycerine perfectly. In 1879, through Kvyatkovskii, he offered his services to the Executive Committee for the preparation of destructive missiles. He took part as technician in the preparation of the explosion in Odessa. He then went to Odessa to prepare mines and afterwards took a Rühmkorff coil needed for the blowing up of Zhelyabov in Alexandrovsk. In the middle of December he returned to St. Petersburg where he participated in the preparation of mines for blowing up the Winter Palace and undermining the Sadovaya, and bombs for the operation on 1 March 1881. Nikolai Ivanovich, being one of the best educated members of the party, attended to his duties with the seriousness of a student of surgery and did not get involved with the details of the assassination. Arrested on March 17th after the murder of Alexander II, he began in prison, first on the walls and then on paper brought to him, to draw the design of an aeronautical machine, which he mentioned in his last words. He was executed on 3 April 1881. He was completely complacent during his execution, on the eve of which he had calmly slept in his cell.

P. SHCHEGOLEV'S INTRODUCTION TO N. I. KIBAL'CHICH'S PROJECT

N. I. Kibal'chich's lawyer V. N. Gerard, in his plea at a special session of the Senate, characterized the accused by declaring: "When I presented myself before Kibal'chich as his lawyer, the first impression I gained was that he was engaged in a matter which had nothing to do with this trial. He was occupied with research on some aeronautical missile; he requested that he be given the opportunity to record his mathematical investigations of this invention. He wrote them down and presented them to the authorities."

Kibal'chich himself ended his final speech by stating with regard to his invention: "On a certain matter, to which my lawyer has already made reference, I should like to issue the following statement. I have recorded a design of an aeronautical machine. I consider it a very practicable scheme and have submitted detailed explanations of it together with drawings and computations. Since I shall probably not be able to obtain the opinions of experts on this project, and in general shall not be able to follow its fate, and since it is possible that someone might use it, I therefore hereby declare publicly that this is my project, and its outline prepared by me is in the hands of Mr. Gerard."

Much has been said and written in non-Russian journals on Kibal'chich's
project, but it remained unpublished. The author of a memoir on Kibal'chich
which appeared in 1882, wrote: "As regards his project of an aeronautical
machine, if I am not mistaken, it consists in the following: all engines in use
now (steam, electrical, etc.) are not powerful enough to propel air balloons;
it appears that Kibal'chich's idea was to replace existing engines by some
42 explosive introduced beneath a piston. This idea, in itself, is not new, as
far as I know, but includes such important details as which substance to
use, under what conditions, etc. It would have been quite unfortunate had
the inquisitorial zeal of the authorities compelled them to fight even their
dead enemy and bury with him this possibly very important invention.
It is quite probable, however, that it will simply be stolen — there is no
protesting from the other world!

Those who knew Kibal'chich cannot be surprised about his philosophical, tranquil death. He was not a violent person, he was incapable of raising a hand against a fellow human being, nor could he be complacent when he had to fight. With his capacity for giving all his heart to worthwhile ideas, he could at the end face death with tranquility, more serene than most other people. The day before his death, as is known, he was only worried about the fate of his design of an aeronautical machine, just as Archimedes was worried about the fate of his circles." *

The fate of Kibal'chich's project was as follows.

The head of the Gendarmerie Directorate, General Komarov, reported on 26 March 1882 (No. 1617) to the Department of Imperial Police that "in fulfilling the request of Nikolai Kibal'chich, son of a priest, accused of a state crime, I have the honor of presenting to you his project of an aeronautical device."

This report carries two remarks: "Filed on March 1st" and "Now is hardly the time to send this to experts for evaluation since it may only cause undesirable talk." To prevent this undesirable talk Kibal'chich's project was placed in an envelope which was sealed and filed.

This sealed envelope remained in the file for... 36 years. The file was found only in August 1917 in the archives of the Police Department. The envelope was opened and the project first published in the "Byloe."

Kibal'chich, however, had stated that his project should be submitted to experts for their opinion, and their reply and views were awaited. On 31 March 1881, two days before his execution, N.I. Kibal'chich decided to dispatch to "His Excellency the Minister for Internal Affairs" the following request:

"At the order of Your Excellency my design of an aeronautical machine has been submitted to a technical committee for consideration. Could

* Nikolai Ivanovich Kibal'chich, London, 1882 (Collection in favor of the Red Cross, "National Freedom"), 24 pp.

your Excellency issue an order permitting me to meet a member of this committee in connection with this project, not later than tomorrow morning; or at least obtain a written reply from the committee after examination of my project, also not later than tomorrow. I request of Your Excellency to permit me before my death to meet all my comrades in the trial, or at least Zhelyabov and Perovska."

43 There is no need to add that Kibal'chich's request, made before his death, yielded no results.

For 37 years Kibal'chich's project was public property. We reproduce it verbatim. *

P. Shchegolev

PROJECT OF AN AERONAUTICAL MACHINE

(By Nikolai Ivanovich Kibal'chich, formerly student of the Institute of Communication Engineers, member of the Russian Social-Revolutionary Party.)

Being in prison, I am writing down this project a few days before my death. I believe that my ideas can be realized, and this belief strengthens me in my terrible situation.

Should my idea, after careful evaluation by experts, be considered feasible, I shall have been happy to have rendered a great service to the fatherland and to mankind. I can thus meet death calmly, satisfied in the knowledge that my idea will not perish with me but will live on amongst the people for whom I have given my life. I therefore request those experts who will evaluate my project to consider it as seriously and conscientiously as possible, and give me an answer as soon as possible.

I consider it necessary, first of all, to note that had I been free I would not have had sufficient time to work out this project in detail and prove its possibility by mathematical computations. I certainly do not have the opportunity now of obtaining the necessary material. Hence, this task — to substantiate my project by means of mathematical computations — should be carried out by the experts in whose hands my project remains. Furthermore, I am not familiar with the large number of similar projects which have appeared recently; or rather, I know approximately the ideas on which these projects are based, but I do not know the form in which the inventors intend to realize them. However, as far as I know, my idea has not yet been proposed by anyone else.

In my considerations of an aeronautical machine, I first of all had to decide how to propel such a machine. It may be considered that steam power, a priori, will not be suitable in this case. I do not remember exactly what percentage of the heat energy transmitted to the steam [by the fuel]

* It is of interest to note here the remarks made on Kibal'chich's project by Lieut.Col. Roustam Bek in his book "Aerial Russia" published in London in 1916. He writes on p.12: "Russian aviation was born at the beginning of the reign of Czar Alexander III who in 1881 succeeded his assassinated father. It is said that one of the murderers of Czar Alexander II the Liberator was a skillful engineer and mathematician named Kibaltich, who worked out the project of an airship while being imprisoned in the fortress of Petropavlovsk. After his execution this project was submitted to the consideration of the Minister of War, General Vannovskii, who showed much interest in it." [Retranslated from Russian.]

is utilized in the form of work, but I do know that this percentage is very small. In addition, a steam engine is very cumbrous and consumes much coal. I therefore believe that whatever devices are combined with it, be they wings, lifting airscrews, or others, a steam engine will not be able to lift itself into the air.

44 A much larger part of the energy supplied is transformed into useful work in electric motors, but large electric motors again require steam engines. I suggest that the electric motor and the steam engine be set up on the ground, and that a galvanic current be transmitted to the aeronautical machine via a wire like those used for telegraphy. The machine, so to speak, slides with a special metal part along the wire and thus obtains the power necessary to actuate the wings or other similar devices of the missile. It cannot be asserted that such a missile is feasible, but even if it were possible, it would in any case be inconvenient and costly, and would offer no advantage over propulsion on rails.

Many inventors, amongst them Dr. Arend, base the propulsion of aeronautical machines on the muscle power of human beings. Having taken the bird as model for the design of their projected machines, they assume that it is possible to construct devices such as an aeronautical machine driven by its own power, which enables it to lift itself and fly in the air. I think that even if it is possible to build such a flying machine, it will be in the form of a toy and without any real significance.

What source of power should then be used for the aeronautical machine? In my opinion this should be a slowly burning explosive.

A large quantity of gases is produced more or less rapidly when an explosive burns; these gases contain enormous energy while they are being formed. I do not remember exactly what amount of work expressed in kg · m can be obtained by the combustion of 1 lb of gunpowder, but if I am not mistaken, 1 lb of gunpowder exploding in the ground can blow up 40 lbs of soil. In short, no other substance in nature, as explosives, can develop so much energy in a short time.

However, by what means should the energy of the gases formed during the combustion of explosives be used to do work during a certain time interval? This is possible only on the condition that this enormous energy expelled by the combustion of the explosives be set free during a certain time interval and not instantaneously. If we take a pound of granular gunpowder which deflagrates instantaneously upon ignition, mold it into a cylinder under great pressure, and then ignite one end of this cylinder, we shall find that the fire does not take hold of the entire cylinder immediately, but that it spreads quite slowly from one end to the other at a certain speed. The burning rate of compressed gunpowder has been determined by means of many experiments, and amounts to 4 lines* per second.

The design of combat rockets is based on this property of compressed gunpowder. The design is as follows. A cylinder of compressed gunpowder is placed tightly in a sheet-metal cylinder open at one end and closed at the other. The gunpowder cylinder has on its center line a cavity in the form of a bore. Combustion of the compressed gunpowder starts on the surface of this bore and spreads during a certain time interval to

* [One line = 1/10 inch.]

the outer surface of the compressed gunpowder cylinder. The gases formed during the combustion of the gunpowder exert a pressure on all sides; the pressure forces acting on the sides are in equilibrium, whereas the pressure force acting on the bottom of the sheet-metal shell is not balanced by an opposite force since the gases can escape freely at the other end. The rocket is therefore pushed forward in the direction in which it was set up in the launching stand before being ignited. The flight path of the rocket is a parabola similar to that of a shell fired from a gun.

Let us now assume that we have a cylinder of known dimensions made of sheet iron, which is hermetically closed on all sides and has only an opening of given size at the bottom. A piece of compressed gunpowder, in the form of a similar cylinder, is arranged along the center line of this sheet-iron cylinder and the gunpowder is ignited at one end (Figure 61). Gases are then formed during combustion, which will exert pressure on the entire internal surface of the metal cylinder; however, the pressure forces acting on the lateral surface of the cylinder will be in equilibrium, and only the pressure force acting on the closed end of the cylinder will not be balanced by an opposite force since the gases can escape freely on the other side through the hole in the bottom. If the cylinder is set up with the closed end on top, it will be lifted upward at a certain gas pressure which depends on the internal volume of the cylinder, on the one hand, and on the thickness (diameter) of the piece of compressed gunpowder, on the other.

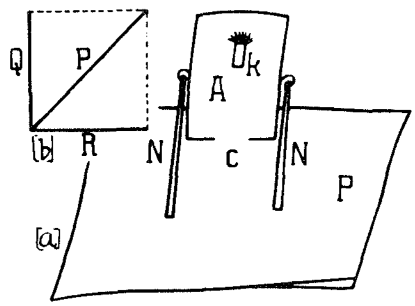

FIGURE 61. Kibal'chich's reaction machine

I do not have at my disposal data which might enable me, even approximately, to determine the quantity of compressed gunpowder to be burned in unit time in order that a cylinder, of given dimensions and weight, be subjected to a pressure force acting on its top; this force is exerted by the gases formed during the combustion of the gunpowder, and is equal to the weight of the cylinder. I believe that in practice, however, this problem can be completely solved, i. e., that at given dimensions and weight of cylinder it is possible, with cylindrical pieces of compressed gunpowder of a certain diameter, to obtain a pressure force exerted by the gases on the cylinder top equal to the weight of the cylinder. This is in fact proved by rockets. Rockets are at present being made which are able to lift explosive shells weighing up to 5 lbs. It is true that the example of the rocket is not altogether applicable here, since rockets have flight speeds which would be useless for an aeronautical machine. These speeds, however, are achieved by inserting a considerable quantity of compressed gunpowder into the rocket, so the combustion surface is large. If a much smaller upward flight speed is required, the quantity of gunpowder to be burnt in unit time will be far less. I do not actually know if the compressed gunpowder must be fitted tightly into a shell in order to obtain slow and regular burning. However, even if this should be necessary, this would not prevent the use of compressed gunpowder in this machine.

The following is therefore a schematic description of my apparatus:

A cylinder (Figure 61) (A) having a hole (C) at its bottom carries along its axis, close to the top, a gunpowder candle (K) (as I shall call the cylinder
46 of compressed gunpowder). Cylinder (A) is by means of columns (N, N) secured to the central part of platform (P) on which the aeronautical machine stands. Special automatic mechanisms must be devised for igniting the gunpowder candle and replacing each burnt one by another so that combustion is continuous. Such a device — replacing the gunpowder candles as fast as they are burnt — could be actuated by a clockwork mechanism by virtue of the regular combustion of the gunpowder candles. I shall not, however, deal with this device here, since it can be easily developed at the present state of technology.

Let us assume that candle (K) has been ignited; cylinder (A) then becomes filled with burning gases within a very short time. Part of these gases exerts a pressure force on the top of the cylinder; if this force exceeds the weight of the cylinder, platform, and aeronautical machine, the apparatus should rise into the air. We note, incidentally, that the upward motion of the machine will be due not merely to the pressure of the gunpowder gases. The burning gases filling cylinder (A) have a smaller specific weight than that of the air displaced by them, and according to the laws of aerostatics, the weight of the apparatus should thus be reduced by the difference between the weight of the air previously contained in cylinder (A) and that of the gunpowder gases filling it. We thus encounter here the favorable circumstances which in aerostatics cause lift. The machine can be raised to a high altitude by the pressure of the gases if this pressure on the upper base during the ascent always exceeds the weight of the machine. If it is desired that it remain stationary at a certain altitude, it will be necessary to insert thinner gunpowder candles so that the pressure force exerted by the gases formed will be in equilibrium with the weight of the machine.

The aeronautical machine can thus be held in relation to the surrounding air like a stationary vessel in relation to the surrounding water. In the same way we can propel our machine in the desired direction.

Two methods for this are possible.

We can employ a second cylinder, similar to the first, arranged horizontally with the hole in its bottom, not pointing downward but sideways. If we insert a device with gunpowder candles, similar to the first, and ignite the candle, the gases will impinge on the base of this second cylinder and propel the apparatus in the corresponding direction. This second cylinder should be movable in a horizontal plane so that it may be set up in any required direction. This direction may be determined with the aid of a compass exactly as in the case of navigation on water.

It appears to me, however, that we can restrict ourselves to a single cylinder arranged in such a way that it can be inclined in the vertical plane and rotated to describe a conical surface. Inclination of the cylinder permits both maintaining the cylinder in the air and propelling it in a horizontal direction. We thus assume that the pressure force exerted by the gases on the base of the cylinder can be represented graphically by (P), and we resolve this force into 2 components (Q) and (R). If the component (Q) is always equal to the weight of the machine, the latter will fly in a horizontal plane, being propelled by the force component (R). The cylinder should therefore be inclined to such a degree that flight takes place in a horizontal plane. To ensure that the flight is in a certain direction, it is 47 necessary to rotate the cylinder along a conical surface so that its axis comes to lie in the required direction. It seems to me, however, that with 2 cylinders it will be possible to achieve a steadier flight and a greater stability of the machine. In fact, with 2 cylinders the oscillations of the machine as a whole will make it deviate less from the desired direction than when only one cylinder is provided. Furthermore, it will be more difficult to obtain the same speed with one cylinder than with two.

As regards the stability in general, it appears to me that it will be adequate in view of the fact that the cylinders are arranged above the heavy parts of the machine in such a way that the center of gravity of at least one of the cylinders, e. g., the upper one, lies on the same vertical as the center of gravity of the machine as a whole. Besides, stability can be ensured by devising some kind of motion regulator, such as wings, etc.

To lower the apparatus to the ground it is necessary to insert gunpowder candles of progressively decreasing diameter, so that the machine will descend gradually.

In conclusion I note that in my opinion not only one kind of compressed gunpowder cylinder can be used for this purpose; there exist many slowly burning explosives, like gunpowder, also containing saltpeter, sulfur, and carbon, but in other proportions or together with different substances. Some of these compounds might be even more suitable than compressed gunpowder.

It will be possible only by means of experiments to prove whether my idea is correct or not. Besides, only tests can establish the necessary relationships between the dimensions of the cylinder, the diameter of the gunpowder candle, and the weight of the machine to be lifted. Initial experiments may be conveniently carried out with small cylinders even in a room.

REMARKS ON KIBAL'CHICH'S PROJECTS

N. I. Kibal'chich, in proposing his reaction engine, only envisaged its use for flight in air; he did not foresee that the same principle can be applied also to flight outside the atmosphere, i. e., in space. It may be assumed that he already was acquainted with Jules Verne's ideas on the possible use of reaction engines for the propulsion of bodies, since the Russian translation of Verne's book "Around the Moon" had already appeared in 1874 in its second edition. This book describes the use of rockets for changing the motion of a shell in which the hero of the story flies to the moon.

Approaching Kibal'chich's project strictly from the aspect of proving the possibility of launching his machine and guiding it in flight, it certainly does not withstand criticism. The velocity of gunpowder gases and their energy are insufficient for launching the machine which its author envisages. Nevertheless, as regards the originality of the idea and the methods of realizing it, one can only admire the man whose love of new inventions, and whose scientific work occupied him completely before his execution. His confidence in the indubitable accuracy of what was to him an apparently new principle of flight fortified and encouraged him before his approaching death.

e) **Further works**

THE REACTION-PROPELLED AIRSHIP OF 1882

Pul'k Rabek in 1882 proposed the following project of a reaction-propelled airship with a gondola rigidly secured to the balloon. The airship
48 was to be propelled by air being sucked in at the front and ejected to the rear by means of fans. The length of the airship was to be 100 m, its diameter 15 m, and its volume 6,515 m^3.

In 1888 Ciarcu launched a boat on the Seine, having an engine driven by the reaction due to the detonation of a special explosive. However, the tests had to be discontinued because of an accident during the explosion of the composition in which two assistants of the experimenter were killed.

In 1886 Engineer Eval'd experimented with a small airplane propelled by a rocket at the riding school of the Horse Guards in St. Petersburg.

GESHVEND'S STEAM PLANE

In 1887 F. Geshvend published in Kiev a pamphlet under the title "Obshchee osnovanie ustroistva vozdukhoplavatel'nogo parokhoda (paroleta)" (General Fundamentals of the Design of an Aeronautical Steam-Driven Vehicle (Steam Plane)), in which he developed the idea of the reaction work done by steam, which he had proposed even earlier in his pamphlet "Obshchee osnovanie primeneniya takoi raboty k zhel.-dor. parovozam" (General Fundamentals of the Use of this Work in Railroad Steam Locomotives). The development consisted in the application of the reaction caused by discharged steam to the flight of an airplane. In this pamphlet Geshvend gave a drawing of the airplane in 3 projections; his computations on them yielded the following results: takeoff speed, 104.5 verst*/hr; wing area, 350 sq. ft.; drag, 28.29 pood**; lift, 81.15 pood; angle of attack of wings during takeoff, 16° in flight, 6.7° at a speed of 157 verst/hr, and 4.1°
49 at a speed of 200.8 verst/hr; steam consumption, 520 lb/hr. At an angle of attack of 3° the speed was to be 260 verst/hr and the steam consumption, 480 lb/hr (Figures 62 and 63).

A trip from Kiev to St. Petersburg was to take 6 hr with 5 intermediate stops of 10 min each. The water consumption could be reduced by 50% if condensation was to be employed, e. g., 260 instead of 520 lb/hr. Consumption during a one-hour flight would be 40 lb fuel (kerosene) and 6.5 pood water. The boiler pressure was to be 10 atm. The plane was to carry 3 passengers and one engineer. It was to be controlled by means of a rudder; the latter was to turn the steam nozzle about a vertical axis in order to alter the pressure of the steam on the wings. The engine power was to be 199 hp. The maximum steam consumption was to be 960 lb/hr. The diameter of the nozzle exit section was to be 0.62 in., and the heating surface of the boiler, 80 ft^2. The plane was to weigh 69.6 pood, including 7 pood water in the boiler, a water reserve of 6.5 pood for a one-hour flight, and one pood fuel. The useful lift was to be 11.55 pood. The airplane was to cost 1,400 rubles.

* [One verst = 1.067 km.]
** [One pood = 36 lb.]

(48)

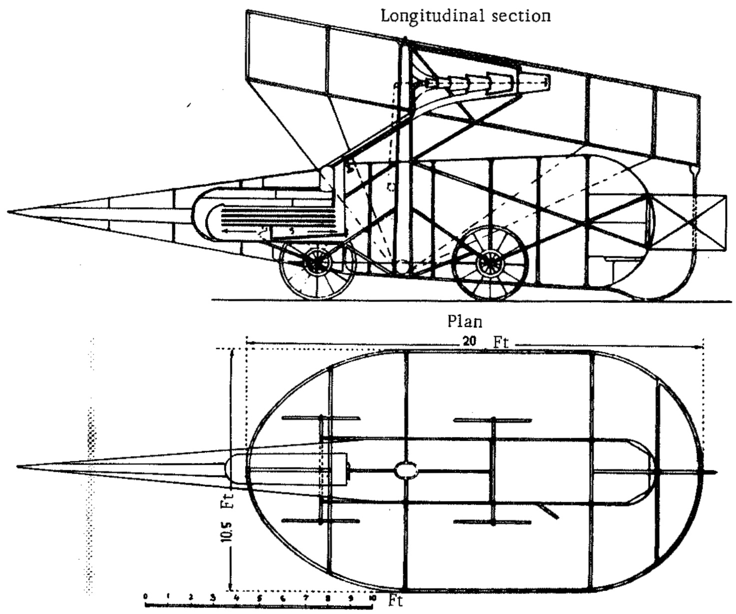

FIGURE 62. Geshvend's steam plane

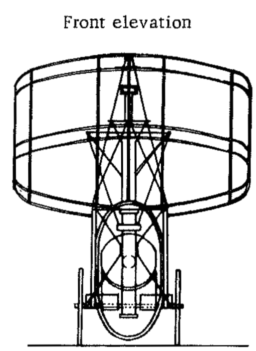

FIGURE 63. Geshvend's steam plane

It is seen from the drawing that the engine employs the reaction caused by the discharged steam. The latter leaves the boiler through a pipe and passes through a series of nozzles similar to injectors, which aspirate a large mass of air which is then ejected from the seventh nozzle.

BOURDON'S MULTIPLIER

In 1888 Bourdon proposed an instrument for measuring the velocity of the wind. This instrument was very sensitive since it multiplied this velocity many times by means of an ingenious device. The instrument consisted of 3 conical duplex ejector tubes located one inside the other; the air in each tube exerted a suction force on the tube inside it. Thus, air entering on the left at a velocity (v) (Figure 64) and passing through tube (3) exerted a suction force on tube (2), and it exerted a suction force on tube (1) while flowing through tube (2). A tube led from the throat of tube (1) to manometer (b) and caused a differential pressure (m) in it. Figure 65 shows the velocities and pressures in the 3 tubes as functions of the wind speed v; for example, at v = 11 m/sec the corresponding vacuum under ordinary conditions is approximately 11 mm water column (w. c.) (curve V), whereas the vacuum in tube (3) is approximately 33 mm w. c., in tube (2) approximately 140 mm w. c., and in tube (1) approximately 600 mm w. c.

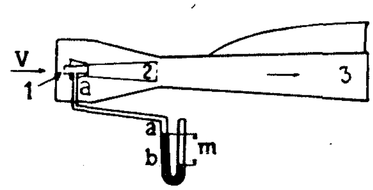

FIGURE 64. Bourdon's multiplier

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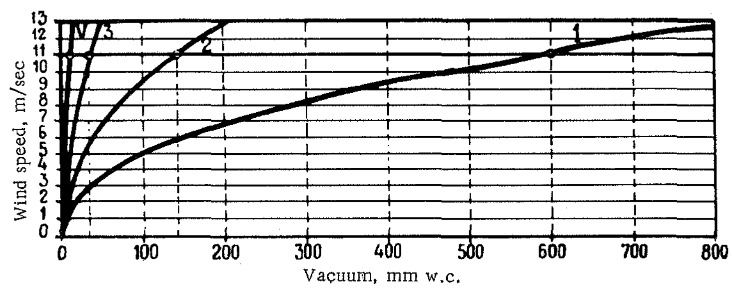


FIGURE 65. Discharge velocity in Bourdon multiplier

This instrument can be reversed, i. e., gas can be forced through tube (aa) (Figure 64) and ejected to the right via tube (1). It is then possible, with
50 the aid of tubes (2) and (3), to aspirate a large mass of air from the right and to eject it through tube (3). This induces a considerable reaction.

ROCKET AIRSHIP

Around 1888 a Frenchman was granted a patent for an airship which was to be equipped with a gun in the gondola. The recoil caused by firing the gun was to propel the airship in the required direction.

The French writers Le Faure and Graffigny, in their novel "Aventures extraordinaires d'un savant russe," Paris, 1889, describe two reaction machines used by inhabitants of the moon for navigation on the water and flight in the air.

The first machine (Figure 66) was used for navigation on water; it consisted of floats *(A)*, *annular cabin (B)*, *engine (C)*, *and hold (D)*. A pump aspirated water through a hole in the forward float and ejected it through a hole in the aft float. The suction force and reaction were to propel the vessel from right to left.

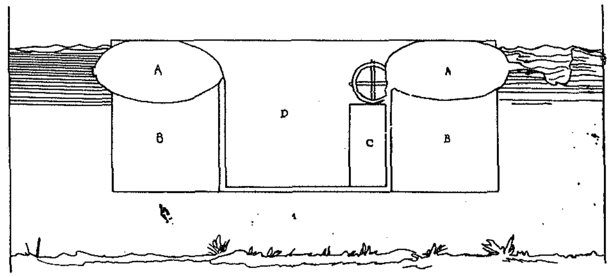


FIGURE 66. Reaction vessel of Le Faure and Graffigny

The second machine (Figure 67) consisted of a spaceship with wings and a reaction (jet) engine. A special mixture, upon exploding, produced gases which were ejected from the stern and caused a reaction propelling the machine in the opposite direction. The authors, however,
51 assumed that the thrust was caused by the pressure of the gases on the air.

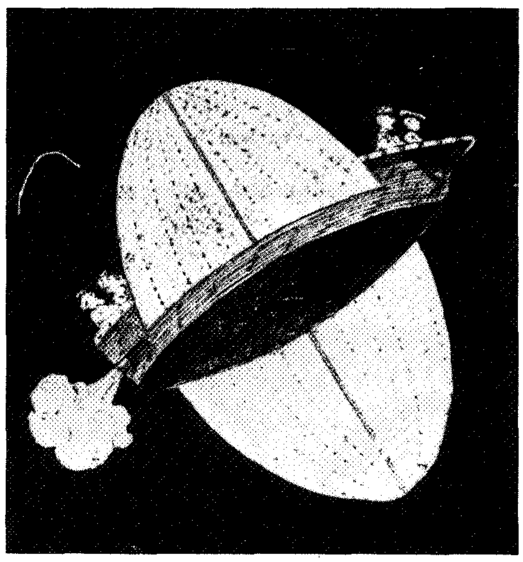


FIGURE 67. Le Faure and Graffigny reaction spaceship

At the end of 1890 there appeared in the USA the design of a special airship, devised by an engineer named Beatty, which was to be propelled by the reaction of gases produced from the explosion of pellets fed automatically to the explosion chamber behind the airship. A series of impacts due to these explosions were to propel the airship in the desired direction (Figure 68).

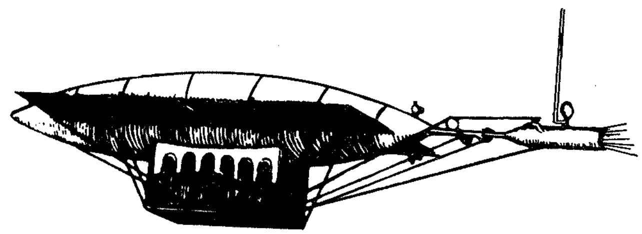


FIGURE 68. Beatty's reaction airship

52 GUSTAVE TROUVER'S ORNITHOPTER

In 1891 Gustave Trouver presented to the French Academy of Sciences the design of a flying machine resembling a fantastic flying dragon with extended wings secured to the legs of a horseshoe-shaped hollow tube (Figure 69). An increase in the pressure of the air contained in this tube would cause it to straighten out and force the legs outward, while a reduction of the air pressure would cause the tube to bend more. A series of such pressure variations would cause vibrations of the tube which would transmit its motion to the wings. The pressure fluctuations were to be caused by successive explosions of cartridges containing a mixture of hydrogen and oxygen, located in an automatically revolving drum. A model of this machine weighed 3.5 kg and could fly to a distance of 75 m, while 12 cartridges were exploded. The bird rose after each explosion and then descended slightly. After 12 explosions it descended to the ground in a beautiful glide.

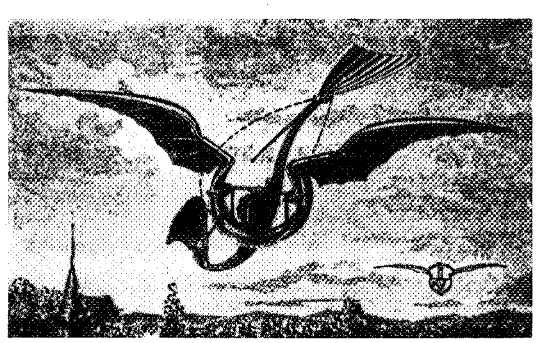


FIGURE 69. Trouver's ornithopter

PHOTOGRAPHING THE EARTH BY USE OF A MISSILE OR ROCKET

In 1891 Ludwig Rohrmann was granted German patent No. 64209 for the use of a rocket for photographing the surface of the earth. The operation of this rocket (Figure 70) was as follows:

53 A launcher with rocket (***A***) is set up on the ground. When the rocket is ignited it flies into the air. At a certain instant it explodes, and a parachute is released together with a camera set to take the required pictures. The parachute with the camera is then pulled back to the launching site by means of cable (***e***) and winch (***f***). The rocket itself consists of shell (***c***) and fuel (***a***). After burnout, charge (***b***) explodes and ejects the parachute and the camera by means of plate (***d***) after shell (***c***) has burst.

(52)

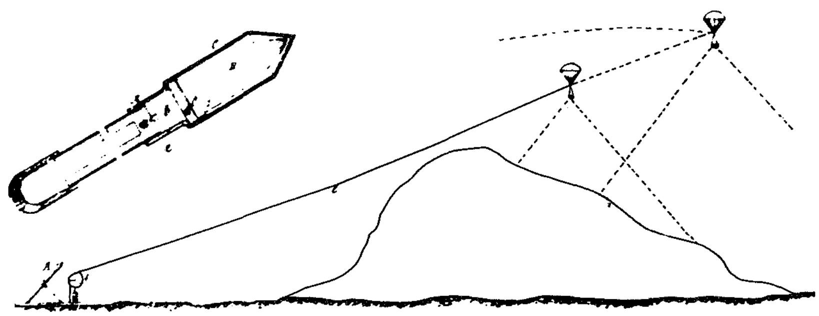


FIGURE 70. Rohrmann's photographic rocket

PETERSEN'S ROCKET AIRSHIP

In 1892 Nikolai Petersen, in Guadalajara (Mexico), was granted a patent for an airship propelled by a rocket engine. Figure 71(1) is an elevation of this airship. It consists of gas balloon (***a***), contained inside shell (***b***). Passenger cabin (***a'***) with windows (***c***) is located beneath the balloon. The stern has a recess containing nozzle (***m***) having the shape of a truncated cone whose narrow end is in contact with cylinder (***k***) (Figure 71 (4)). The latter is similar to a revolver cylinder and contains a number of rockets. It can rotate about 2 axes secured to 2 rings. One axis (***e***) is carried on columns and enables the cylinder to rotate about a horizontal axis with the aid of lever (***r***)(Figure 71(4)). The other axis (***h, h***) is held between the outer(***d***)and inner (***g***) rings and permits rotation of the cylinder about a vertical axis by means of worm (***w***) and worm wheel (***g***) (Figure 71(5)). Ring (***g***) has 2 round holes; one of these is located opposite nozzle (***m***), and the gases
54 formed during explosion of the rocket escape through it. The other hole is located at the bottom on the left and serves for the insertion of new rockets into the cylinder and for removal of the spent rocket cases. Rockets (1) are inserted into the cylinder and fired successively with the aid of an electric igniter (Figure 71(7)). A rudder action, necessary for changing the direction of motion, is obtained by rotating the entire rocket

engine at the stern about axes (*h, h*) and (*e, e*). The direction of the reaction will then differ from that of the center line of the airship, and the latter will turn in the required direction.

While the theory is of interest, the invention itself is hardly suitable in practice, since 1) propulsion is by impulses which endanger the structure of the airship, 2) adjustment and replacement of the rockets is manual and thus tedious and unreliable, 3) no computation of the quantity and power of the rockets is given and there is no indication of their weight, while an airship of the size shown on the drawing is hardly likely to be able to lift the required quantity of rockets, and 4) no safety device is provided against explosions.

(53)

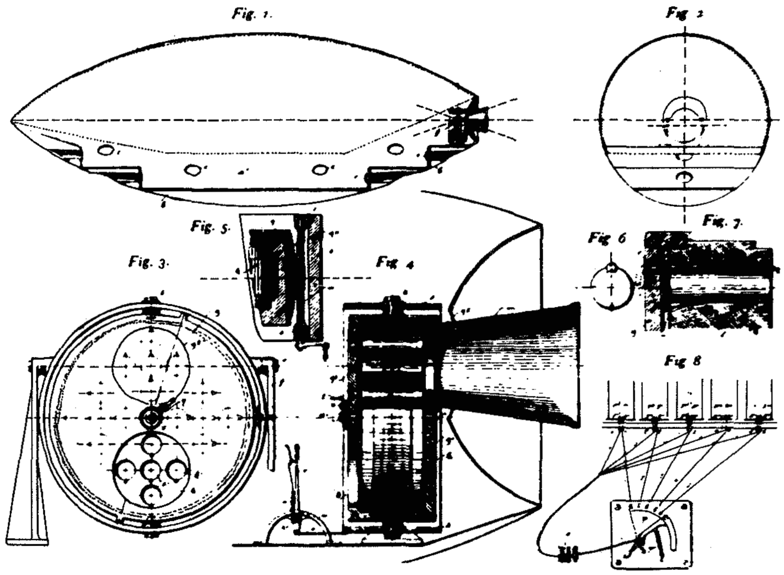


FIGURE 71. Petersen's rocket airship

In 1892 patent No. 68783 was granted to E. Lavarenne (Paris) (Figure 72a). In this machine a special engine forces compressed air, steam, or gas through chamber (*C*) into two nozzles (*A*) and (*B*). Nozzle (*B*) points downward and nozzle (*A*) to the rear. The reaction provides lift and propels the machine forward. Discharge of the gas through the nozzles is promoted by 4 fans mounted on rotating shafts (*a, a*) and (*b, b*).

Many projects of flying machines employing different methods of utilizing the reaction due to ejected liquids or gases have appeared at various times. Many of these are described in the book, "Die Entwicklung der Flugzeugapparate an Hand der deutschen Patentliteratur vom Jahre

1879—1911," published by B. Alexander-Katz, Berlin 1917. Amongst them the following projects might be mentioned:

In 1895 patent No. 89890 was granted to Karl Reiter in Munich (Figure 72b). Air in this machine is aspirated through the upper end of a casing (having the shape of a truncated cone) which is rotated about its axis by an engine. The air is thrown against the circumference of the base by the centrifugal force and is ejected downward through holes along this circumference, causing an upward reaction.

In 1895 patent No. 86738 was granted to Gebert in Berlin. The machine was to be lifted and propelled horizontally by the reaction created by gas ejected from a rotating wing. The reaction was to be increased by a system of pipes (a) similar to injectors (Figure 72c).

In 1895 the Peruvian engineer Pedro E. Paulet invented a rocket whose description (in Spanish) appeared in Lima in "El Commercio" on 7 October 1927.

The rocket was 10 cm high and its nozzle exit section had a diameter of 10 cm. A mixture of nitrogen peroxide and gasoline was periodically introduced into the nozzle by means of valves and ignited by electric sparks. According to Paulet the rocket weighed 2.5 kg; 300 detonations per min produced a thrust of 90 kg on a dynamometer.

(55)

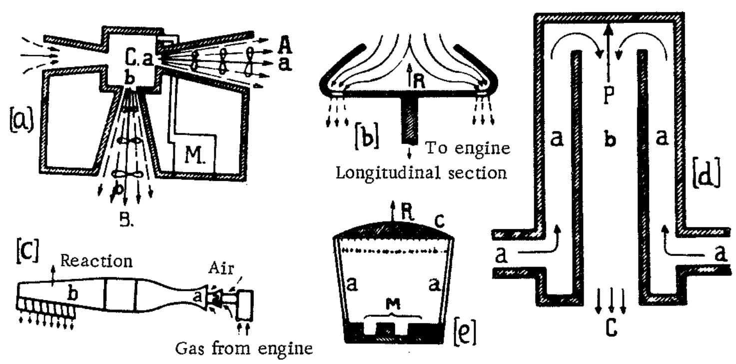


FIGURE 72. Reaction machines:

a) Lavarenne; b) Reiter; c) Gebert; d) Fedorov; e) Antonovich

A. FEDOROV'S GAS REACTION MACHINE

In 1896 A. Fedorov proposed the design of a reaction machine which was to be propelled in space by the reaction created by discharged gas, air not being used as supporting medium (Figure 72d). The gas (steam, compressed air, or carbon dioxide) was to flow through pipe (*a*) into pipe (*b*)
55 from which it was to escape via outlet (*c*) into space, creating a reaction P which was to propel the machine in the direction of ***P***.

In 1901 patent No. 134182 was granted to Wappler in Spandau. The machine (airship) was to be propelled by the reaction caused by air aspirated by fans at the nose of the airship and forced through a pipe to the stern where it was to be ejected to the rear.

PROJECTS OF REACTION MACHINES BY MATERIKIN, BERMAN, SOKOLOVSKII, AND POZNANSKY

At the end of 1908 there appeared a notice in the newspapers that an inventor named Materikin together with Berman, Doctor of Natural Sciences, had suggested using, for purposes of flight, the reaction caused by compressed gas or liquid air discharged from a rocket.

The same idea was expressed in a technical journal by an inventor named Sokolovskii. Poznansky in Germany worked in the same direction. He used compressors or so-called gas-jet engines operating in bursts.

In 1909 patent No. 228654 was granted to Antonovich in St. Petersburg (Figure 72e). The machine was to be maintained in the air through the reaction caused by the detonation of an explosive mixture ignited by electric sparks. The detonations were to follow one another in rapid succession and produce the necessary impulses. The drawing shows a platform carrying device (M) for the production of the gaseous mixture (gasoline and air). The mixture flows upward through pipes (*a*) into vessel (*c*) from which it is ejected downward through a large number of pipes, exploding at the outlet.

A brief exposition of the theory of reaction engines operating in space or in the atmosphere was given by Prof. A. Budau in his lectures on the theory and design of flying machines (A. Budau, "Vorträge über Theorie und Bau der Flugapparate," Vienna, 1909, p. 90).

56 WEGENER'S REACTION-PROPELLED FLYING MACHINE

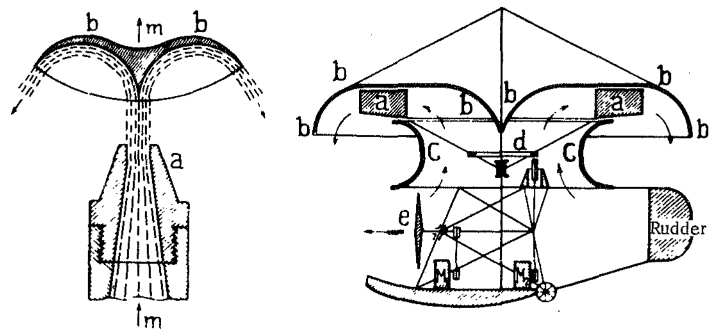
This machine, which was never built, was described in 1909. It was to consist of a heavier-than-air flying machine with a shape similar to a submarine. It was to be 13 m long with a diameter of 6 m, to be made of steel, and to weigh 4,320 kg. In the opinion of its inventor, it would have had a lift exceeding 1,200 kg, able to develop a speed of up to 30 m/sec, and a power of one hp which would have produced a lift of 12—16 kg.

KENNEDY'S REACTION-PROPELLED AERONAUTICAL MACHINE

In 1909 the British engineer Rankine Kennedy suggested using the reaction resulting from a jet of gas for maintaining a flying machine in the air.

The idea on which this machine is based (Figure 73) is as follows: Gas flows out of nozzle (*a*) and impinges on blades (*b*), thus changing its direction by almost 180°, and leaves in the direction of the arrows. The reaction causes the machine to be propelled in direction (*m*). The nozzle and blades are rigidly interconnected. The idea itself was correct, but misapplied by the inventor in his design of a flying machine (Figure 74).

Air is directed against blades (b) by centrifugal blower (a) which aspirates it via annulus (C). The blower is driven via gears (d) and a transmission from engine (M_2). The other engine (M_1) propels the machine horizontally with the aid of airscrew (e).



FIGURES 73 and 74. Kennedy's reaction-propelled machine

In this arrangement the air is simply circulated from bottom to top and back again, so that there is no lift.

In 1911 Wilhelm Gaedicke proposed a jet plane.

f) **René Lorin's work**

We shall now describe some designs and computations ascribed to the French engineer René Lorin, an enthusiastic adherent of the reaction-
57 propelled flying machine in the form of a winged rocket, which had already
been suggested in 1867 by Butler and Edwards, and for which a patent had been granted to van de Kerchove and T. Snyerrs Jr. in 1881. In 1886 it had been described by Geshvend in Kiev, in 1888 by Le Faure and Graffigny, and quite recently has acquired such adherents as F. Tsander, Hohmann, Valier, and Tsiolkovskii for use in interplanetary flight. Lorin's ideas are explained below in Russian in A. Gorokhov's plan.

58 LORIN'S AIRPLANE EMPLOYING DIRECT REACTION (JET PLANE)

In 1908 the French Engineer René Lorin proposed a high-speed airplane propelled by the pressure force exerted on the air (direct reaction) by the products of combustion of a liquid fuel ejected through nozzles (Figure 75).

Fuselage (C) of the airplane was to be cylindrical and rest on skids (q) (two in front and one at the rear). The fuselage was to weigh about 100 kg. Two engines (P) were to eject the products of combustion beneath wings (S). The pilot was to sit in the rear and control both the operation of the engines and their rotation about horizontal axis (aa), thus stabilizing the airplane.

(57)

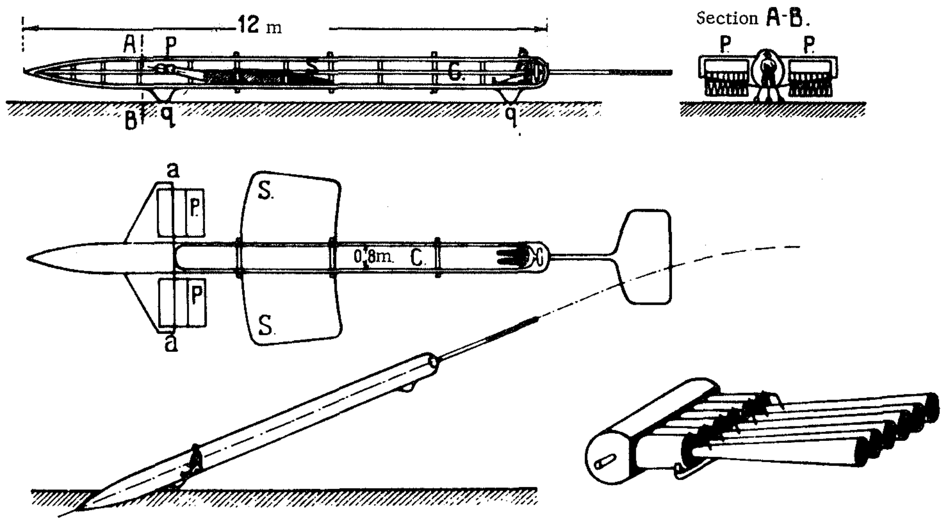


FIGURE 75. Lorin's jet plane

At takeoff the nozzles of the engines were to be almost vertical, afterwards turning gradually to a horizontal position.

During landing the airplane was to hit the ground at the minimum possible speed. A special shock absorber was to reduce the impact on the pilot. At a landing speed of 30 m/sec and with the pilot weighing 70 kg his kinetic energy would be $\frac{70.30^2}{2 \cdot 9.81} = 3{,}211$ kg · m. Distributing this energy over the length of the fuselage (12 m) by means of the shock absorber, we find that the force acting on the pilot is $\frac{3{,}211}{12} = 268$ kg, which should be distributed over his entire body by means of elastic shock absorbers.

LORIN'S REACTION-PROPELLED AERIAL TORPEDO

A description of René Lorin's aerial torpedo was printed in 1910 and again in 1912. It consisted of an aeronautical machine propelled by a reaction engine and guided by remote control. Its flight speed was to be 200 km/hr. The machine (Figure 76) consisted of a fuselage made from smooth aluminum sheets polished on the outside.

The main parts were as follows: 1) sharp nose (*A*), 2) cylindrical body (*B*), 3) conical extension (*CDEF*), and 4) tail (*G*) consisting of the elevator and the rudder.

The weight of the fuselage, inclusive of wings (*M*), was 12 kg.

The engine was located at (*B*). Its exhaust pipes (*e*) were arranged in such a way that they occupied very little space. The engine had 8 cylinders 120 mm in diameter, the stroke was 80 mm, and the engine speed 1,200 rpm. The engine weighed 36 kg. It was cooled by air entering through openings (*a*, *v*) in the fuselage. Similar openings were provided for admitting the air necessary for engine operation.

Stability was ensured by the high speed, as in the case of an arrow.

The controls were actuated with the aid of generator (D) driven from the engine shaft via gears. It generated d. c. for actuating the rudder and elevator, for ignition, and for 2 reflectors (F_1) and (F_2) permitting observation of the flight of the torpedo and its guidance at night.

59 The tail consisted of elevator (G_1) and rudder (G_2) actuated by 2 electric motors.

Elevator (G_1) was controlled by barometer-anemometer (b) combined with contact (C). The barometer made possible flight at an indeterminate altitude [sic]. Depending on the atmospheric pressure, the barometer either closed a circuit, thus energizing solenoids (E_1) and (E_2) and turning elevator (G_1), or opened the circuit so that (G_1) was returned to its normal position by spring (r). Rudder (G_2) was controlled by detector (d). The circuit described required a relay including a distributor and control instruments, which transmitted the following maneuvers: 1) deflection of rudder (G_2) to the left or to the right, or its return to the normal position, and 2) stopping the engine and landing.

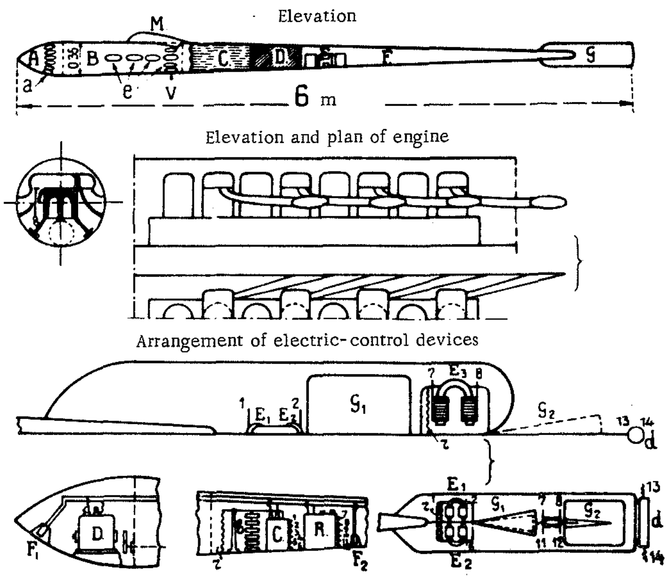


FIGURE 76. Lorin's reaction-propelled aerial torpedo

The weight of the control instruments, generator, solenoids, distributor, and contacts was approximately 10 kg. The fuel and lubricating oil weighed 10 kg; they were located at the center of gravity (C) of the airplane. A load of 12 kg could be carried in hold (D). The overall weight of the torpedo was 79 kg.

The torpedo had to be launched by an impact since the engine could not provide the necessary initial speed.

In the opinion of the inventor the torpedo required a thrust of 8 kg in
order to acquire a speed of 200 km/hr (55 m/sec). At 20 r/sec the engine
would emit $8 \cdot 10 = 80$ bursts per sec, 40 on each side, at a periodicity of
1/40 sec. During this time the torpedo would cover a distance of
60 $1/40 \cdot 55 = 1.37$ m, exceeding that separating the outermost exhaust pipes.
Each new burst thus occurred in a medium unperturbed by the preceding
bursts, thus improving the engine operation.

CHARACTERISTICS OF LORIN'S REACTION ENGINE

Any engine can be called a reaction engine, and the difference between them consists solely in the manner in which the reaction is utilized. Thus, an airscrew is a reaction engine since it utilizes the reaction of the air on its blades. The driving wheel of a steam locomotive is a reaction engine since it utilizes the reaction of the rail (friction), etc.

The term reaction engines should properly be applied only to those employing direct reaction, since the thrust developed directly results from the reaction caused by the ejected products of combustion of the fuel mixture. A shortcoming of these engines is that they develop a large power but a small thrust. In fact, the work done by the engine is equal to the kinetic energy of the gases ejected, which is $mv^2/2$ when v is their velocity in m/sec; the work performed is thus proportional to the square of the velocity and to the mass (m) of the gases.

The thrust T is found from the condition that the impulse is equal to the momentum:

$$T \cdot t = m \cdot v.$$

Setting $t = 1$ sec, we obtain $T = mv$, i.e., the thrust is proportional only to the first power of the velocity (of the gases). However, the gas discharge velocity is proportional to the square root of the pressure of the gas. Hence, the lower the compression in the cylinder, the smaller is the difference between the kinetic energy and the momentum of the gases. [These magnitudes are incommensurate since their dimensions differ.].

Let us determine the thrust developed by a gas engine employing direct reaction. Assume that the 50 hp engine weighs 50 kg and has a speed of 1,500 rpm; the cubic capacity of its cylinders is 7 liters. The number of suction strokes per sec is $1{,}500/60 \cdot 2 \cong 12$ (for a single-cylinder engine). The total volume of the gases discharged is $12 \cdot 7 = 84$ liters and their mass is $84 \cdot 1.293/9.81 = 11$ g*. This mass is ejected at a velocity of 800 m/sec** (it is assumed that the gas is discharged into vacuum, and the mass of the entrained air is neglected). The momentum of the gases is thus $11 \cdot 800 = 8{,}800$ g·m/sec or 8.8 kg·m/sec, i.e., the thrust is approximately 1.2 kg/l engine cubic capacity, or equal to 1/6 of the engine weight. This value can be increased if such a reaction engine is specially designed so

* 1.293 is the density of air at 0° C and 760 mm Hg. This does not apply to gases, but the products of combustion contain a considerable amount of carbon dioxide whose density is higher than that of air, so that this compensates for the difference in weight.

** The discharge velocity of the gases exceeds 1,500 m/sec in turbines.

that its weight is reduced and its construction simplified. It was proved that an engine weight of 4 kg/l cubic capacity can be obtained.

LORIN'S JET PLANE WITH CATAPULT

Lorin in 1911 proposed an all-metal jet plane to be launched from the ground with the aid of an electric carriage running on rails. The jet engine of the airplane was to begin operating when a certain speed had been attained on the ground, so that the plane could take off and fly.

61 Figure 77 shows this airplane on the electric carriage. The exhaust pipes (nozzles) of the engine are not shown; their design was the same as that shown on p. 54. The pilot was seated almost at the stern of the plane in a separate cabin which could slide inside the tubular fuselage on guides (a, a), which are partially shown in the drawing of the plane (Figure 77, plan).

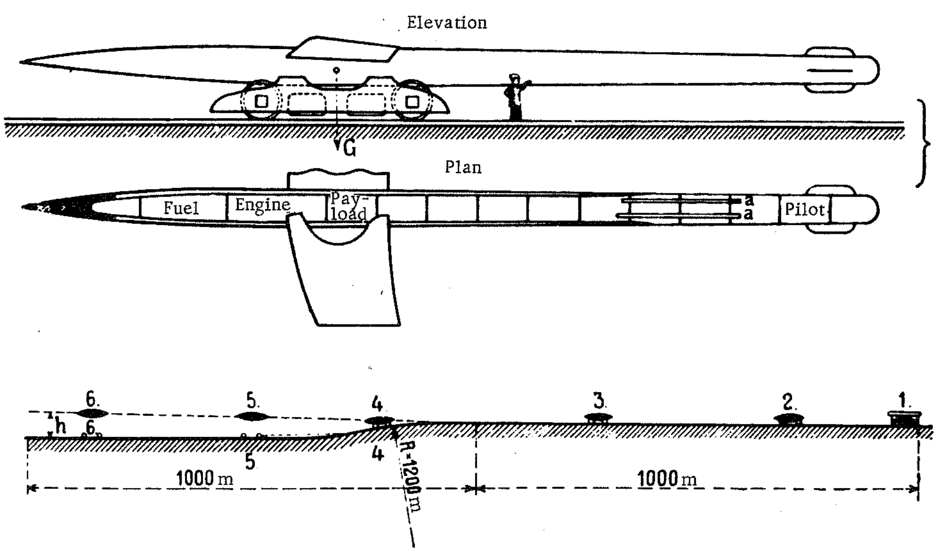


FIGURE 77. Jet plane with catapult designed by Lorin

The takeoff procedure was as follows: the electric carriage pulled the airplane over a distance of one km, the speed gradually increasing to 300 km/hr at the end of the track.

62 The flight path then became curved in a vertical plane (along a circle or a parabola) at an initial radius of 1,200 m, and then went over into a straight line. Due to the centrifugal force at the beginning of the curve, the effects of the wings, the speed attained, and the operation of its own jet engine, the airplane left the carriage and began to fly by itself. The carriage continued to travel on the track until it was braked.

The airplane landed on soft ground, digging into it along an inclined line to a depth of 2 m. The landing speed was reduced by the pilot actuating air brakes at the tail (Figure 78).

In addition, as a result of its inertia, the cradle in which he was sitting tended to slide forward inside the airplane upon collision with the ground. It thus tensioned elastic cables which absorbed the kinetic energy and reduced the shock.

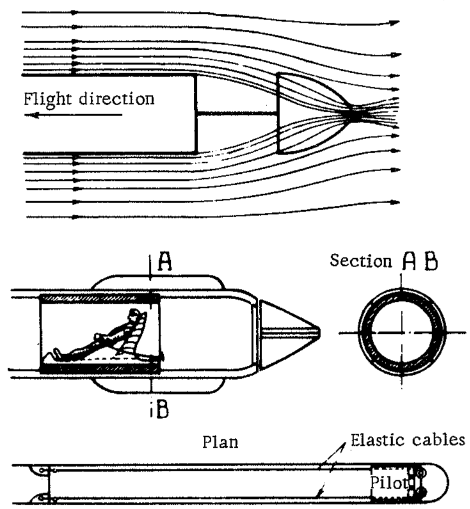


FIGURE 78. Lorin's brake

(63)

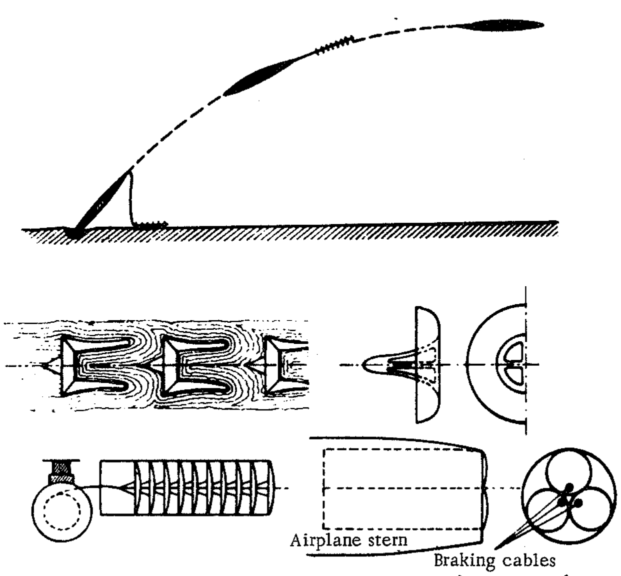
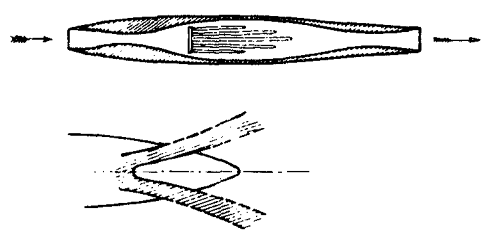


FIGURE 79. Lorin's brake

Lastly, upon approaching the ground it was possible to extend a long tail from the stern of the airplane. This tail had a large number of braking surfaces which are shown in detail in Figure 79. This drawing illustrates the formation of eddies at the tail plates, one of these aluminum plates, the arrangement of one row of plates at the stern of the airplane, and 3 rows of these plates.

EXPERIMENTS WITH JET ENGINES

O. Chanute carried out experiments with stationary jet engines in the USA in 1909 and 1910. He concluded that it would be necessary to perform experiments with moving engines. Death, however, prevented
63 him from doing this. Lorin in 1913 suggested the use of a wind tunnel with an air speed of up to 100 m/sec for testing jet engines. The jet engine (Figure 80) was to be set up in the direction of air flow and secured to an aerodynamic balance. Air entering the engine from the nose encounters the products of combustion which are ejected through nozzles at the stern. The balance indicates the reaction. It is also useful to investigate the effects of inclined nozzles at the stern (Figure 81).

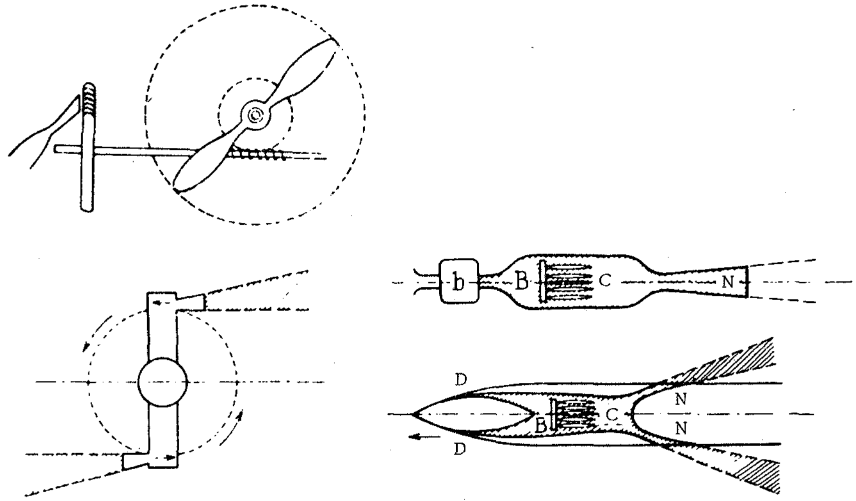


FIGURES 80 and 81. Lorin's experiments

64 FROM THE GAS TURBINE TO LORIN'S JET ENGINE

Figure 82 shows a turbine consisting of a disk rotating at a tangential velocity of 200 m/sec. A power of one hp at the disk rim corresponds to a reaction of $75/200 = 0.375$ kg at the nozzle. Let us assume that this turbine drives an airscrew, and determines the thrust developed by the latter when it moves at a speed of 75 m/sec. We assume that both the airscrew and turbine efficiencies are 0.60. The thrust per hp developed by the airscrew then is $75 \cdot 0.60 \cdot 0.60/75 = 0.36$ kg, i.e., less than the reaction at the turbine disk.

It would seem logical to utilize the reaction of the turbine blades directly. This has been proposed in the design of a gas turbine (Figure 83) consisting of a combustion chamber and a nozzle; the products of combustion escape in a direction normal to the axis of rotation. A jet engine is obtained if the radius becomes infinitely large.



FIGURES 82 (top left), 83 (bottom left), 84 (top right), 85 (bottom right). Lorin's engine

Two kinds of such engines can be distinguished, namely, with continuous and with discontinuous discharge of gases. Although the efficiency with continuous discharge is higher than with discontinuous, certain considerations lead to the latter being preferred. It permits a simpler design, e.g., devices for precompressing the air can be omitted and low compression ratios be employed.

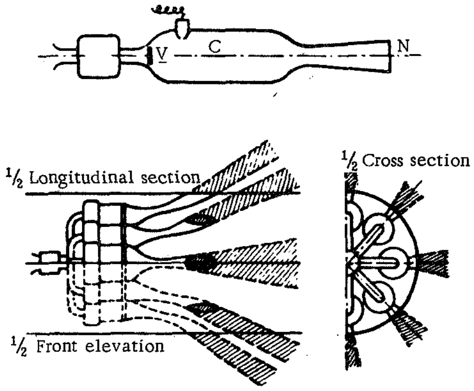
In any case, both kinds of engines have to aspirate large amounts of air and, with the aid of liquid fuel, transmit a large kinetic energy to the discharged combustion gases.

JET ENGINES WITH CONTINUOUS DISCHARGE

Figure 84 shows schematically a jet engine with continuous discharge. C is the combustion chamber, *B* is the burner, b is the compressor or blower, and N is the nozzle. The design of the compressor or blower is the most difficult. The following measures can be taken to simplify its design:

65 At flight speeds between 50 and 100 m/sec, it is possible to admit the impinging air into ducts (D, D) (Figure 85) arranged at the front of the airplane, so that the air is already compressed due to its motion [i. e., the velocity head is converted into a pressure head]. Ignition and detonation of the mixture occurs as explained before, and the gases escape at a velocity which is higher than the air-inlet velocity. This causes the reaction.

The possibility of using atmospheric air and mixing it with liquid fuel greatly reduces the weight of the fuel [and oxidizer] in relation to that of an explosive mixture capable of detonating without the introduction of air.



FIGURES 86 and 87. Lorin's engine

Thus, 1 kg gasoline requires about 17 kg air for its combustion; hence, 1 kg gasoline can replace 18 kg of some other explosive if atmospheric air is used.

An engine with discontinuous discharge of the combustion gases is far simpler (Figure 86). The fuel mixture burns in combustion chamber (C) after being ignited by means of an electric spark plug; the products of combustion escape via nozzle (N). The partial vacuum created causes valve (V) to open, through which a new air charge is aspirated.

High-power engines require multiple combustion chambers and nozzles as shown in Figure 87. A common carburetor distributes the mixture to the combustion chambers. Thus, a gasoline consumption of 100 kg/hr entails an air consumption of 2,000 kg/hr, or 0.5 m^3/sec.

g) A. Gorokhov's jet plane

In his paper "Mekhanicheskii polet budushchego" (Mechanical Flight of the Future) Engineer A. Gorokhov describes his design of a jet plane to fly in the atmosphere. The plane is propelled by the reaction due to the discharge of gaseous products of combustion of liquid fuel (gasoline, alcohol, kerosene, oil, etc.) whose vapors are mixed with atmospheric air in the combustion chamber and are then ignited.

The plane is provided with wings in order to sustain it in the air. The speed of the plane exceeds 350 km/hr.

The fuselage has a shape which ensures minimum drag (Figure 88). The plane has two very small wings (W, W) situated in jets of gas ejected from openings in the fuselage. These openings (O, O) are arranged on each side. The tail carries an elevator and a rudder.

66 The fuselage and the wings are of steel; the inside of the fuselage has the form of a continuous girder.

The engine consists of two symmetrically arranged compression and combustion chambers (C, C) in which the air is compressed by two blowers (B, B) driven by engine (E). The blowers aspirate air from the atmosphere via openings (D) and pipes (P, P). The products of combustion are discharged into the atmosphere through nozzles (N, N). Air is admitted to the combustion chamber by means of two slide valves (V, V) actuated by engine (E). Liquid fuel is injected into combustion chambers (C, C) during the compression period by means of a pump.

The products of combustion are exhausted via two further slide valves (V, V) which, like the injection pump, are also actuated by engine (E).

The angle of inclination of nozzles (N, N) to the flight path can be changed by moving combustion chambers (C, C) in relation to the valve chests.

The engines operate as follows: Blower (B) compresses the air in combustion chamber (C); inlet valve (V_i) is then closed, after which liquid fuel is mixed with air and the mixture ignited. Outlet valve (V_o) is opened after the mixture has burnt, and the products of combustion are discharged into the atmosphere. Valve (V_i) is then opened, and the combustion
67 chamber is scavenged with both valves open.

(66)

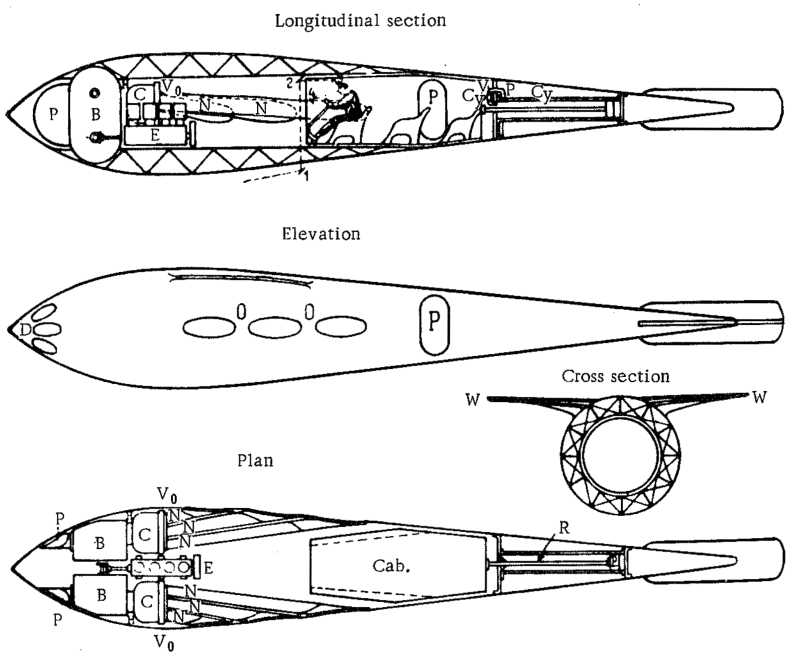


FIGURE 88. Gorokhov's jet plane

(67)

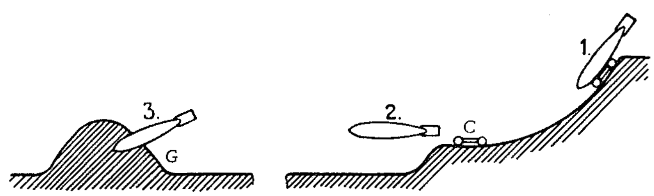


FIGURE 89. Takeoff and landing according to Gorokhov

Valve (V_o) then closes, compression takes place, and the process described is repeated.

Carriage (C) may be used for takeoff (Figure 89). The airplane then slides down a slope and thus acquires the speed necessary for regular operation of the engine.

A catapult may also be used for takeoff.

Landing is possible on soft ground (G) where plane and wings are buried, thus smoothly absorbing the shock. The engine compartment, being the heaviest part, penetrates deep into the earth, whereas the passenger cabin continues to move a certain distance in relation to the fuselage as a whole, since it is elastically connected to the latter. This connection is as follows: Cabin (C) can move along guides. During landing its momentum is converted into viscous friction by a dashpot. The latter consists of cylinder (c) and piston (P) connected to cabin (C) by means of rod (R) (Figure 88). During landing the cabin entrains the piston which forces the liquid from the cylinder via pipe (p) through valve (V); the latter serves to adjust the degree to which the shock is absorbed.

The flight direction is observed with the aid of mirrors (1, 2, 3, 4).

This airplane has, however, the following shortcomings:

First of all, as designed it is suitable only for flight in the terrestrial atmosphere since air, required for the operation of its engine and the combustion of the fuel, has to be aspirated from outside. Oxygen has to be carried if the plane is to be used for interplanetary flight. Besides, landing directly in a mound of soft soil is dangerous.

The inventor gives no computation of the dashpot, but it can be shown, a priori, that the latter is inadequate, and that the impact will not only harm the passengers but will cause the entire plane to disintegrate.

Furthermore, no provision is made for ensuring directional stability; lastly, no performance computation is given at all, i. e., it is not stated what should be the weights of airplane, payload, fuel, and engine in order to make flight by means of direct reaction possible.

THE EFFICIENCY OF DIRECT REACTION

Engineer A. Gorokhov, in his paper "Mekhanicheskii polet budushchego" (Mechanical Flight of the Future), gives the following approximate computation of the work performed by an internal-combustion engine whose exhaust
68 gases are ejected from the combustion chamber and induce a direct reaction, as in a rocket, but do not act on a piston driving a shaft and airscrew (Figure 90).

The table gives a comparison of the utilized part of the fuel energy for two engines. One drives an airscrew while the other is a direct-reaction engine. The engine driving the airscrew utilizes only 25% of the energy contained in the fuel. At an airscrew efficiency of 50%,* the overall efficiency is only $0.25 \cdot 0.50 = 12.5\%$.

Utilization of the fuel is better when the products of combustion are released straight from the engine, thus inducing a direct reaction, since their expansion is closer to adiabatic than in the former case; here the heat lost to the walls is less.

69 We shall denote the heat energy contained in the fuel by E. In the direct-reaction engine the kinetic energy of the exhaust gases includes 1) all the energy corresponding to the effective work performed by the engine $= \frac{1}{4}$ E, 2) half of the heat lost to the walls $= \frac{1}{6}$ E, and 3) the kinetic energy of the exhaust gases $= \frac{1}{6}$ E. The total is 0.58 E, and the overall efficiency is thus 58%.

* This efficiency can now be taken as 80%.

(68)

Engine and airscrew			
Supplied to airscrew	1/4	Supplied to piston ... 1/3	Energy of fuel = 1
Lost through friction	1/12		
Lost as heat of gases	1/6	Exhaust losses ... 1/3	
Lost as kinetic energy of gases . .	1/6		
Heat losses to walls of combustion chamber	1/3		

Direct-reaction engine			
Mechanical work performed by gases . . . . = Useful work of reaction		1/4	Energy of fuel = 1
Lost through friction	1/12		
Lost as heat of gases	1/6		
Kinetic energy of exhaust gases . . . . . . = Useful work of reaction		1/6	
Heat lost to walls of combustion . . chamber	1/3		
Utilized part of these losses . . . . = Useful work of reaction		1/6	

Gorokhov considers as the most suitable flight speed that which is equal to half the exhaust velocity of the gases (550 m/sec), i. e., 275 m/sec, at which the above-mentioned overall efficiency of 58% is obtained.

At lower flight speeds the overall efficiency is correspondingly less. Thus, at a flight speed of 100 m/sec the overall efficiency will be

$$58 : \frac{275}{100} = 21\,\% .$$

René Lorin in his paper "Etude sur la propulsion des aéroplanes à grande vitesse" bases his work on A. Gorokhov's calculations, but gives a different computation. Assuming an airscrew efficiency of 0.80, he obtains the overall efficiency of the engine and airscrew as $0.25 \cdot 0.80 = 0.20$. He then compares a direct-reaction (jet) engine in which the gases are ejected at a velocity of 250 m/sec with an engine driving an airscrew at a [flight] speed of 25 m/sec.

The power developed by the engine is

$$A = F . V$$

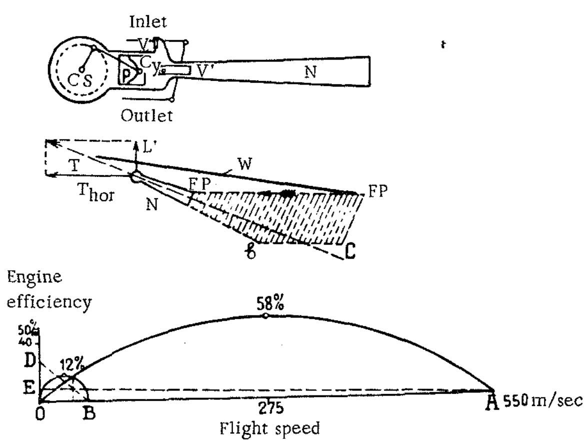
i. e., it is equal to the thrust multiplied by the velocity. The higher the speed obtained with the engine, the less will therefore be the thrust developed by it. The thrust developed by the jet engine will therefore be less than that developed by the airscrew in inverse proportion to the speeds: $25/250 = 0.1$. The overall efficiency of the jet engine thus exceeds that of the engine driving the airscrew by a factor of $0.58/0.20 = 2.9$. The thrust developed by the jet engine is thus $0.1 \cdot 2.9 = 0.29$ times that developed by the engine driving the airscrew.

70 The airscrew thus develops a higher thrust as long as the flight speed is low. However, when the latter increases, the thrust developed by the airscrew decreases quite rapidly. On the other hand, the thrust developed by the jet engine remains almost constant, since the flight speed is small in relation to the discharge velocity of the gases.

We shall, as an example, compute the thrust which the jet engine shown in Figure 90 can develop. The engine consists of cylinder (C), piston (P), crankshaft (CS), and two valves (V) and (V'); the exhaust valve is provided with nozzle (N) through which the gases escape and in which the work of the reaction is performed.

The crankgear shown on the drawing serves only for charging the cylinder with fresh mixture and actuating the inlet and exhaust valves which are opened at the required instants once every two revolutions of the crankshaft. The engine thus operates like an ordinary four-stroke internal-combustion engine.

(69)



FIGURES 90–92. Gorokhov's theory

Assuming a cylinder capacity of 50 dm^3 and a rotational speed of 1,500 rpm, we obtain the volume of aspirated air per second as

$$\frac{50 \cdot 1500}{2 \cdot 60} = 625.\, dm^3.$$

This air weighs $625 \cdot 1.263 = 808.225$ g (force) or $808.125/9.81 = 82.3$ g (mass).

Let the combustion pressure be 6–8 atm, and the pressure at the instant at which the exhaust valve opens, 4–5 atm. According to experiments the gases are in this case discharged continuously at a velocity of approximately 550 m/sec. The thrust developed is obtained from the momentum of the gases:

$$m.v = 82.3 \,.\, 550 = 45.265 \; kgfm.$$

We assume that the gases are discharged continuously and neglect the reaction of the atmosphere. This thrust would be developed in empty space, e.g., during interplanetary flight. During flight in the atmosphere the air not only serves as support but also provides fuel [oxidizer] since the oxygen mixed with the hydrocarbons of combustible substances provides heat that is converted into mechanical work.

René Lorin suggested that the axis of nozzle (N) be inclined to the flight path (FP—FP) (Figure 91). In the case of discontinuous flow of gases through the exhaust valve the gases will always encounter new layers of more or less stagnant air. Figure 91 (shaded portion) shows the column of gas ejected by the engine. Due to the inclination of the axis of nozzle (N) in relation to the flight path (FP—FP) the thrust T can be resolved into the lift L and the horizontal thrust T_{hor}. Wing (W) is situated in the jet of ejected gas (FPFPbc).

There is reason to assume that in this case the total mass of the gases set into motion is 4 times larger than the mass of the air aspirated by the engine. It can then be assumed that the discharge velocity is 50% of 550 m/sec.

The momentum of these gases is

$$m \cdot v = 82.3 \cdot 275 \cdot 4 = 90.530 \text{ kgm/sec}$$

71 We obtain the fuel consumption from the actual kinetic energy:

$$\frac{mv^2}{2} = \frac{82.3 \quad 550^2}{2} = 12447.87 \text{ kgm}$$

The efficiency at which the energy of the fuel is converted into the kinetic energy of the freely discharged gas was found to be 58%. The energy supplied by the fuel [per sec] thus is

$$\frac{12447.27}{0.58} = 21461^{*} \text{ kgm}$$

An ordinary gasoline engine consuming this amount of fuel and having an efficiency of 25% would develop a power of

$$21461 \cdot 0.25 = 5365 \text{ kgm/sec, or } \frac{5365}{75} = 71.5 \text{ hp.}$$

A 71.5 hp engine thus develops a thrust of 90 kg, i.e., 1.26 kg/hp, whereas a car develops a thrust of 1 kg/hp at a speed of 200 km/hr, and even less at higher speeds.

Figure 92, for comparison, shows the efficiency of an engine with airscrew (curve *OB*) and that of a jet engine (curve *OA*). The abscissae represent the flight speed in m/sec, whereas the ordinates indicate the efficiency in %.

The thrusts are also given for the airscrew (line *DB*) and for the jet engine (line *EA*).

On 10 June 1911 patent No. 236377 was granted to Dr. Bing in Berlin for a jet engine. According to Esnault-Pelterie this patent contains the idea of a rocket very similar to that proposed by Goddard in 1915. The purpose of the machine was to explore the upper layers of the atmosphere with the aid of a jet engine. Bing, however, envisaged discharge of the gases in the 3 coordinate directions for the automatic control of the plane.

* Gorokhov here erred in the calculation, obtaining 18,750 instead of 21,461 kgm.

R. Esnault-Pelterie envisaged the possibility of designing a jet plane as early as 1911 (Figure 93).

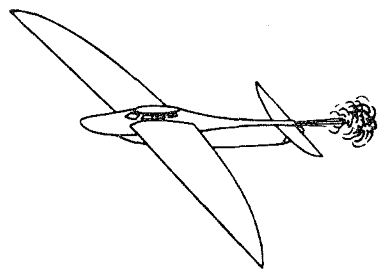


FIGURE 93. Esnault-Pelterie's jet plane

h) **Latest works**

CRASSUS' JET HELICOPTER

In Hamburg in 1912 Engineer Crassus proposed a jet helicopter of the following design (Figure 94): The gondola of the machine was to be secured to a vertical shaft which carried the generators producing the combustible substance. The latter was to flow along this shaft and after being ignited
72 was to be discharged through a large number of curved nozzles arranged on the circumference of the upper wheel.

The reaction force induced was to rotate the wheel together with the blades secured to it, thus creating the lift.

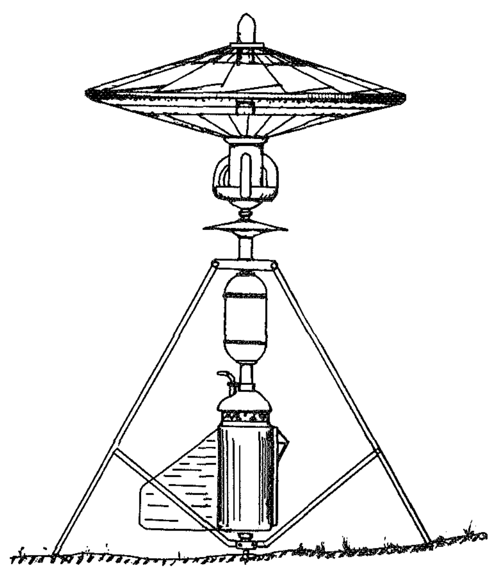


FIGURE 94. Crassus' jet helicopter

PATIN AND ROUILLY'S JET GYROPTER

In France in 1912 Patin and Rouilly proposed a heavier-than-air flying machine which externally resembled a sycamore seed (Figure 95).

(73)

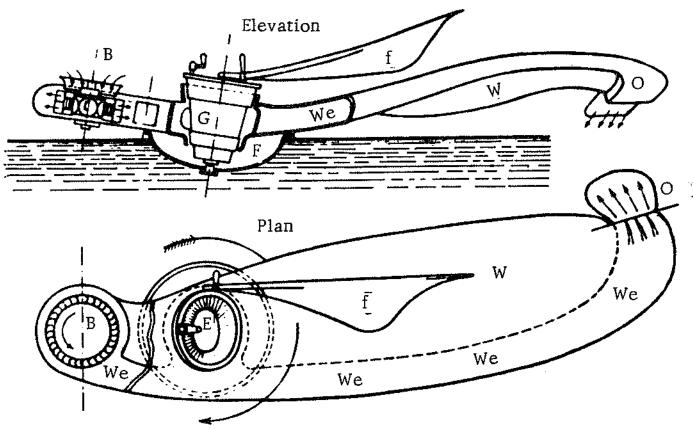


FIGURE 95. Patin and Rouilly's gyropter

The machine consisted of a large wing (W) whose leading edge (We) contained a duct. The gaseous products of combustion were discharged from engine (E) via this duct and opening (O) after being mixed with air aspirated by blower (B). Gondola (G) was located in the center of the machine. The reaction force due to the discharged gases rotated the wing about gondola (G) which remained almost stationary since it was carried by the wing on ball bearings and was also prevented from rotating by fin (f).

(73)

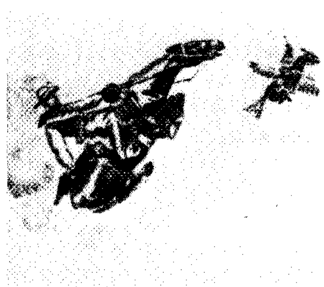


FIGURE 96. Rocket and humor

73

Float (F) enabled the machine to stay on the water. When the engine was stopped, the machine landed like a parachute; drag caused the wing to rotate.

This machine was built and tested. It was equipped with an 80 hp rotary Rhône engine operating at 1,200 rpm. The wing area was 12 m^2. The discharge velocity of the gases was 100 m/sec at a flow rate of 7 m^3/sec. The weight in operation, including the pilot, was 500 kg.

ROCKET AND HUMOR

Figure 96 is a caricature of the application of the reaction principle which appeared in the "Fliegende Blätter." An American cowboy pursues an Indian, but the latter flaps enormous wings and flies away. The cowboy, firing toward the rear with his repeating revolver, is lifted into the air by the recoil and overtakes the Indian.

LEPINTE'S ROCKET-ASSISTED PLANE

In 1924 the French captain Albert Lepinte suggested that landing of airplanes be facilitated by actuating rockets arranged beneath the wings. Figure 97 shows the arrangement of the rockets and their design. The drawing on top shows the rocket consisting of closed metal cylinder (1), asbestos shell (2), gunpowder charge (3), a porcelain shell (4), sleeve (5), and electric detonator (6).

The drawing in the center shows rocket (1), airscrew thrust (2), and reaction force (3) created by the rocket. The unnumbered arrow represents the resultant of the forces, the force which enables the airplane to fly over the ditch.

74

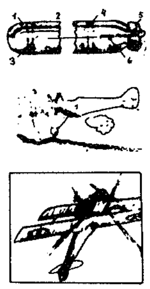


FIGURE 97. Lepinte's rocket-assisted plane

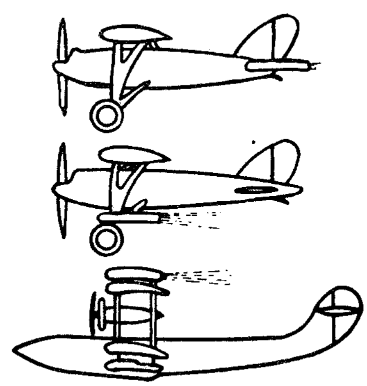


FIGURE 98. Minery's rocket-assisted plane

The drawing at the bottom shows the airplane in flight with the rockets in action prior to landing. This idea was taken up in 1926 by H. Minery. In 1927 he proposed that an airplane, having lost speed slightly above ground, might regain stability by means of a rocket engine (Figure 98) using, for example, gunpowder. One kg of gunpowder, supplying an energy of 320,000 kgm and burning for 5 sec, can develop a power of $320{,}000/75\cdot5 =$ > 800 hp, thus permitting the airplane to attain a speed sufficient for operation of its rudder and airscrew.

The idea of braking an airplane during landing continued to occupy designers. Thus, No. 8 of "Aviation and Chemistry," 1928, [it is not known in what language this journal was published] gave a picture illustrating this method. Two rockets were in front of the airplane, ejecting gases forward.

ZELLNER'S HEAT PENDULUM

The German scientist Zellner designed an instrument performing oscillations, similar to a pendulum, caused by reaction force (recoil).

This instrument (Figure 99) consists of a water-containing retort suspended from a stand and heated by a burner. When the water boils, the steam escapes through an opening and thus causes a reaction force which pushes the retort in the opposite direction (toward the right on the drawing); the retort is thus cooled so that less steam is formed. The retort then returns to the left, being alternately heated and cooled, so that it oscillates from side to side.

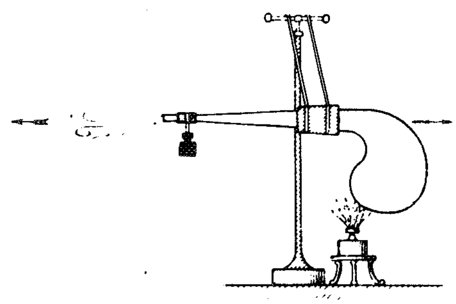


FIGURE 99. Zellner's heat pendulum

75 VENTOUX-DUCLOS' REACTION ENGINE

Engineer Ventoux-Duclos proposed that a series of explosions be caused to take place in the combustion chamber of a reaction engine. This was to be done by means of rapidly opening and closing ports leading to exchangeable cartridges with explosive charges.

In his paper "The Airplane of the Future" [in German], A. Wegener took up Lorin's idea, writing as follows:

Such a jet plane is possible. An airplane, similar in appearance to an ordinary plane, is equipped with a gas generator instead of the usual engine and airscrew. The gas generator aspirates air from the surroundings and mixes it with a special kind of fuel; upon combustion this yields a strongly expanding mixture which is led via an exhaust pipe into the wing. The pipe is placed along a spar of the wing (or replaces a spar) and has a number of openings which permit the gases to escape above the upper surface of the wing in a direction opposed to that of flight. This greatly increases the difference in the relative air flow velocities at the upper and lower surfaces of the wing, and thus increases the lift. The effect is even more pronounced if slotted wings are used.

i) The jet engines of Melot and others

As early as 100 years ago, attempts were made to propel boats by the reaction force created by jets of water. Water was pumped from the river into a high tank and discharged from it with a high velocity at the stern. This method was employed in shallow areas and during stormy weather when neither propeller nor oars functioned well enough to propel lifeboats.

In France engineer H. F. Melot invented a kerosene jet engine and carried out tests with it. The energy of combustion in this engine was converted directly into recoil energy without intermediary connecting rod, crank, and airscrew. Melot's engine is shown schematically in Figure 100. After combustion the gas escaped through a narrow opening at a very high speed. The reaction force thus created is proportional to the mass of the gas and to its velocity, while the kinetic energy of the gas is proportional to its mass and to the square of its velocity. However, when the gas is discharged at a high velocity the reaction force is small in relation to the huge loss of kinetic energy. The efficiency can be raised by increasing the amount of air inside the engine, thus increasing the mass ejected so that the discharge velocity is reduced. This is achieved by means of the four injectors shown on the drawing. The gases formed in the engine flow through pipes and encounter
76 an inflow of air in the four injectors which increases from injector to injector.

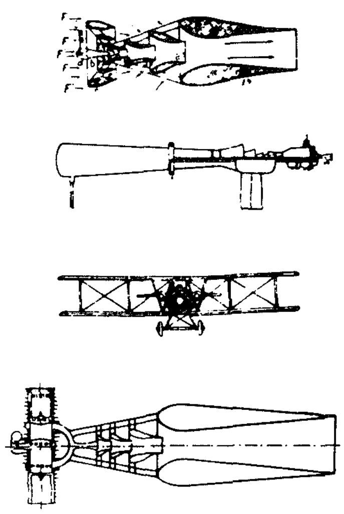


FIGURE 100. Melot's engine

Melot carried out his experiments in 1920. His last design was a two-stroke internal-combustion engine.

A horizontal cylinder has two partitions which form the combustion chamber. Each partition carries an electric spark plug which ignites the gas supplied to the combustion chamber under pressure. Three rows of ports are arranged in the chamber walls; the central ports connect the combustion chamber to the carburetor, while the outermost ports connect it to the exhaust pipe leading to the first injector.

A piston moves to and fro inside the cylinder. Recesses in its crown correspond to the rows of ports. The piston speed is sufficient for the compression of the gas to be high enough for self-ignition, so that pre-compression and spark ignition are necessary only during starting. The engine weighs approximately 4.8 kg/hp.*

Such an engine might be of value for high-speed airplanes.

Melot also designed similar engines developing 250 and 750 hp. The engine he built developed about 30 hp at a flight speed of 50 m/sec and had a thrust of approximately 75 kg.

Figure 100 shows Melot's engine as well as another version of it, and its arrangement in an airplane.

USE OF ROCKET TURBINES FOR CONVERTING SOLAR HEAT INTO MECHANICAL WORK

In 1920 K. Baetz suggested discharging carbon dioxide from nozzles secured to the circumference of a wheel. This would cause the wheel to

* 1 kg/hp according to "Flugsport," 1926, p. 145, and 0.5 kg/hp according to V.V. Fl., No. 13, p. 39, 1922.

rotate, producing mechanical work. The CO_2 was to be supplied to the nozzles via pipes from a tank where it was to be obtained from carbonic acid (H_2CO_3) heated by solar energy to 60°C. The relevant computations were published by the inventor in "Die Rakete," 1928, p. 101.*

ANDREEV'S ROCKET APPARATUS

In 1921 in the USSR A. F. Andreev applied for a patent for a portable rocket apparatus which, in his opinion, a person could carry on his back like a knapsack. Vessels in this apparatus contained liquefied methane and oxygen which upon combustion produced a reaction force. The latter enabled the person to move over a distance of 20 km at a speed of 200 km/hr. The entire apparatus with the fuel weighed about 50 kg. The fuel weighed 8 kg. The total weight of the person with the apparatus was about 100 kg.

A description of the apparatus patent (application No. 3255, 18 February 1921) follows.

77 GRANTING OF THE PATENT WAS PUBLISHED ON 31 MARCH 1928. THE PATENT WAS VALID FOR 15 YEARS BEGINNING 15 SEPTEMBER 1924.

The proposed flying apparatus with rocket engine is intended for the transportation of a person or small loads for a distance of up to 20 km.

The drawing (Figure 101) shows the design of the vessel for the liquefied gas in Figures 1 and 2, and the telescopic girder in Figures 3 and 4.

The apparatus consists of two parts arranged independently of each other, namely 1) a vessel for two liquefied gases: oxygen and a hydrocarbon, with a duplex pump directly connected to the vessel (Figures 1 and 2); 2) a telescopic girder with two adjustable rockets and a telescopic pipeline inside the girder, supplying fuel to the rockets (Figures 3 and 4). The vessel for the liquefied gases is made from a strong shatterproof material and has double walls (1); the space between them is evacuated in accordance with the principle of the Dewar flask. The vessel is divided into two independent parts (a) and (b). The liquefied gases are protected against shock and concussion during transport by the interior of the vessel being subdivided by a system of thin partitions (2) into communicating cells like a honeycomb. Two valves (3) are arranged at the bottom of the vessel (Figures 1a and 2) according to the number of gases (two) in the two parts of the vessel. The liquefied gases are, at the required instant, admitted through these valves from the vessel into the pumps described below. Handle (4) of each valve shutting off or admitting the gas is connected to a rod linked to telescopic girder (5), which automatically opens the valves when the girder is extended and closes them when the girder is telescoped. The metallic duplex pump consists of two independently operating pumps (6) of the type used to inject liquids into internal-combustion engines, and it is actuated by large powerful spring (7). The pinion of spring (8) drives the gears of pumps (9). These pumps serve to supply predetermined

* [This is apparently the gist of the proposal. The author of the book either did not understand it, or could not express himself clearly.]

amounts of liquefied gases to the rockets. Two pipes (10) issue from each pump. The entire system of the twin vessel (a) and (b), with valves and pumps, is secured to common rigid metal frame (11). The telescopic
78 girder consists of rigid box (12) and two telescopic trusses (13) at the sides of this box. Each of these telescopic trusses contains telescopic pipeline (14) which serves as continuation of pipe (10). This pipeline consists of telescoping copper pipes parallel to the two trusses in such a manner that the gases can be supplied to the rockets irrespective of the distance to which the girder is extended. The body, which has to be transported by means of the rocket apparatus, e.g., a person or a missile with asphyxiating gas or explosives, is secured to the center of the rigid box of the girder. The gases are discharged at a high temperature during operation of the rockets; the girder protects from the discharge the items located in the center of the system, such as the vessel with the liquefied gases and the payload. The entire girder is made of light, strong metal. Rockets (15) are arranged at the end of each telescopic truss. The interior of the rockets is made of a refractory material withstanding high temperatures; exteriorly the rockets are enclosed in steel shells (16). The two gases enter through openings (17) in each pipeline, expand in part of duct (18), and mix at the beginning of the bend. They thus form a combustible mixture which upon burning has a maximum discharge velocity along curved duct (19) and causes a reaction force when leaving the rocket. The rockets are secured to the girder in such a way that during flight they can be rotated about axis C—D

(77)

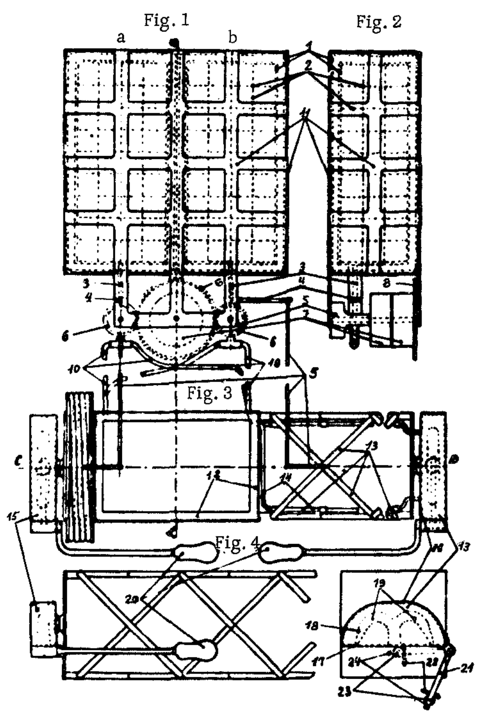


FIGURE 101. Andreev's rocket backpack

for the purpose of altering the angle of inclination of the gas jets in relation to the apparatus as a whole. The rockets have control handles (20) which serve: a) to extend and telescope the girder when pulled in either one of the two directions parallel to axis C—D; b) to ignite the gases when the handle is moved to a certain angle so that it is parallel to axis A—B and perpendicular to C—D, so as to put into operation ignition device (21) (which is similar to a gasoline lighter). After a spar has been obtained and the mixture ignited, the entire device is automatically returned to its initial position where it is not subjected to the hot gas jet discharged from the rocket.

Further rotation of the handles permits the angle of inclination of the rockets to be altered in relation to axis A—B; this permits the motion to be controlled, since the ratio of the weight of the body located in the center of the telescopic girder to the impulsive force of the rockets acting in a certain direction in space determines the direction of motion of the apparatus. The arrangement of the two main parts of the apparatus, i.e., the vessel for the liquefied gases (Figures 1 and 2) and the telescopic girder with the rockets and the telescopic pipelines (Figures 3 and 4), in relation to each other, both as regards the distance and the position, can be varied according to the shape and size of the body to be transported by the apparatus. Thus an elongated, heavy body, having the shape of a mine, can be secured to the rear of the girder along axis A—B. The vessel with the liquefied gases is then placed directly above the girder. When the body is spherical or only slightly elongated but light, e.g., a missile with a toxic but light gas, the vessel containing the two gases, being heavier, is positioned beneath the girder, with the missile above it. When a person is to be transported, the rigid box of the girder is secured to the chest. The vessel with the gases is then placed on the back of the person like an ordinary knapsack.

Liquefied gases flow from vessel parts (a) and (b) through valves (3) and pumps (6) while the engine is in operation. The pumps deliver the gases
79 at a constant pressure through pipelines (10) and (14) to rockets (15) where they are burnt. The discharge velocity of the products of combustion is high, so that the reaction force created by them is also large. The latter propels the entire apparatus in space, together with the body to be transported.

j) Gussalli's double-reaction turbine

In 1923 the Italian engineer L.Gussalli proposed a reaction engine, which he called a double-reaction turbine. The principle of this engine is as follows (Figure 102, top):

Assume that fuel burns in chamber (C) (Figure 102a). If the chamber is tightly closed on top by cover (B) screwed to (C), the expanding gases will exert a pressure on the walls, bottom, and top of chamber (C), whose resultant is R. Now we slightly separate (B) from (A), but leave a rigid connection between them (Figure 102b). After combustion the gases are deflected at the depression in cover (B) and escape at a certain velocity v. The entire system will then be propelled by the reaction force R_1 in the direction of the latter. Assume now that cover (B) can move toward

80 chamber (C) at a certain velocity v_0 (Figure 102c). The gases escaping from beneath cover (B) will then have a velocity V which is higher than in the case illustrated in Figure 102b. Cover (B), and thus the entire engine connected to it, is therefore subjected to a larger reaction force R_2. This reaction force R_2 is called by Gussalli double reaction; he proposed to obtain it in the following manner (Figure 102, bottom left): combustion occurs in chamber (C) from which the gases are discharged through nozzle (N) and impinge on the blades of turbine disk (B). The latter rotates in a direction opposed to the gas jet, being driven by engine (E) via step-up gears (G) and a shaft. The relative velocity of the gases leaving the turbine blades is added to the peripheral velocity of the turbine disk, so that the absolute velocity of the gas leaving the turbine blades will be larger than the velocity of the gas discharged from the nozzle. The entire engine is thus subjected to reaction force R_2.

(79)

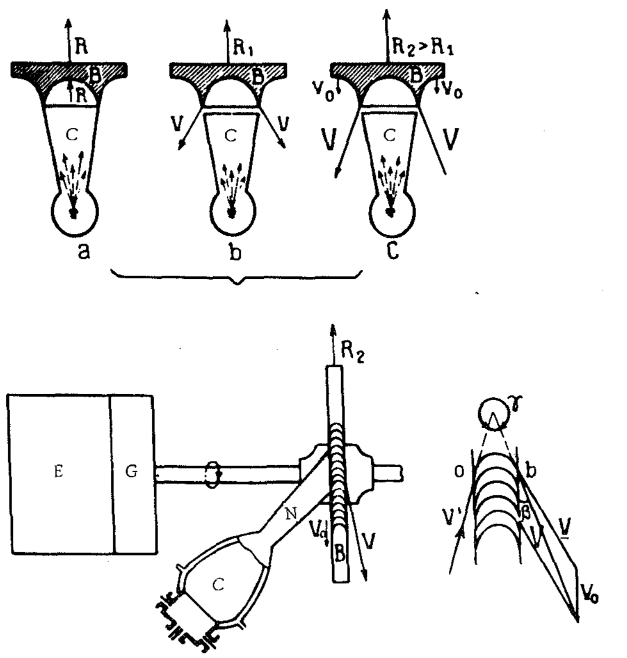


FIGURE 102. Gussalli's double-reaction turbine (schematic)

The velocity diagram is shown in Figure 102, bottom right, where v' is the gas-inlet velocity, v_0 is the peripheral velocity of the turbine disk, v is the gas-outlet velocity relative to the blades, V is the absolute gas-outlet velocity. Thus, at $v' = 1{,}500$ m/sec, V could be 2,100 m/sec. The angle β varies inversely with the circumferential speed v_0 and directly with the angle γ through which the gas stream is deflected.

Gussalli proposed that the turbine disk be rotated at a peripheral velocity of 500 m/sec.

The reaction force to which each turbine blade is subjected is

$$F = m\frac{v^2}{r},$$

where m is the mass of the gas leaving the blade, v is the gas velocity relative to the blade, and r is the radius of blade curvature. It follows from this that the reaction varies directly with v and inversely with r.

Gussalli tested his device, using a 50 hp Laval turbine and a Serpollet steam generator. The turbine speed was 16,000 rpm. Gussalli proved that the thrust obtained in his tests of this double-reaction turbine was considerably higher than that obtained with an ordinary direct-reaction engine. Figure 103 is an overall view of this turbine.

(81)

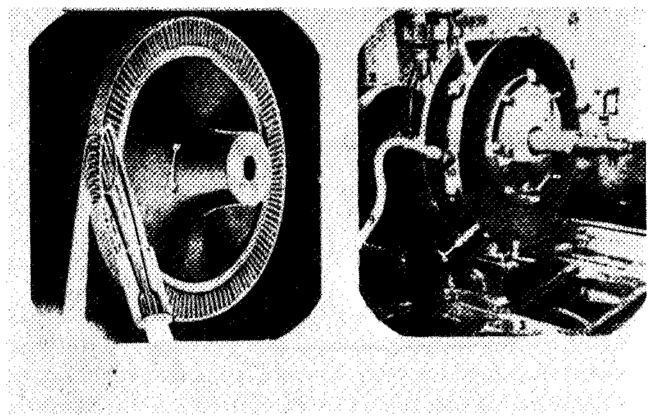


FIGURE 103. Gussalli's turbine

The use of double-reaction force for the propulsion of airplanes was also suggested by Didelot. His proposal was as follows:

The airplane rolls on the ground, being propelled by the thrust of an airscrew with horizontal axis. The [relative] opposed current of air acts on turbine blades, creating lift. The latter is increased if the turbine is rotated in the opposite direction, as proposed by Didelot. This principle is the basis of De Cierva's autogiro. Gussalli's idea, however, does not give the required results if engine (E) is arranged with the turbine on a common base.

k) Reaction planes, airships, and railcars

Model of Russian rocket plane.

One model, built by Turkestanov and participating in the 1924 model-airplane competition held in Tiflis [Tbilisi], had a rocket engine. The model took off very smoothly and flew successfully through the air. However, the wings broke after a short time, and it crashed after a flight of 32 m.

81 ROCKET PLANE

A notice appeared in the "Samolet" that the French Ministry of War had given financial assistance to a laboratory in which a novel airplane had been developed in strictest secrecy. This airplane had no airscrew but was rocket-propelled. The fuel mixture was compressed in a chamber and upon ignition produced gases which were successively discharged through a series of orifices in the tail of the airplane, thus imparting to it the necessary translational motion. The speed of this plane was assumed to be 600 km/hr.

THE "TSIOLKOVSKII 20" AIRSHIP OF THE FUTURE

Tsiolkovskii's idea of using rocket engines and metal airships whose lift was to be obtained by exhausting air from the airship shell impressed B. Lobach-Zhuchenko who, in his book "Vozdushnye soobshcheniya i perelety cherez morya i okeany" (Air Communication and Flights Over Seas and Oceans), described a flight on a future rocket-propelled airship and its assumed design.

He wrote, "The long, silvery, cigar-shaped body of the airship "Tsiolkovskii 20" appeared on the horizon carrying 500 passengers at a speed of 500 km/hr. After a few minutes had passed, the airship hovered above the watchers and then descended slowly and smoothly.... This is its design: it embodies the rocket principle in the form of several reaction engines. The direction of the reaction can be changed by turning the engines, and this changes the direction of flight. The reaction generally has an inclined direction and thus provides both lift and forward motion; it creates lift only if its direction is vertical.

82 The rocket engines are located at several points: at the stern, on the sides, and at the bottom of the airship; two engines are even fitted at the bow in order to permit motion astern during maneuvering...

It is superfluous to add that the appointments of the airship are the last word in engineering: loudspeakers, radio-telephone, television, etc., all for the convenience of the passengers."

USE OF TSIOLKOVSKII'S ROCKET FOR RAIL PROPULSION

In "Nauka i Tekhnika" (Science and Technology), Engineer Fenteklyuz mentioned the possibility of mounting Tsiolkovskii's rocket on a railroad flatcar and propelling the latter on the track by reaction (Figure 104b).

USE OF JET ENGINES FOR RAIL PROPULSION

In the same journal Fenteklyuz proposed that jet engines be used to propel trains (Figure 104a).

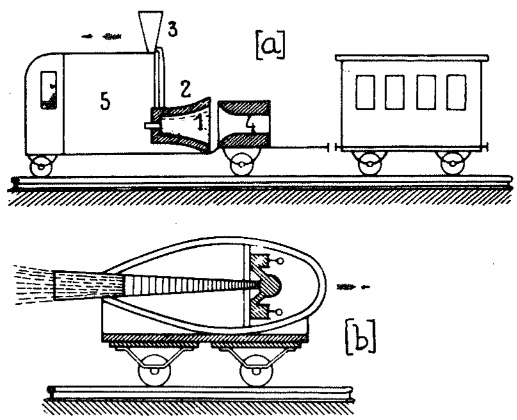


FIGURE 104. Reaction-propelled railcars

A car is placed at the head of the train, the engineer being seated in front. The fuel is carried behind him, and the jet engine is placed in the rear. The fuel might be either pulverized coal or oil atomized during the operation. The engine consists of 4 or 5 combustion chambers (cylinders), each of which operates independently. A quantity of automatically introduced fuel is in cylinder (2) combined with the necessary quantity of air and ignited by means of an electric spark plug energized from a magneto. Reverse motion is obtained by turning the engine around; the nozzles thus point in a direction opposite to that of travel. Figure 104a shows combustion chamber (1), cooling water (2), radiator (3) with water, silencer (4), and fuel reservoir (5).

83 TSIOLKOVSKII'S HOVERTRAIN

In 1927 Tsiolkovskii proposed the construction of a fast train traveling without wheels and lubrication. Figure 105 is the section and plan of a car of this train; the bottom of car (B) has two grooves (G). Railroad bed (RB) and rails (R) are in the same plane. Air is forced into grooves (G, G) by two independent engines and expands in a narrow gap between the car and the track. The air lifts the train a few mm and escapes along the edges of the car bottom. The car does not move on the rails, but is carried on a thin layer of air and is subjected only to the very slight friction of the air itself, like a flying object. Flanges prevent the car from leaving the rails and reduce the air outflow, since the air currents change direction abruptly at these points. The bottom of the car has shallow flutes (F, F) which also reduce the air outflow. The air enters through an orifice (OF) in the front of the car and escapes partly through the gap around the latter and partly through orifice (OR) in the rear. The reaction force thus created propels the train. The shape of the car at the front and rear is designed to reduce air resistance. The engine delivering the air to the orifice in the rear may be independent of the other engines.

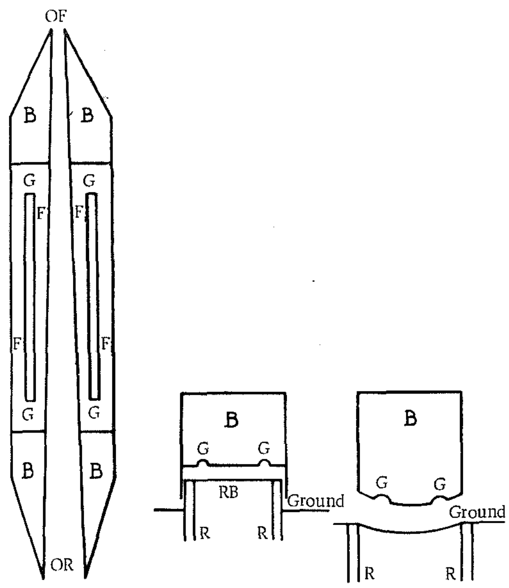


FIGURE 105. Tsiolkovskii's hovertrain

The drawing on the right shows the section of a different car having a cylindrically convex bottom and no flanges. This design improves the stability but makes track construction more difficult.

1) Opel and Valier's rocket vehicles

In 1928 Messrs. Opel, German automobile makers, carried out a series of trials testing rockets for propulsion on land and water. Car No. 1 had 12 rockets at the rear (4 in each row). Ignition was by means of electric sparks; the contacts were arranged on a keyboard. The first trial run of this car took place on 11 April 1928 under the direction of Volkhard on the test track at Rüsselsheim near Mainz. A speed of 100 km/hr was attained within 8 sec.

84 Figure 106 is an overall view of this car, while Figure 107 shows its rear with the rockets.

Wings were fitted to the sides of the car, which forced it against the ground during the run.

85 Engineer Volkhart had prepared a slightly different car design in order to obtain better streamlining (the rear tapered to an edge and wings were fitted ahead and astern of the wheels) (Figure 108, top). Due to production considerations, however, the car was built more in accordance with Valier's ideas (Figure 108, bottom).

F. W. Sander (Figure 109) played an important role in this and later trials. He was born in 1886 at Glatz in Silesia [now Klodzko, Poland]. After finishing high school, he worked for some years as an engineer

(84)

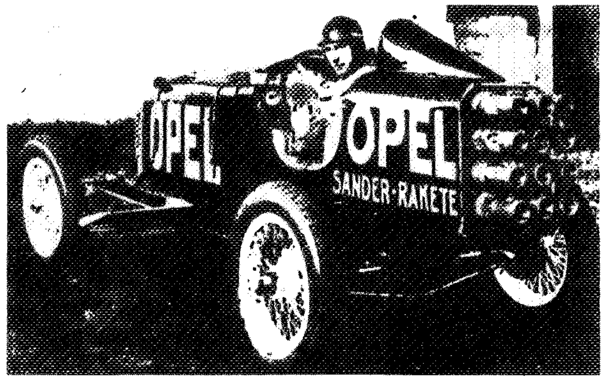


FIGURE 106. Opel-Sander rocket car No.1

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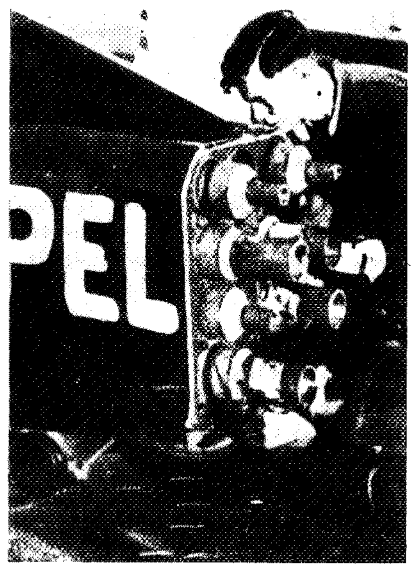


FIGURE 107. Details of Opel-Sander rocket car No. 1

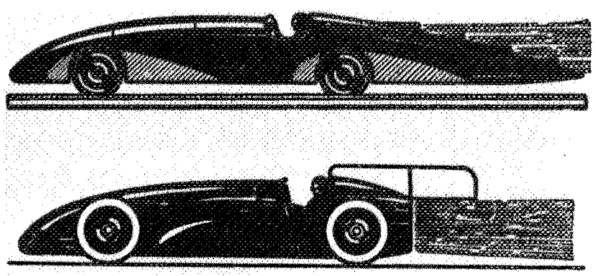


FIGURE 108. Rocket cars designed by Volkhart (top) and Valier (bottom)

designing steam engines and ice machines in Hildesheim, and internal-combustion engines in Hanover. In 1920 he invented a rescue apparatus for saving lives at sea. From 1911 onward he was scientific consultant to Messrs. Cordes at Wesermünde. He later designed rocket cars.

86

FIGURE 109. F.W. Sander

The "Opel-Sander No. 2" car (Figure 110) was designed after the successful trials at Rüsselsheim. This car carried 24 rockets and had a smoother outline. It even had larger wings at its sides. On 23 May 1928 this car attained a speed of 236 km/hr on the Avusbahn near Berlin. The average speed after the end of acceleration was 196 km/hr. The car weighed 800 kg. Each rocket contained 5.4 kg gunpowder. Figure 111 is a cross section of such a rocket (of Goddard's type).* The thermal efficiency of the rocket was only 15%, and the mechanical efficiency 3%.

Figures 112 and 113 show details of the car, namely, the rocket nest and the control lever.

Lastly, Figure 114 shows in detail a front wing of the car.

Max Valier also participated enthusiastically in this work, together with Opel and Sander.

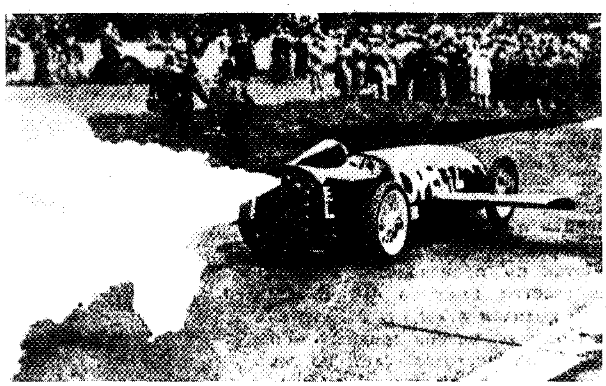


FIGURE 110. Opel-Sander rocket car No. 2

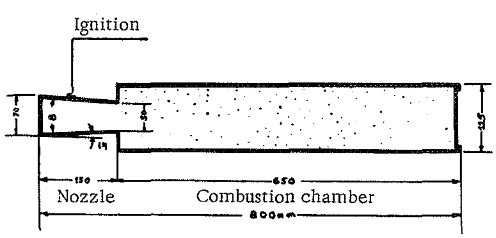


FIGURE 111. Opel car rocket

* According to Scherschevsky the nozzles had exit-section diameters of 80 mm and throat diameters of 35 mm. The divergence angle was 30°.

(87)

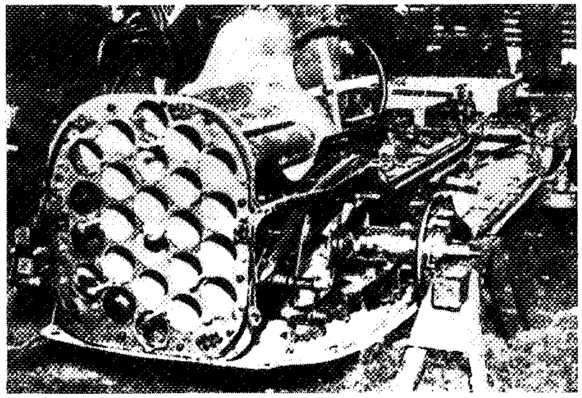


FIGURE 112. Details of rocket nest of Opel-Sander car No. 2

(87)

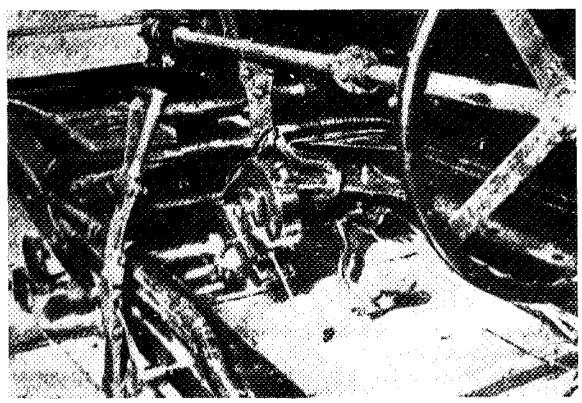


FIGURE 113. Details of control lever of Opel-Sander car No. 2

(88)

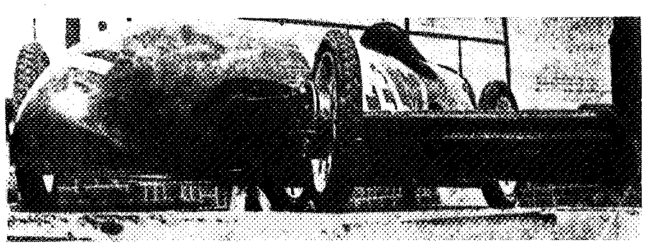


FIGURE 114. Details of Opel-Sander car No. 2

The next stage in the trials was the test of a rocket-propelled railcar (No. 3). The first trial of the latter was carried out on 23 June 1928 on a straight section of the Hanover-Celle line near Burgwedel. The railcar was started without a driver, being controlled automatically. A reduced number of rockets was fitted in it at first, and ignited successively by electric spark. Figure 115 is a photograph of the railcar taken during the run. The trial was successful. Figure 116 shows the railcar schematically. Its frame was 3.5 m long. Provision was made at the rear for the installation of 24 rockets. A braking rocket and wings with negative angles of attack, forcing the car onto the rails, were fitted in front. Braking was effected automatically by the rocket and wings at the front, and by a special claw gripping the rails (Figure 116). Figure 117 gives an overall view of the railcar.

(88)

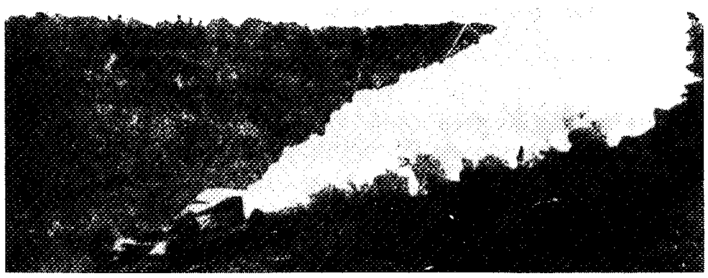


FIGURE 115. Opel-Sander railcar No. 3 in motion

(89)

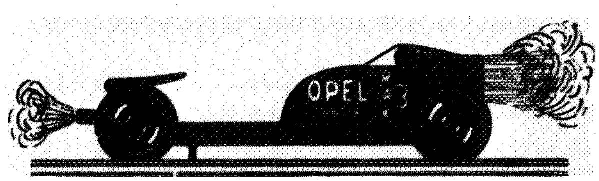


FIGURE 116. Opel-Sander railcar No. 3 (schematic)

87 The track length was 5 km. The test run was carried out over a length of 2 km. A speed of 180 km/hr was attained. One of the rockets exploded and flew into the air during the trial.

The trial was repeated on 25 June 1928. Electric Löbner clocks were set up along the track at intervals of 250 m in order to measure the trial speed. All 24 rockets were actuated, being ignited successively in groups of 6. A cat was placed in the railcar in order to investigate the effects of the acceleration on the body.

88 However, the high acceleration caused derailment of the car; the rockets exploded, and the vehicle was damaged. The newspapers reported that Opel had also built a rocket yacht. An explosion occurred on it during trials on the Rhine and, although the passengers were saved, the yacht sank.

(89)

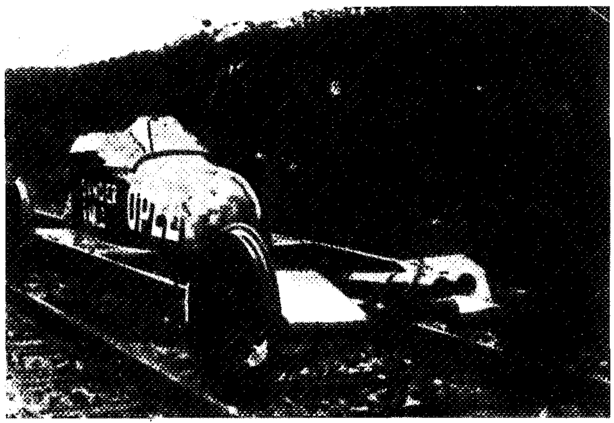


FIGURE 117. Opel-Sander railcar No. 3

After the trials with Messrs. Opel, Valier concluded an agreement with Messrs. Eisfeld for the purpose of continuing tests with rocket-propelled vehicles on land.

The new trials were based on the following principles:

1. The vehicle was to function as did the rocket staff, and the rocket was to pull and not push it.
2. The mass of the vehicle should be minimal, absolutely and relative to the mass of the charge.
3. The vehicle should be forced against the ground by the [vertical] component of the recoil and the air pressure, and not by its weight alone.
4. Propulsion should be achieved by a large number of small but powerful rockets.

Figure 118 shows the first experimental Valier-Eisfeld rocket trolley. Its rockets had a diameter of 35 mm and a length of 35 cm; the wheelbase was 1.8 m.

The trial was carried out on 11 July 1928. The total weight of the 8 1.2 kg rockets was 9.6 kg. Each rocket contained 400 g gunpowder and developed a thrust of 22 kg. The test run was carried out on a 200 m-long
89 track having a grade of 5%. Two rockets operated at first, and a speed of 45 km/hr was obtained. The second trial was carried out with 4 rockets, the speed attained being 80 km/hr.

(90)

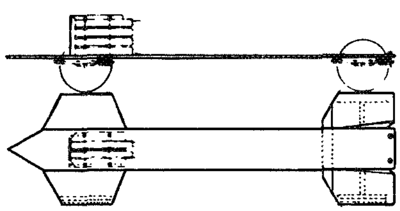


FIGURE 118. Valier rocket trolley No. 1

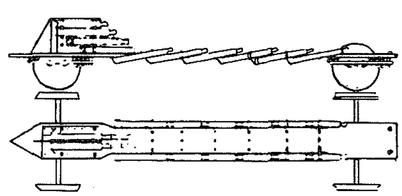


FIGURE 119. Valier rocket trolley No. 2

The second trolley is shown in Figure 119. It had a wheelbase of 1.5 m. The 8 rockets at the rear were supplemented by 12 more rockets arranged at a slope of 1/6. Trials were carried out on a 500 m-long track on 14 July 1928. The 22 kg vehicle attained a speed of 100 km/hr with 6 rockets in operation. The trolley again attained a speed of 100 km/hr with 4 rockets on 17 July 1928.

(90)

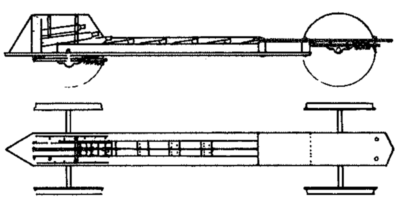


FIGURE 120. Valier rocket trolley No. 3

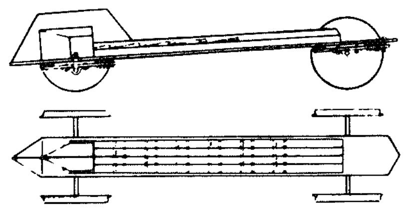


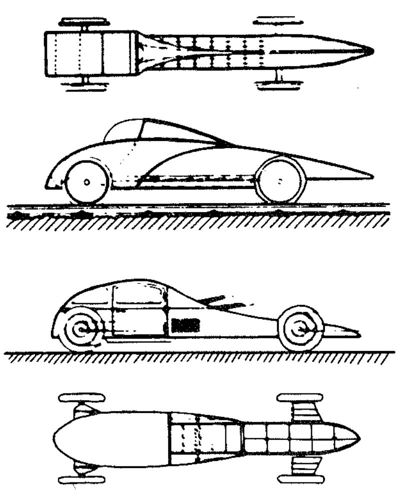
FIGURE 121. Valier rocket trolley No. 4

A new trolley was built thereafter (Figure 120). Its wheelbase was 2.4 m and the wheel diameter was 1.00 m; 16 rockets could be installed on the trolley which weighed 42 kg without the rockets. This trolley was successfully tested on 23 July, 6 rockets being fired.

The design of the trolley was changed again after this (Figure 121). The new trolley could carry 26 rockets. Its weight without the rockets was 44 kg; each rocket weighed 1 kg. A preliminary trial was held on 25 July with 12 rockets, 4 rockets operating at the same time. The thrust developed was 120 kg, and a speed of 180 km/hr was attained.

The first official trial of the "Eisfeld-Valier Rak I" (Figure 121) was held on 26 July. Four rockets were fired during the first and second runs. During the third run, 4 rockets were fired first, followed by groups of 4, 4, and 6 respectively, with 2 second intervals. A speed of 180 km/hr was attained in 2 sec, but the trolley left the rails when the last 6 rockets were fired.

(91)



90

FIGURE 122. Valier rocket trolley No. 5 and rocket car No. 6

The trials were continued on 3 October 1928. The first trial was successful, but at the second trial it was found that the wheels of the trolley were too weak when the load was increased.

Figure 122 shows two new types of rocket vehicles. These are the trolley and the car proposed by M. Valier for the near future.

Rockets are not suitable for propulsion on land at comparatively low speeds, since their efficiency is low (only 3% at 200 km/hr). A rocket engine becomes advantageous at considerably higher speeds, e.g., 2,000 km/hr.

m) Reaction airscrews and turbines

REACTION AIRSCREW WITH COMPRESSOR

It has recently been proposed to transmit energy to an airscrew by means of the reaction created by jets of air discharged through orifices in the trailing edges of the airscrew blades. In one of these proposals the air is to be supplied to the interior of the blades by a compressor (Figure 123a). However, this arrangement is not advisable since such a mechanism is very heavy and has a low efficiency due to the large losses in the compressor, pipes, and airscrew.

(92)

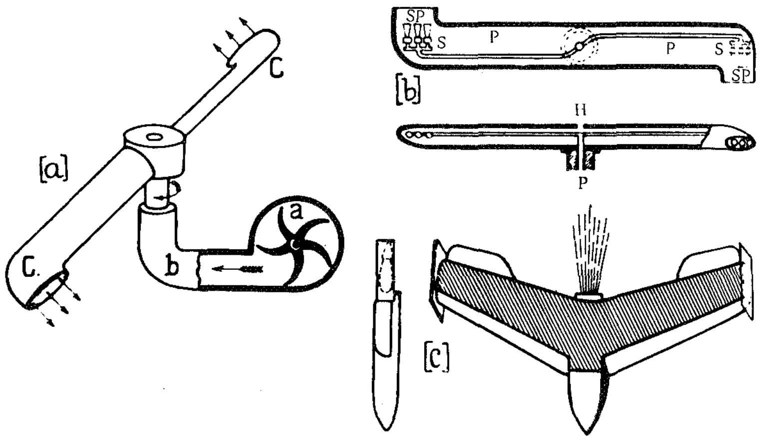


FIGURE 123. Reaction airscrew and rocket plane

91 YUR'EV'S REACTION AIRSCREW

V. N. Yur'ev proposed a reaction airscrew of the following design (Figure 123b): A hollow airscrew has a small hole (H) in its hub, through which the blades, acting like a centrifugal blower, aspirate air and discharge it at their tips, to which liquid fuel is also supplied through pipes (P) and atomized in sprayers (S). The atomized fuel is mixed with the air, ignited by spark plugs (SP), and burnt. The hot gases formed flow through pipes past the spark plugs and are ejected through nozzles at the blade tips, thus creating a reaction and rotating the airscrew. The fuel is supplied to pipes (P) by a pump. The efficiency can be increased by slightly precompressing the air entering the airscrew. This is achieved by fitting a centrifugal blower to the hub, which is driven by the airscrew via gears. This blower may also be used to improve the airscrew performance at high altitudes.

ROCKET WITH GAS TURBINE

The lift in one of the proposed rocket ships shown in 1927 at the Moscow exhibition of interplanetary machines was to be provided by airfoils and a gas turbine with blades through which the exhaust gases were to be ejected.
92 Heinrich Hein in his article "Der Schuss in den Weltraum" expressed the wish that rockets be used to take photographs of the Earth and its atmosphere from a high altitude (e.g., 6,400 km).

n) Experiments with rockets in Breslau [Wroclaw] and the Rhön

Flight tests of a model plane equipped with a rocket engine were carried out in Breslau on 23 November 1927. The biplane model weighed 200 g. The rocket engine weighed 120 g and was mounted in front below the wings. In flight the model performed a loop. Takeoff and flight lasted 10 sec. The plane landed in a glide. The rocket was later arranged more to the front, thus improving the performance. The wing span of the model was initially 2 m, but was later reduced.

A Göttingen 410 section wing was used in rocket flight tests in 1928.

Particulars of this model were as follows: wing span, 1.5 m; load, 6 kg/m^2; angle of attack, 2°; sweep angle, 24°. Ailerons provided stability (Figure 123c).

ROCKET TESTS

In 1927 Winkler studied the operation of rockets in the engine laboratory of the Technical College of Breslau. He determined the reaction force (recoil) caused by gas discharge from the rocket. An indicator, such as is normally used for determining the steam pressure, was used for this purpose.*

Figure 124 is the thrust diagram computed by him, while Figure 125 shows the test stand. A gunpowder fireworks rocket was used in the tests. Its overall weight with a protective steel casing was 120 g; the charge weighed 15 g, and the casing, 40 g. The gases were discharged upward. The diagram scale was 25 mm = 1 kg/cm^2. Since it became necessary to change the
93 pressure during the tests, some alterations had to be made. The diagram scale thus became 7 mm = 1 kg/cm^2.

The indicator drum was rotated by an electric motor at a peripheral speed of 40 cm/sec. The time marks were made on paper by an electromagnetic seconds pendulum with a pen, the scale being 0.4 mm = 0.001 sec.

The diagram shows that the reaction lasted for 0.35 sec, although the total duration of combustion was several sec. However, during the remainder of the time the reaction did not exceed 1%, so that the rest of the diagram was discarded.

* Both gunpowder and liquid oxygen with alcohol were used as propellent.

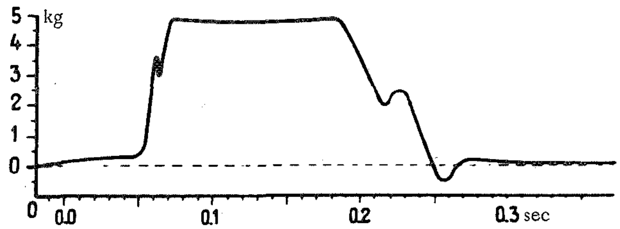


FIGURE 124. Rocket-thrust diagram

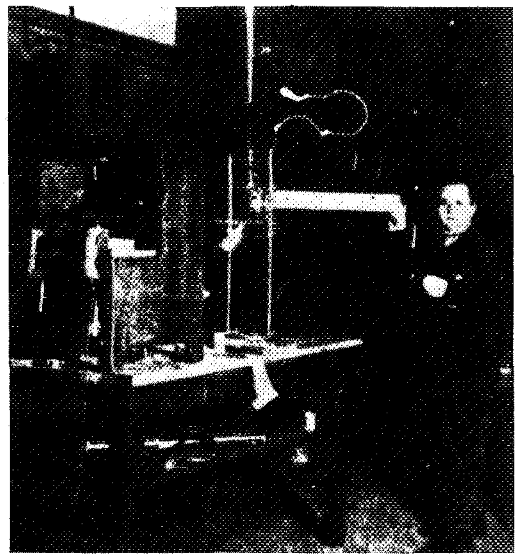


FIGURE 125. Rocket tests in Breslau

94 The diagram shows the following:
The impulse law gives

$$P.t = m.v = \frac{G}{g} v,$$

where P is the reaction; t is the time during which the reaction is effective; m is the mass ejected; G is its weight; $g = 9.81\ \mathrm{m/sec^2}$; v is the rocket speed attained. The latter is

$$v = \frac{P}{G}\, gt.$$

We obtain from the diagram: $P = 4.8\,\mathrm{kg}$, $t = 0.15\,\mathrm{sec}$, $G = 150\,\mathrm{g}$. Hence,

$$v = \frac{4.8 \cdot 9.81 \cdot 0.15}{0.150} = 47\ m/sec.$$

In reality the speed would be slightly higher, since the weight is reduced by 15 g.

The acceleration is

$$b=\frac{v}{t}=\frac{47}{0.15}=314\ m/sec^2.$$

The distance traversed by the rocket in vertical flight during combustion of the propellant is

$$h_1=\frac{b-g}{2}t^2=\frac{304}{2}\cdot 0.0225=3.42\ m.$$

The maximum speed attainable by the rocket when the gravitational acceleration is taken into account is

$$v_0=(b-g)t=304\cdot 0.15=45.6\ m/sec.$$

The maximum altitude attained, neglecting air resistance, is thus

$$h=h_1+\frac{v_0^2}{2g}=3.42+\frac{45.6^2}{19.6}=3.4+106\cong 110\,m.$$

The altitude attained is 80 m when air resistance is taken into account.

The gas-outlet velocity (c) is obtained from the equation

$$\frac{G}{G_0}=e^{\frac{v}{c}},$$

[assuming $G = G_0$ at $v = 0$] whence

$$c=v\frac{\lg e}{\lg\frac{G}{G_0}}=47\cdot\frac{0.4343}{\lg\frac{0.150}{0.135}}=47\cdot\frac{0.4343}{0.045}=453\ m/sec.$$

95 With a better nozzle we obtain c = 1,800 m/sec or even more (according to Goddard), whence

$$v=c\frac{\lg\frac{G}{G_0}}{\lg e}=1800\cdot\frac{0.045}{0.4343}=187\ m.$$

while the reaction will be

$$P=\frac{Gv}{gt}=\frac{0.150\ .\ 187}{9.81\ .\ 015}=19.1\ kg.$$

Hence,

$$b=\frac{v}{t}=\frac{187}{0.25}=1250\ m/sec^2;$$

$$h_1=\frac{b-g}{2}t^2=\frac{1240}{2}\cdot 0.0225=13.95\ m.$$

$$v_0=(b-g)t=1240\cdot 0.15=186\ m/sec.$$

$$h=h_1+\frac{v_0^2}{2g}=13.95+\frac{186^2}{19.6}=14\times 1{,}756\stackrel{*}{\doteq}1770\ m$$

* [These figures are reproduced from the Russian text; the correct expression is 14 + 1,765 = 1,779 m.]

Johannes Winkler was born on 29 May 1897 in Karlsruhe, Silesia, studied at high schools in Oppeln [now Opole] and Liegnitz [now Legnica], and finished his secondary education in Danzig [now Gdansk]. There he also studied for two semesters at the Technical College and then began to work on submarine design. After the end of World War I, he studied for a total of eight semesters at the universities of Breslau and Leipzig, passing his examinations in 1927.

Problems of cosmic rockets had attracted him earlier. He founded the journal "Die Rakete" in 1927, as well as the Association for Interplanetary Communications.

TESTS OF VALIER'S ROCKETS

In 1927 the German inventor and scientist Max Valier began his tests to determine the operating conditions of rockets used as engines. For this
96 he designed a test stand (Figure 126) similar to a decimal balance. The tip of an inverted rocket could be placed on the upper edge of the balance beam which rested on a dynamometer whose pen recorded the pressure diagram on a rotating drum.

(95)

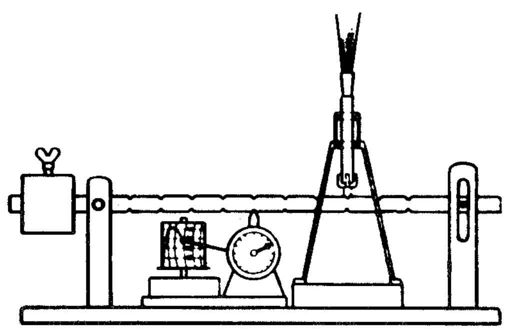


FIGURE 126. Valier's rocket test stand

Examples of the diagrams obtained are given in Figure 127. They indicate the duration of burning in sec, and the thrust (recoil) in kg. The area bounded by the curve (after deducting the weight of the rocket) represents the thrust in kg multiplied by the time in sec and expresses the work performed by the rocket, the scale being the same. It also gives the mean thrust R of the rocket. The quotient of the charge weight divided by the duration of burning gives the quantity of gunpowder m transformed into gas per sec (where m is given in kg (force), and if divided by $g = 9.81$, in kg (mass)). The latter magnitude is employed here. We thus obtain the fundamental equation of the rocket thrust $R/m = C$, which yields the gas-outlet velocity.

Tests were first carried out with rockets tightly filled with gunpowder; the nozzles had various diameters. The ratio of the cross-sectional area of the rocket to that of the nozzle varied between 1 and 100.

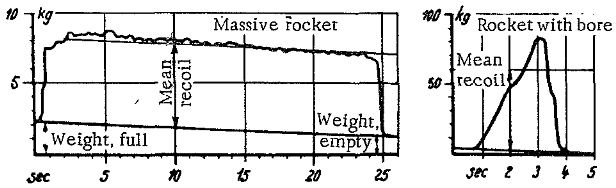


FIGURE 127. Rocket-operation diagram according to Valier

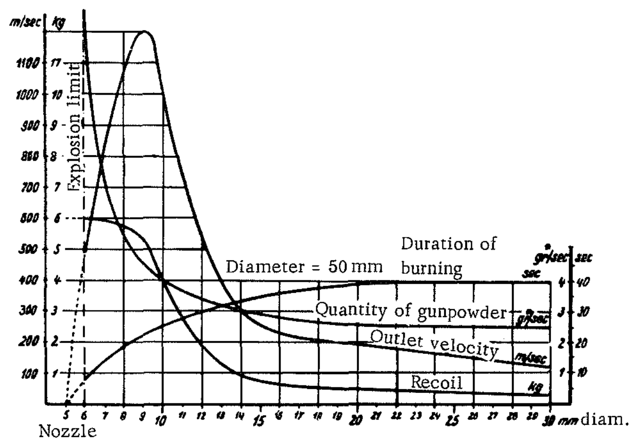


FIGURE 128. Operating diagram of rocket

Figure 128 gives an example of the results obtained with a tightly filled rocket of 50 mm in diameter and different nozzle diameters (5 — 30 mm). The curves give the recoil in kg, the gas-outlet velocity in m/sec, the quantity of gunpowder consumed in g/sec, and the duration of burning in sec. Explosion occurred when the nozzle had a diameter of 6 mm. The gas-outlet velocity was maximum when the nozzle had a diameter of 9 mm.

A rocket with a conical cavity (bore) gave a different diagram (Figure 127, right).

97 HOEFFT'S PROJECT OF ROCKET TRIALS

Engineer Hoefft (Figure 129) in his report, submitted in Breslau on 9 February 1928, described his proposed trials of rockets of different types called by him RH (Rakete-Hoefft) and designated by the Roman numerals I to VIII.

The first type (RH I) was called a recording rocket. It was to be 1.2 m long, have a diameter of 20 cm, and weigh 30 kg. Its propellant was to consist of 10 kg alcohol and 12 kg liquid oxygen. It was to be carried to a height of 10 km by a balloon and was to contain a meteorograph weighing 1 kg.

At this altitude it was to be launched automatically from the balloon and fly upward 100 km. Stability was to be obtained by means of a gyroscope. Landing was to be effected by means of a parachute.*

The RH II rocket was to be similar to the preceding one, but with gunpowder as propellant.

The RH III rocket was to be a two-stage rocket weighing 3 t and carrying a payload of 5—10 kg in the second stage. This was to be a luminous gunpowder which upon impact on the moon was to explode and emit a bright light visible on earth.

In addition, the rocket was to fly around the moon with the aid of gyroscopic control taking pictures of its invisible part, and then return to earth.

FIGURE 129. Engineer Hoefft

The RH IV rocket was to be similar to the RH III and was to transport mail over the earth with the aid of a parachute.

The last two types were initially to be carried to a height of 6 km by balloon or auxiliary rocket, or launched from a high mountain.

Detailed computations were performed for the RH V rocket which was to be launched from the water surface (H = O) vertically to a height of 25 km and then to proceed along a curved path. Its initial weight was to be 30 t, and its final weight, 3 t; its midsection area was to be 8 m^2; its shape factor, 1/4; its vertical acceleration, 30 m/sec^2. This rocket was also to be used as the last stage of the multistage RH VI, VII, and VIII rockets.

(98)

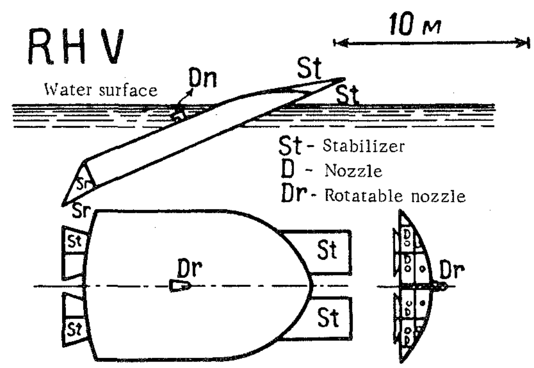


FIGURE 130. RH V rocket

Figure 130 shows the RH V rocket. Its length was to be 12 m, its breadth 8 m, and its height 1.5 m. The gas-outlet velocity was to be 4 km/sec,

* According to Hoefft 20 kg fuel would have been needed to carry a payload of 1 kg to the moon.

giving a flight speed of 9.2 km/sec. The rocket, carrying 2—4 persons, was to take off and land on water. A similar rocket, launched with the aid of additional RH VI, VII, or VIII rockets, was to fly around the moon and return to the earth. The landing procedure envisaged was as follows: At re-entry into the atmosphere at a speed of 12 to 13 km/sec the rocket, by means of rotatable nozzles, was to be turned perpendicular to the flight path so that the air would brake it. When the speed had become less than the velocity of sound, the rocket was to be turned by the pilot and glide down onto the water surface, on which it was to be propelled by burning the remaining fuel.

98 Figure 131 gives the launching conditions. The abscissas indicate the drag of the RH V rocket in t during launching at an acceleration of 30 m/sec^2. One curve shows the variation of the atmospheric pressure with the altitude. Another curve shows the flight speed of the rocket. The pressure is shown on top at a scale 10 times larger for the sake of clarity. The curve denoted by RH V indicates that the rocket is launched horizontally from the water surface and continues its flight in a vertical direction for 24 km, after which its path is described by a Keplerian ellipse. The curve denoted by RC 5.5 shows how the drag decreases when the rocket is launched at an altitude of 5.5 km. The discontinuities of the R-curves indicate the transition from subsonic to supersonic speeds.

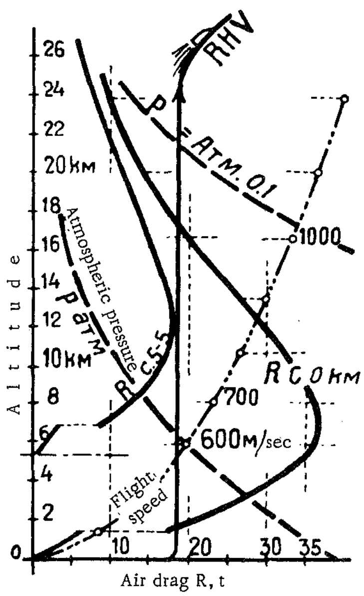


FIGURE 131. Launching of Hoefft's RH V rocket

Figure 132 gives the landing at re-entry and braking conditions at a speed of 12 km/sec at an altitude of 80 km (upper diagram). The permissible deceleration during braking by air resistance is taken as 40 m/sec^2. The flight path is represented on the upper diagram with altitudes of 70, 60, 50, and 40 km indicated by horizontal lines. The flight speed decreases by 1 km/sec every 25 sec. The midsection area of the rocket is taken as 8 m^2 and its weight as 3 t (RH V). The diagram in the center represents the curved earth's surface and the flight path with braking over a distance of 1,800 km
99 for 5 min (according to the formula ($R = v^2 F\gamma/g$). The lower diagram shows the total flight path. The glide begins at its end.

The use of the RH V rocket as the last stage of a RH VI or VII rocket opens up the possibility of flights to the Moon, Mars, or Venus. Figure 133 shows such a rocket. The shaded part is the last stage (RH V); at a certain altitude the first stage separates and lands on water, still guided by the pilot. The second stage continues its flight. A third stage is added in the RH VIII rocket whose takeoff weight is 12,000 t; the speed of the RH V rocket is 27.6 km/sec.

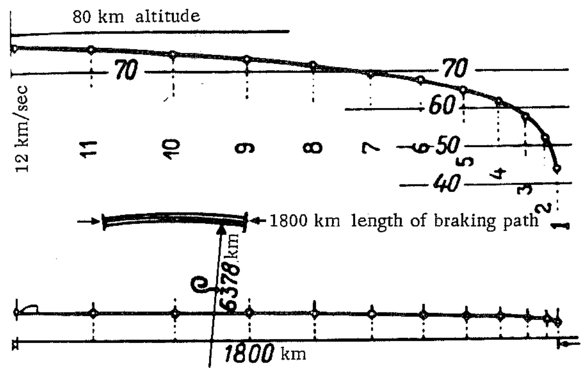


FIGURE 132. Landing of Hoefft's rocket

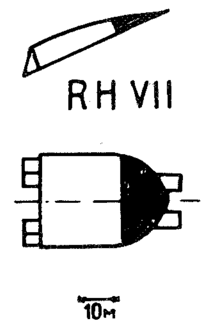


FIGURE 133. Hoefft's multistage rocket

Rocket specifications		RH VI	RH VII
Number of stages		2	2
Length	m	26.4	32.5
Breadth	"	17.6	21.6
Height	"	3.3	4
Takeoff weight:			
overall	t	300	600
of last stage	"	3	3
at burnout of first stage	"	60	60
at separation of first stage	"	30	30
Speed			
before separation of first stage 4 • 1.6 . .	km/sec	6.4	4 • 2.3 = 9.2
of last stage . . . . 4 • 2.3 . .	"	9.2	4 • 2.3 = 9.2
total	"	15.6	18.4

100

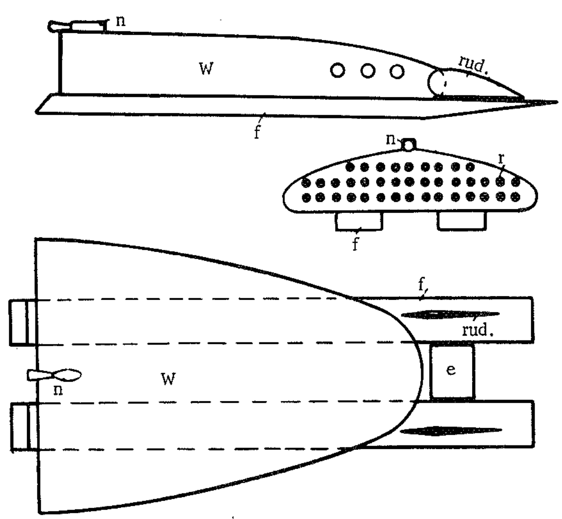


FIGURE 134. Hoefft's rocket

Figure 134 shows in greater detail the layout of Hoefft's rocket spaceship with two floats (f) for takeoff from water. In fact the spaceship consists of wing (W) (with a cabin inside) carrying a number of rockets (r) at the rear. Rotatable nozzle (n) ensures directional stability; (e) is the elevator, and (rud.) is the rudder. The takeoff weight is 30 t, while the landing weight is 3 t. The wing area is 100 m^2, and the landing speed 34.7 m/sec.

ROCKET-ASSISTED AIRPLANE TAKEOFF

Engineer A. Pröll investigated how to facilitate the takeoff of heavy airplanes. He suggested that the reaction force created by air or water ejected from the rear of the airplane at a high velocity induced by the combustion of the propellant (as in the Humphreys gas turbine) be utilized. The thrust thus obtained is considerable. For instance, at an airplane speed of 20 m/sec and a pressure of 5 atm in the combustion chamber, the velocity of the jet of water discharged is

$$v = \sqrt{2g \cdot 5.10} = 31 \ m/sec$$

With an exit-section area of 200 cm^2, this yields a reaction of

$$R = \frac{0.02 \cdot 31 \cdot 1000}{9.81} (31 - 20) = 680 \ kg.$$

Such an engine ejects 2,720 kg water in 4 sec. The velocity will be higher at the end of the takeoff so that the pressure must also be increased, possibly up to 10 atm. A shortcoming of this method is the considerable
101 weight of the water which has to be carried, so that it is suitable only for hydroplanes which can take in water and then eject it to the rear or downward.

In 1926 Captain Roberts built and tested such a jet plane in Great Britain.

FLIGHT TESTS OF ROCKET PLANES AND THEIR MODELS

A description of flight tests of rocket planes and their models appeared in the journal "Z. F. M." of 1928. These tests were carried out by the research institute of the Rhön-Rossitten Association. The description included two papers: one called "Technical Survey" by A. Lippisch, and the other called "Flights" by F. Stamer. The contents of these papers follow.

I. Technical Survey

The tests were begun on the initiative of M. Valier, F. Sander, and Messrs. Opel with the airplane "Ente" [duck] on 10th and 11th June 1928, on the Wasserkuppe. The rockets were obtained from the Sirius fireworks plant of F. Sander at Wesermünde and were of the following types:

1. For models:
   a) a starting rocket developing a thrust of 75 kg and burning for 3 sec;
   b) a starting rocket developing a thrust of 175 kg and burning for 3 sec;

c) a continuous-action rocket developing a thrust of 3 kg and burning for 30—40 sec.

2. For full-scale planes:

a) a starting rocket developing a thrust of 360 kg and burning for 3 sec;

b) a continuous-action rocket developing a thrust of 20 kg and burning for 30 sec.

These rockets weighed up to 6 kg. The weight was reduced by 70% after burnout.

The first test was carried out with a model of airplane No. 4 (Storch = Stork) using two rockets arranged one on top of the other beneath the wing (Figure 135a). A steep ascent was obtained with the 75 kg-thrust rocket (Figure 135c), since the lines of action of thrust and drag did not coincide. The second test was carried out with a 5 kg-thrust continuous-action rocket located beneath the wing of the model. This trial, however, was also unsuccessful because of the insufficient stability of the model. The third test was carried out with a redesigned model (Figure 135b). The rocket was located between the wings which had a larger sweep angle; the tail was also altered.

102

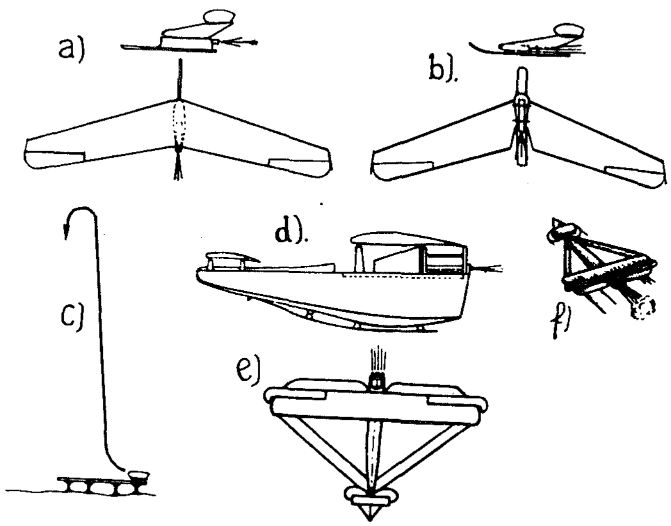


FIGURE 135. Rocket planes

The model was first tested without igniting the rocket by launching it with a rubber band. This trial was completely successful. The model was then launched with a 5 kg-thrust continuous-action rocket and a rubber band. The model flew for a short distance, exhibited stability, and landed smoothly near the starting point.

The test was repeated by using a 175 kg-thrust starting rocket instead of the rubber band. An acceleration of 12 g was obtained at a model weight of 14 to 15 kg. At ignition the rocket propelled the model in a steep ascent to an altitude of 80—100 m, as if shot out of a gun. After burnout the model began a glide and landed smoothly.

102 The third test was carried out with the same model and a 175 kg-thrust starting rocket. The tail was set for a steep glide in order to prevent a steep ascent during takeoff and to obtain a high speed. The model took off at a smaller slope and a higher speed (up to 500 km/hr), but dropped almost vertically after burnout and crashed.

The tests showed that flights of models can be quite successful with rockets if the latter are centered. It thus became possible to continue with manned flights on the airplane "Ente," whose static stability and endurance at large accelerations were higher than those of tailless planes. This plane is shown in Figure 135d. Figure 136 is a photograph of it in flight. The rockets were arranged in the center of the fuselage end. At first it was suggested that they be enclosed in a metal casing; the latter was, however, omitted because of delays in fitting it.

(103)

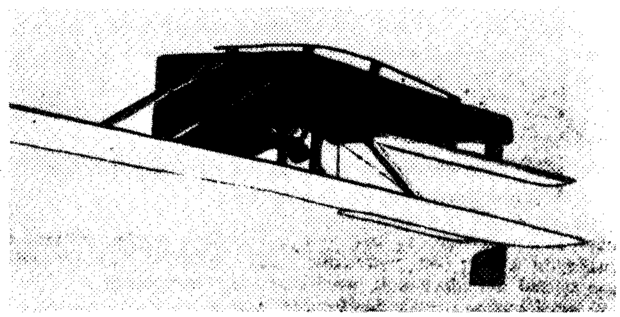


FIGURE 136. Rocket plane in flight

Two rockets were fitted. The moment arising during their non-simultaneous action was to be equilibrated by the rudder. The rockets were ignited electrically by the pilot. They were located far behind the center of gravity, so that a counterweight had to be fitted to the nose of the plane for equilibrium. This counterweight could be moved or discarded after burnout.

Continuous-action rockets developing a thrust of 12—20 kg, corresponding to a power of 7 to 8 hp, were sufficient for the flight itself. Starting rockets developing a thrust of 360 kg were not used in view of the large anticipated accelerations.

103 II. Flights

The initial flights were carried out with two rockets developing thrusts of 12 and 15 kg. A rubber rope was used for launching.

The first start was unsuccessful. The plane did not rise from the ground even when the 12 kg-thrust rocket was ignited. The second trial was carried out with rockets developing thrusts of 15 and 20 kg. The plane took off easily with the aid of the rubber rope and the 15 kg-thrust rocket. The flight, however, was not horizontal but at an angle, and the plane landed after 200 m without the 20 kg-thrust rocket having operated.

The third trial was carried out with two 20 kg-thrust rockets. The plane took off correctly with the aid of a rubber rope and one rocket. After flying 200 m and climbing the pilot turned 45° to starboard and continued for another 300 m. He then made another 45° turn to starboard. The first rocket had by then burnt out, and the second was ignited. Thus propelled, the plane flew another 500 m, turned 30° to starboard, and landed after 200 m when the second rocket had burnt out. The total length of the flight path was 1,300—1,500 m. The flight lasted 40—80 sec. Takeoff was scarcely noticeable. The thrust was almost uniform. Burning of the rocket was quite audible. The eccentricity of the thrust could be easily compensated with the rudder. The flight was pleasant due to the absence of the vibrations and torque of the engine.

The next flight was carried out with two 20 kg-thrust rockets which were to be ignited in succession. Takeoff was smooth with the aid of a rubber rope, the first rocket being ignited during the ascent. However, this rocket exploded after 1 or 2 sec. Four kg of gunpowder were blown out and set fire to the plane. The pilot went into a glide, landed safely, and almost managed to extinguish the fire; however, as a result of damage to the insulation, the second rocket was ignited and again set fire to the plane, burning it completely.

It may be assumed that the charge was adversely affected by shocks in the car and this caused the rocket to explode.

104 The pilot came to the following conclusions:

1. The rockets must be insulated from combustible parts of the plane.
2. The rockets must be fixed securely to the plane.
3. The jet of burning gases must not impinge on combustible parts of the plane.
4. The ignition wires must be well insulated.
5. The usual ignition regulator must be supplemented by an additional one, to be used to switch off the current in case of faulty operation of the rockets.
6. Each rocket must be located inside a steel casing and be ejected to the rear with the casing, should it explode.
7. These casings must be insulated from one another and must not become hot when adjacent rockets burn.
8. Particular attention must be paid to the correct functioning of the electric igniter, in order to prevent accidental closing of a circuit.

Flight of airplanes with rocket engines is quite feasible in general.

The center of gravity of the rockets in the "Ente" was about 1 m behind the center of gravity of the airplane. A weight had to be placed at the nose of the airplane at a distance of 2 m from the center of gravity; this weight could be moved after burnout of the rockets. The length of the jet of burning gases attained 1 m; its presence requires a special design of the tail of the airplane or a special arrangement of the rockets.

OTHER TESTS OF ROCKET ENGINES

A small model of a gunpowder rocket was tested in 1928 on the Tegernsee in Germany. The model rose to an altitude of 10 km (?) at a maximum speed of 211 m/sec. A proposal was made to build a recording rocket capable of rising to an altitude of 150 km.

The airplane plant of Raab-Katzenstein in Kassel, in the person of its chief pilot Raab, came to an agreement with Messrs. Opel on the construction and subsequent flying of a rocket plane. A small sport biplane "Grasmücke," built by Raab-Katzenstein, was to be used for the trials. The following alterations were made in it: It was converted into a "Canary" with elevator in front, and installation of the rockets was proposed at the rear (Figure 135 e and f). Engineer Bizai tested a rocket-propelled model monoplane having a wing span of 0.8 m near the Danube on 26 May 1928. Trials were carried out by the Akaflugverein, a Viennese glider club. An all-metal plane equipped with a single rocket supplied by the Sirius plant
105 was used. The speed attained was 41.7 km/hr (according to other sources, 24 rockets were used and the speed was 158 km/hr). Similar tests were also carried out with models in Magdeburg.

In Czechoslovakia Engineer Levy carried out tests with reaction-propelled vehicles. The fuel used was gasoline. A rocket plane designed by Scherschevsky was not to be equipped with a special cabin like an ordinary airplane, but everything was to be located inside the wings. The rocket nozzles were to be at the rear (Figure 137).

(104)

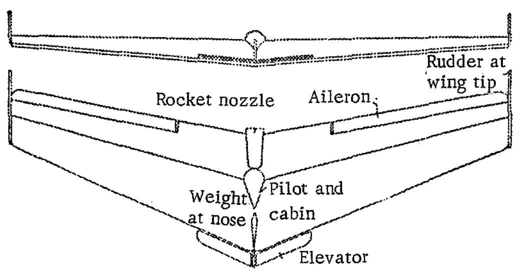


FIGURE 137. Rocket plane according to Scherschevsky

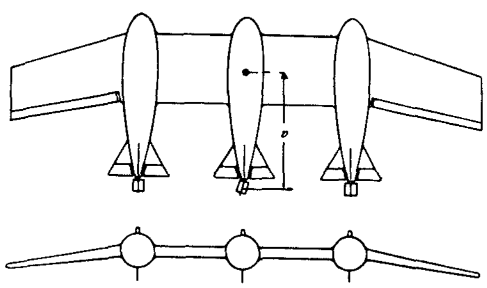


FIGURE 138. Reaction-propelled airplane with 3 fuselages

Figure 138 shows an airplane with three fuselages carrying jet engines at their ends. Rudders for controlling the plane outside the atmosphere, utilizing the reaction of the discharged gases, were also to be located at the rear. Elevators and rudders for flight in the atmosphere are visible at the sides of the tails. Ailerons are fitted to the ends of the wings.

In 1928 the French inventor Jean Chapedelin proposed and built a model of a gyropter partly employing the reaction principle (Figure 139). The machine consisted of a cabin on wheels. A 40 hp engine located inside aspirated air through slots in the cover, thus creating a partial vacuum which kept the machine in the air. The air was then forced to the sides or rear by lateral blowers; the induced thrust propelled the machine sideways or forward. The slots through which the air entered the machine were opened or closed by the pilot who could thus create different moments for controlling the machine.

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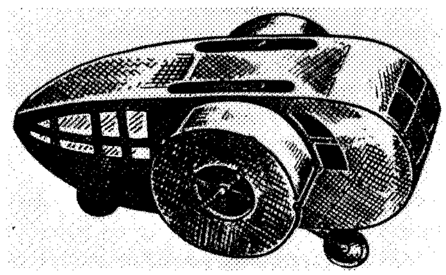

FIGURE 139. Chapedelin gyropter

A 1:10 scale model was built. It was 48 cm long, 24 cm broad, and was propelled by a 1/7 hp electric motor and two turbines 15 cm in diameter and 6 cm wide. The model weighed 750 g. The model took off easily at a turbine speed of 7,000 rpm and remained in the air. The current was supplied from the ground through wires. The lift was 5 kg/hp.

107 *Chapter IV*

ELEMENTS OF THE THEORY OF REACTION ENGINES

The theory of reaction engines, as applied to rocket flight, has been expounded in the works of Tsiolkovskii, Oberth, Goddard, Hohmann, and others. It will be discussed by us in books to follow. In addition to some theoretical considerations already given (the work done by Lorin and Gorkhov), we shall now present 3 theoretical works on this subject by Rost, Popovatz and Drzhevetskii. The first two discuss the operation of direct-reaction engines, while Drzhevetskii's demonstrates their affinity to other aircraft engines (helicopters).

a) **Rost's theory**

Consider a vessel on wheels (Figure 140) in which a constant air pressure h is maintained by means of a blower. Valve e is arranged at at the bottom of the vessel. A force Fh acts on the surface area F of this valve when it is closed. When the valve is open, the air escapes from the vessel at a velocity

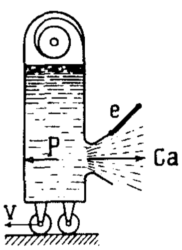

FIGURE 140. Rost's theory

$$c_a = \sqrt{\frac{2g}{\gamma} h} = \sqrt{\frac{2\cdot 9.81}{1.296} h} = 3.961\sqrt{h}\ m/sec$$

A force of the same magnitude Fh then acts on that area of the wall which is opposite the open valve. In addition, there acts in the vessel another force Fh which imparts to the air its outlet velocity Ca. The total force acting on the wall of the vessel thus is

$$P = 2Fh; \text{but } h = \frac{v^2\gamma}{2g},$$

whence

$$P = \frac{\gamma}{g} Fv^2 \cong 0.13\ Fv^2.$$

If the vessel moves to the left with a speed v corresponding to the pressure h_1, then $Ca = 0$, and the reaction will be equal to the static force Fh or

$$P = \frac{v^2\gamma}{2g} F.$$

108 Assume that the mass of the gas discharged from a rocket nozzle of area F at a velocity v is $M = 0.13\,Fav$. This mass has a kinetic energy

$$\frac{Mv^2}{2} = \frac{0.13\ F \cdot v^3}{2},$$

which requires that the engine develop a power of

$$B = \frac{0.13 \cdot F \cdot v^3}{2 \cdot 75 \cdot \eta}\ \text{hp}, \qquad (1)$$

where η is the engine efficiency.

The reaction is

$$P = 2Mv = 2.0.13 \cdot Fv^2\ kg \qquad (2)$$

Dividing (2) by (1), we obtain the thrust in kg/hp

$$\frac{P}{B} = \frac{2 \cdot 75 \cdot \eta}{v} \qquad (3)$$

In 1908 in Germany Moritz Poznansky suggested that a flying machine employing this principle be built. The compressed air delivered by the blower was to be discharged downward.

The following is a calculation for such a machine:

By (3) a thrust of 75 kg requires 1 hp at $V = 1$ m/sec and $\eta = 0.5$. However, $a \cong 290\ m^2$ in this case; $a = 390\ m^2$ for a lift (= vertical thrust) of 100 kg. At $v = 20$ m/sec, we obtain $P = 3.75$ kg/hp and $a = 0.036\ m^2$; hence, $a \cong 1\ m^2$ at $P = 100$ kg.

b) Drzhevetskii's theory

Let us assume that a machine weighing P kg has to be maintained in space (Figure 141). Let a gas (air) be discharged for this purpose from the machine at a velocity v in m/sec. The density of air is taken as $1.29\ kg/m^3$. To maintain the machine in the air, it is necessary that the reaction caused by the discharge of the air be equal to the weight P of the machine

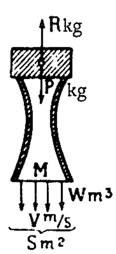

FIGURE 141. Drzhevetskii's theory

$$R = P \qquad (1)$$

Since the momentum is equal to the impulse, we obtain

$$P.1_{\text{сек.}} = M.v \qquad (2)$$

where M is the mass of discharged air per sec.

The volume of this air is

$$W = \frac{Mg}{1.29} = \frac{M \cdot 9.81}{1.29} \cong 8M,$$

However, from (2)

$$M = \frac{P}{v},$$

whence

$$W \cong 8 \frac{P}{v} m^3.$$

109 The cross-sectional area of the air jet is

$$S = \frac{W}{v} \cong 8 \frac{P}{v^2} m^2 \tag{3}$$

The pressure ψ at which the air is discharged is obtained from the formula

$$v = \sqrt{\frac{2g}{1.29} \psi},$$

whence

$$\psi \cong \left(\frac{v}{4}\right)^2 mm \text{ w.c.}$$

The force acting on the cross section of the air jet thus is

$$\pi = \psi . S = \left(\frac{v}{4}\right)^2 8 \frac{P}{v^2} = \frac{P}{2} kg$$

(A 1 mm-high layer of water weighs 1 kg/m^2).
The useful work performed at a velocity v m/sec is

$$T = \pi v = \frac{Pv}{2} \; kg/m$$

or

$$\frac{Pv}{150} \text{ hp.} \tag{4}$$

Let ρ be the efficiency of the airscrew or some other propulsion device. Then

$$T_m = \frac{Pv}{\rho \, . \, 150} \text{hp.} \tag{5}$$

Consider the following cases:

Helicopter. Let the airscrew efficiency be $\rho = 0.8$. The weight of the machine is $P = 500$ kg. The area of the airscrew disk is 10 m^2. We then obtain $v = 20$ m/sec from (3). The power required is by (5):

$$T_m = \frac{500 \, . \, 20}{0.8 \, . \, 150} = 83 \text{ hp.}$$

Rocket. $v = 3{,}000$ m/sec, $\rho = 0.5$;

$$T_m = \frac{500 \cdot 3000}{0.5 \cdot 150} = 20{,}000 \text{ hp}.$$

This power can be obtained from explosives, but only for a short time when their weight is small.

Remarks: It follows from (5) that the power T_m can be reduced by lowering the velocity v. However, by (3) the cross-sectional area S of the jet must then be greatly increased; this entails a large and heavy machine. Only practical experience can indicate the optimum relationship between S and v.

c) Popovatz's theory

Assume that 1 kg of gas has a pressure of x atm upon explosion and expands completely into the surrounding air, its pressure energy being transformed into kinetic energy. Let t_0 be the absolute temperature of the air and t_1 be the gas temperature after explosion at constant volume, so that $t_1 = xt_0$.

Let C_v be the specific heat of the gas at constant volume. The heat liberated by the explosion of 1 kg of gas thus is

$$c_v (t_1 - t_0).$$

After the expansion the temperature of the gas is $t_2 > t_0$. For the cycle to be closed we must remove from the gas a quantity of heat equal to

$$c_p (t_2 - t_0),$$

where C_p is the specific heat of the gas at constant pressure. The useful work obtained thus is

$$c_v (t_1 - t_0) - c_p (t_2 - t_0)$$

Let E be the mechanical equivalent of heat. We thus obtain the energy

$$L = E\, c_v\, t_0 \left| \frac{t_1}{t_0} - 1 - \frac{c_p}{c_v} \left(\frac{t_2}{t_0} - 1 \right) \right| \text{ kg·m}$$

We can assume without significant error that the expansion is adiabatic:

$$\frac{c_p}{c_v} \doteq \gamma;\ t_2 = \frac{t_1}{x^{\frac{\gamma - 1}{\gamma}}} = t_0 x^{\frac{1}{\gamma}} \text{ and } E\, c_v = \frac{R}{\gamma - 1},$$

where R is the gas constant. We thus obtain

$$L = \frac{Rt_0}{\gamma - 1}\left(\gamma - 1 + x - \gamma x^{\frac{1}{\gamma}}\right)$$

Here L is the work necessary for imparting to 1 kg of gas a mean outlet velocity v; the velocities of the various particles of the gas will, however, differ.

Thus,

$$L = \frac{v^2}{2g},$$

where g is the gravitational acceleration. Hence,

$$v^2 = \frac{2g\,Rt_0}{\gamma - 1}\left(\gamma - 1 + x - \gamma x^{\frac{1}{\gamma}}\right).$$

Consider the following numerical examples:

$$g = 9.81;\; R = 29.3;\; t_0 = 290;\; \gamma = 1.4.$$

1) If $v = 250$ m/sec, then $x = 2.24$ atm. The engine efficiency then is

$$\rho = \frac{c_v(t_1 - t_0) - c_p(t_2 - t_0)}{c_v(t_1 - t_0)} = 1 - \gamma\frac{x^{\frac{1}{\gamma}} - 1}{x - 1} = 0.12$$

even when the heat lost to the engine walls is neglected.

2) If $v = 1{,}000$ m/sec, then $x = 8$ atm and $\rho = 0.33$.

A reaction engine will under ordinary flight conditions generally be less efficient than an engine with an airscrew. However, regarding weight and volume, a reaction engine offers advantages and is more efficient at high flight speeds.

111 *Chapter V*

D. P. RYABUSHINSKII'S WORK

a) Foreword

D. P. Ryabushinskii (Figure 142) was active in various fields of hydro- and aeromechanics, aviation, and aeronautics from 1904, and in that same year he founded the Aerodynamical Institute at Kuchino near Moscow. From 1906 until 1914 he published five bulletins on the work done at this Institute, most of which he carried out himself. The sixth bulletin was published in 1920 in Paris. It contained an original paper by Ryabushinskii on the theory of rockets and a hitherto unpublished report on his experiments with rockets and reaction (recoilless) guns, carried out at Kuchino in 1916. In view of the importance of this paper, we give the following full account.

FIGURE 142. D.P. Ryabushinskii

b) Theory of rockets

Paper by D. P. Ryabushinskii, published in the sixth Bulletin of the Aerodynamical Institute at Kuchino.

1. General Pomortsev's pneumatic rocket

General Pomortsev's pneumatic rocket consists of a steel pipe (Figure 143a), one end of which (B) is closed, while the other (a) contains a convergent-divergent nozzle. This nozzle is closed by a plug which can be pierced with a sharp instrument when required. During the experiments carried out at the Institute, air was compressed to 100—125 atm in this rocket and gasoline or ether was introduced so that an explosive mixture was formed. Gunpowder was inserted in other cases. Pomortsev equipped these rockets with known stabilizers (Figures 143b and 19d) and used the launching stand which he employed in tests of ordinary rockets.

Pomortsev could not finish his experiments since in June 1916 he succumbed to a heart disease from which he had suffered for a long time. He was a well-known pioneer of Russian aviation and had published many works on aeronautics and meteorology. He was an admirable man, possessing a youthful enthusiasm in his scientific research until his death.

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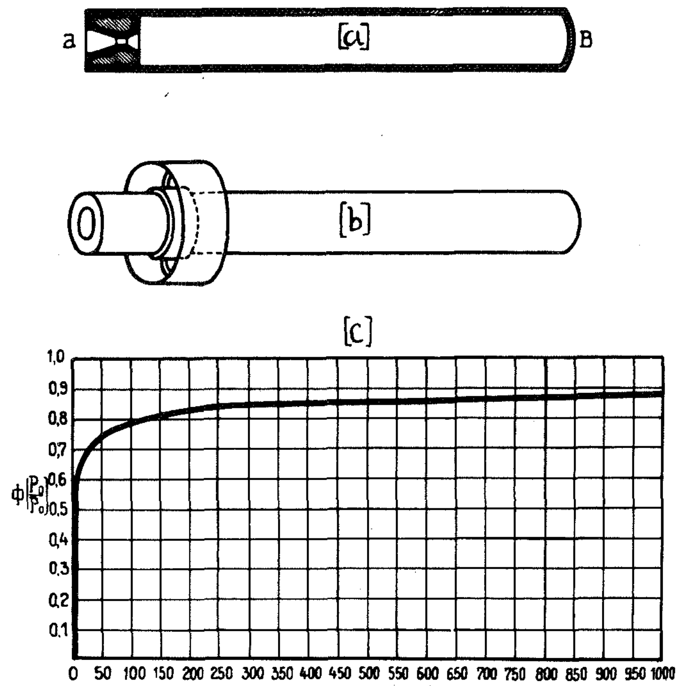


FIGURE 143. Pomortsev's rocket

According to Pomortsev's wish, I continued his research after his death. This paper is the result of my work. In the analysis of Pomortsev's rocket I have applied the known theory of the discharge of a compressible fluid from a vessel in which the pressure decreases as the gas flows out.

The experiments have in general confirmed this theory. Unfortunately, I have been unable to publish the results of these experiments, since the relevant material has remained at Kuchino.

2. Variation of the pressure in the rocket with time

Let P be the initial weight of the air compressed in the rocket, and q be the weight of air discharged through the nozzle during unit time at instant t [mass flow rate]. Assuming the process to be adiabatic, we may write

$$\frac{P-\int_0^t q\,dt}{P}=\frac{\rho_t}{\rho_0}=\left(\frac{p_t}{p_0}\right)^{\frac{1}{\gamma}}, \tag{1}$$

113 where ρ_t and p_t are respectively the density and pressure of the air in the rocket at time t, while ρ_0 and p_0 are the corresponding magnitudes at time $t=o$, when the rocket nozzle is opened.

Let S_m be the cross-sectional area of the nozzle throat, u_m and being respectively the flow velocity and the density in this section; ρ_m is the gravitational acceleration. We then have

$$q = S_m u_m \rho_m g. \tag{2}$$

The theory of gas dynamics states that when the ratio of the pressure to the external pressure p_a satisfies the inequality

$$\frac{p_t}{p_a} > \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}} = 1.9. \tag{3}$$

we have

$$p_m = p_t \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}}, \tag{4}$$

$$\rho_m = \rho_t \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}, \tag{5}$$

$$u_m = \left(\frac{dp}{d\rho}\right)_m^{\frac{1}{2}} = \left(\frac{2\gamma}{\gamma+1}\,\frac{p_t}{\rho_t}\right)^{\frac{1}{2}}, \tag{6}$$

whence

$$q = S_m g \sqrt{\frac{2\gamma}{\gamma+1}\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}} p_t \rho_t} = B p_t^{\frac{\gamma+1}{2\gamma}}, \tag{7}$$

where

$$B = S_m g \left[\frac{2\gamma}{\gamma+1}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} \rho_0 p_0^{-\frac{1}{\gamma}}\right]^{\frac{1}{2}}. \tag{8}$$

Inserting (7) into (1) we obtain

$$P - \int_0^t B p_t^{\frac{\gamma+1}{2\gamma}}\, dt = P\left(\frac{p_t}{p_0}\right)^{\frac{1}{\gamma}},$$

whence, differentiating, we find

$$-\frac{\gamma B p_0^{\frac{1}{\gamma}}}{P}\, dt = p_t^{\frac{1-3\gamma}{2\gamma}}\, dp_t. \tag{9}$$

Integrating (9) and noting that $p_t = p_0$. at $t = 0$, we obtain

$$p_t = p_0 \left[1 - \frac{1-\gamma}{2}\,\frac{B}{P}\, p_0^{\frac{1+\gamma}{2\gamma}}\, t\right]^{\frac{2\gamma}{1-\gamma}}. \tag{10}$$

Substituting for B its value from (8), and setting

$$P = S l \rho_0 g, \tag{11}$$

114 where S is the cross-sectional area of the rocket, and l its length, we may write

$$p_t = \frac{p_0}{(1+At)^{\frac{2\gamma}{\gamma-1}}}, \tag{12}$$

where

$$A = \frac{\gamma-1}{2}\left(\frac{2\gamma}{\gamma+1}\right)^{\frac{1}{2}}\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \frac{S_m}{S.l}\left(\frac{p_0}{\rho_0}\right)^{\frac{1}{2}} \tag{13}$$

Let t be the time interval during which the pressure in the rocket becomes equal to the outside pressure p_a. We may then write

$$t = \frac{1}{A}\left[\left(\frac{p_a}{p_0}\right)^{\frac{1-\gamma}{2\gamma}} - 1\right] \tag{14}$$

Eliminating A between (12) and (14), we obtain

$$p_t = \frac{p_0}{\left\{1+\left[\left(\frac{p_0}{p_a}\right)^{\frac{\gamma-1}{2\gamma}} - 1\right]\frac{t}{t}\right\}^{\frac{2\gamma}{\gamma-1}}} \tag{15}$$

Equations (14) and (15) were derived under the assumption that the mass flow rate during the whole time is given by (7). In fact, when p no longer satisfies (3), i.e., when

$$p_t < 1.9\, p_a \tag{16}$$

the mass flow rate will be different. However, noting that the pressure defined by (16) is small, we can ignore this fact, since its effect on the total impulse given to the rocket is insignificant; it is this latter magnitude which interests us here.

In deriving these formulas we must make the following assumptions:

1. For the nozzle the term $\frac{\partial u}{\partial t}$ in Euler's equation may be neglected in relation to the terms $u\frac{\partial u}{\partial x}$ and $\frac{1}{\rho}\frac{\partial p}{\partial x}$.

2. The flow velocity outside the rocket is very small in comparison with the flow velocity in the nozzle; we may, therefore, neglect the former.

3. The pressure inside the rocket is uniform at any given instant.

3. Variation of the reaction with time

We determine the reaction by multiplying the mass $\frac{q}{g}$ flowing through the nozzle per sec by the discharge velocity u_a corresponding to the pressure difference $p_t - p_a$.

By Saint-Venant's formula,

$$u_a = \sqrt{\frac{2\gamma}{\gamma - 1}\,\frac{p_t}{\rho_t}\left[1 - \left(\frac{p_a}{p_t}\right)^{\frac{\gamma-1}{\gamma}}\right]}.$$

115 whence

$$R = \frac{1}{g}\cdot q u_a = 2S_m\, p_t \sqrt{\frac{\gamma^2}{\gamma^2+1}\left(\frac{\gamma+1}{2}\right)^{\frac{2}{\gamma-1}}\left[1 - \left(\frac{p_a}{p_t}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

or, using (12),

$$R = \frac{2S_m p_0 \sqrt{\frac{\gamma^2}{\gamma^2-1}\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}}\left[1 - \left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{\gamma}}(1+At)^2\right]}}{(1+At)^{\frac{2\gamma}{\gamma-1}}} \qquad (17)$$

Setting $t=0$ we obtain the initial reaction:

$$R_{max} = 2S_m\, p_0 \sqrt{\frac{\gamma^2}{\gamma^2-1}\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}}\left[1 - \left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{\gamma}}\right]} \qquad (18)$$

4. Proof of the theorem that the impulse given to the rocket is independent of the cross-sectional area S_m of the nozzle

From (17) we obtain the total impulse given to the rocket by the expanding gases:

$$I = \int_0^{\bar{t}} R\,dt = \int_0^{\bar{t}} 2S_m p_0 \frac{\sqrt{\frac{\gamma^2}{\gamma^2-1}\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}}\left[1 - \left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{\gamma}}(1+At)^2\right]}}{(1+At)^{\frac{2\gamma}{\gamma-1}}}\,dt \qquad (19)$$

We shall prove that I does not depend on the cross-sectional area S_m of the nozzle.

We may write (13) and (14) in the following way:

$$A = a\,S_m,$$
$$t = \frac{b}{S_m},$$

where a and b are independent of S_m.

Introduce a new variable $t_1 = S_m \cdot t$. Expression (19) then becomes

$$I = \int_0^b \frac{2p_0\sqrt{\frac{\gamma^2}{\gamma^2-1}\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}}\left[1 - \left(\frac{p_a}{p_0}\right)^{\frac{\gamma}{\gamma-1}}(1+at_1)^2\right]}}{(1+at_1)^{\frac{2\gamma}{\gamma-1}}}\,dt.$$

The right-hand side of this equation is independent of S_m so that I also does not depend on S_m, as was to be proved.

Introduce the new variable

$$\eta = \left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{2\gamma}}(1+At) \tag{20}$$

Expression (19) then becomes

$$I = \int\limits_{\left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{2\gamma}}}^{t} \frac{2p_a S_m \sqrt{\frac{\gamma^2}{\gamma^2-1}\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}}}}{\left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{2\gamma}} A} \frac{\sqrt{1-\eta^2}}{\eta^{\frac{2\gamma}{\gamma-1}}} d\eta \tag{21}$$

When $\gamma = 1.4$ this expression can be transformed into elementary integrals, since then $\left(\frac{\frac{2\gamma}{\gamma-1}+1}{2}\right)_{\gamma=1.4}$ is an integer.

We write

$$N = \frac{2p_0 S_m \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \frac{\gamma}{(\gamma^2-1)^{\frac{1}{2}}}}{\left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{2\gamma}} A} \tag{22}$$

$$\xi = \left(\frac{p_a}{p_0}\right)^{\frac{\gamma-1}{2\gamma}} \tag{23}$$

and set $\gamma = 1.4$. This yields

$$I = \int\limits_{\xi}^{1} N \frac{\sqrt{1-\eta^2}}{\eta^7} d\eta \tag{24}$$

writing

$$1 - \eta^2 = u^2 \tag{25}$$

and integrating, we obtain

$$I = \int\limits_0^{\sqrt{1-\xi^2}} N \frac{u^2}{(1-u^2)^4} du =$$

$$= \int\limits_0^{\sqrt{1-\xi^2}} \frac{N}{32} \left\{\frac{2}{(u-1)^4} - \frac{1}{(u-1)^2} + \frac{2}{(u+1)^4} - \frac{1}{(u+1)^2} + \frac{1}{u-1} + \frac{1}{u+1}\right\} du =$$

$$= \Big|_0^{\sqrt{1-\xi^2}} N \left\{\frac{2}{96} \frac{3u^5 - 8u^3 - 3u}{(u^2-1)^3} + \frac{3}{96} \log \frac{1-u}{1+u}\right\} =$$

$$= \frac{1}{3} Sl \sqrt{\frac{2\gamma}{(\gamma-1)^3} p_0 \rho_0} \left\{\sqrt{1-\xi^2}\left(1 - \frac{1}{4}\xi^2 - \frac{3}{8}\xi^4\right) + \frac{3}{16}\xi^6 \log \frac{1-\sqrt{1-\xi^2}}{1+\sqrt{1-\xi^2}}\right\}$$

117 This can be written in the form

$$I = \frac{Sl}{3}\sqrt{\frac{2\gamma}{(\gamma-1)^3}\, p_0 \rho_0}\;\Phi\left(\frac{p_0}{p_a}\right) \qquad (26)$$

where

$$\Phi\left(\frac{p_0}{p_a}\right) = \sqrt{1-\xi^2}\left(1 - \frac{1}{4}\xi^2 - \frac{3}{8}\xi^4\right) + \frac{3}{16}\xi^6 \log\frac{1-\sqrt{1-\xi^2}}{1+\sqrt{1-\xi^2}} \qquad (27)$$

and ξ is given by (23)

The function (27) is represented in Figure 143c.

6. Experimental verification of the formulas obtained

I determined the impulse experimentally by suspending the rocket from a ballistic pendulum, noted its inclincation, measured the rocket range in free flight, and obtained some pressure curves with the aid of a dynamometer.

The ballistic pendulum did not completely satisfy my requirements, since the impulse given to the rocket by the discharged gases was not instantaneous; the gas continued to flow out even when the pendulum was already inclined at a considerable angle.

This greatly complicated the calculations necessary for determining the impulse I.

To alleviate this shortcoming, I designed a large ballistic wheel of 4 m in diameter at the Institute. This wheel consisted of a lever carried at its center on a shaft about which it could revolve. Rockets were fixed to one or both ends of the lever.

The shaft was carried in roller bearings on two heavy columns standing on a brick foundation.

The moment of inertia of this wheel was so large that its reduction due to the discharge of the gases could be neglected.

The speed and angular acceleration of the wheel could be measured with a chronograph. We thus had everything necessary for determining the reaction and the impulse given to the rocket.*

Unfortunately, I could not finish this machine and use it in the investigation of rockets.**

The first 3 investigations mentioned at the beginning of this section give results which are in satisfactory agreement with the theory previously expounded.

* I had already employed a similar method (measuring the angular acceleration) to determine the couples inducing rotation of symmetric surfaces and had obtained results in agreement with the theory despite the small magnitudes of the forces involved. I later tried to use this method in the laboratory in order to study windmills in Askov (Denmark) using Prof. Paul la Cour's large mill; however, the moment of inertia of this mill was so small in relation to the couple of the wind pressure acting on its blades, that a small variation of the wind force caused large irregularities in the operation of the mill, greatly complicating the problem.

** It would have been interesting to study the operation of a direct-reaction engine working automatically like a gasoline engine.

7. The influence of additional explosions

Consider now, as Pomortsev did, the case when the rocket contains gasoline or ether with compressed air, gunpowder or some other explosive.
118 We determine the impulse I in this case from (21) or, with the approximation $\gamma = 1.4$, from (26).

The latter can be written as follows:

$$I = \frac{1}{3}\sqrt{\frac{2\gamma}{(\gamma-1)^3} p_0 v_0 \frac{P}{g}\, \Phi\left(\frac{p_0}{p_a}\right)}. \tag{28}$$

[where v_0 is the specific volume of the gas in the rocket at $t = 0$].

We can easily determine v_0 and thus the absolute temperature T and the pressure p_0, if the reaction caused by the explosion is known. I think that it will be advantageous to replace the compressed air by gunpowder. The design of the rocket will then be much simpler, since it will then only be necessary to insert a certain amount of gunpowder into the rocket and tightly close the nozzle.

8. Determination of the rocket range

Let M be the mass of the rocket, m the mass of the gas contained in it at time t, and w the flight speed of the rocket.

We may then write

$$(M + m)\frac{dw}{dt} = R,$$

whence

$$Mw = \int_0^t \frac{R\,dt}{1 + \frac{m}{M}} \tag{29}$$

From (1) and (12) we have

$$m = \frac{1}{g}\left(P - \int_0^t dtq\right) = \frac{P}{g}\left(\frac{p_t}{p_0}\right)^{\frac{1}{\gamma}} = \frac{m_0}{(1 + At)^{\frac{2}{\gamma - 1}}} \tag{30}$$

Inserting this into (29), we obtain

$$Mw = \frac{1}{1 + \frac{m_0}{M(1 + A\tau)^{\frac{2}{\gamma-1}}}} \int_0^t R\,dt = kI, \tag{31}$$

where $0 < \tau < t$

The term $\frac{m_0}{M(1 + A\tau)^{\frac{2}{\gamma-1}}}$ is generally a small fraction, so that the coefficient k differs little from unity.

The time t during which the compressed gas is discharged from the rocket is small in comparison with total duration of the rocket's flight. We may therefore determine the rocket range X_{max} by assuming that the rocket is launched at an angle of 45°. Neglecting air resistance we obtain

$$X_{max} = \frac{w^2}{g} = \frac{k^2 g I^2}{Q^2}, \tag{32}$$

where Q is the weight of the rocket.

Substituting in this expression for I from (28), we obtain

$$X_{max} = \frac{k^2}{9} \frac{2\gamma}{(\gamma - 1)^3} \frac{p_0 v_0}{g} \frac{P^2}{Q^2} \Phi^2\left(\frac{p_0}{p_a}\right) \tag{33}$$

119 9. The influence of the rocket length on the range

The rocket weight Q and the weight P of the compressed air in the rocket can be expressed as functions of the rocket length l:

$$Q = al + b$$
$$P = cl,$$

where a, b and c are independent of l. Inserting these values into (33), we obtain

$$X_{max} = \text{const}\,\frac{c^2 l^2}{(al + b)^2} = \text{const}\,\frac{c^2}{\left(a + \frac{b}{l}\right)^2}.$$

Lengthening the rocket thus increases its range.

10. Application of the formulas obtained to a numerical example

Consider a rocket consisting of a steel pipe whose length is $l = 2$ m and whose inside diameter is 7 cm. Such a pipe may be assumed to weigh 5 kg, the weight of the nozzle and the faceplate is taken as 2 kg, and that of the stabilizers as 0.5 kg. The total weight of the rocket thus is

$$10 + 2 + 0.5 + 5 = 17.5 \text{ kg}.$$

[including a 5 kg propellant charge]. We assume that the rocket is filled with air at a pressure of 400 atm [this quantity of air would weigh approximately 4 kg].

We thus have to write in (33)

$$\frac{1}{9}\cdot\frac{2\gamma}{(\gamma-1)^3} = 4.86;$$

$$\frac{p_0 v_0}{g} = RT = 29.28\ (273+15) = 8432.64;$$

$$\Phi\left(\frac{p_0}{p_a}\right) = \Phi^2\ (400) = (0.858)^2 = 0.736;$$

$$P^2 = \left(2\,\frac{\pi d^2}{4}\cdot 400\cdot 1.186\right)^2 = (3.65)^2 = 13.37;$$

$$Q^2 = (17.5)^2 = 306.25.$$

Setting $k=1$, we obtain

$$X_{max} = 1317\ m.$$

11. Comparison of rockets with air guns

Let S be the cross-sectional area of both the air gun (Figure 144a) and the rocket (Figure 144b), l_0S the initial volume of compressed air both in the gun and in the rocket, l_1 the overall length of the gun, M the mass of projectile (A) fired by the gun or warhead (A) carried by the rocket, M_1 the mass of the rocket without warhead (A), p the initial pressure in the gun and in the rocket, p_1 the pressure in the gun when the projectile leaves it, and m the mass of the compressed air both in the gun and in the rocket.

120 We may write for the air gun:

$$Spdl = d\,\frac{Mw^2}{2}$$

$$p_0 l_0^{\gamma} = p_1 l_1^{\gamma} = p l^{\gamma}.$$

Integrating, we obtain

$$\frac{Sp_0 l_0}{\gamma-1}\left[1-\left(\frac{l_0}{l_1}\right)^{\gamma-1}\right] = \frac{Mw^2}{2}.$$

Hence, for the air gun,

$$I_{gun} = \sqrt{\frac{2\,Sp_0 l_0 M}{\gamma-1}}\left[1-\left(\frac{l_0}{l_1}\right)^{\gamma-1}\right]. \tag{34}$$

Setting in (26) $l=l_0$ and

$$Sl_0\rho_0 = \frac{P}{g} = m$$

we obtain

$$I_{rocket} = \frac{1}{3\,(\gamma-1)}\sqrt{\frac{2\gamma S p_0 l_0 m}{\gamma-1}}\,\Phi\left(\frac{p_0}{p_a}\right). \tag{35}$$

The ratio of the range X_{gun} of the gun to the range X_{rocket} of a rocket carrying a warhead having the same mass as the projectile is [by (32)]

$$\frac{X_{\text{gun}}}{X_{\text{rocket}}} = \frac{I^2_{\text{gun}}}{I^2_{\text{rocket}}} \frac{(M + M_1)^2}{M^2}$$

or, substituting for the impulses from (34) and (35),

$$\frac{X_{\text{gun}}}{X_{\text{rocket}}} = \frac{9\,(\gamma - 1)^2 \left[1 - \left(\frac{l_0}{l_1}\right)^{\gamma - 1}\right]}{\gamma\, \Phi \left(\frac{p_0}{p_a}\right)} \cdot \frac{(M + M_1)^2}{Mm} \qquad (36)$$

Consider the particular case when $\frac{l_0}{l_1} = \frac{1}{2}$ (Figure 144a). The other magnitudes have the same values as in the example in the previous section.

(121)

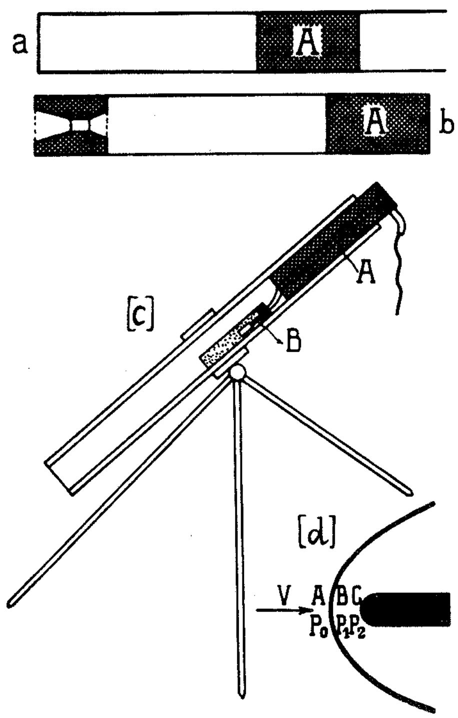


FIGURE 144. Ryabushinskii's rockets

We write

$$9\,\frac{(\gamma - 1)}{\gamma} = 1.07,$$

$$\Phi\left(\frac{p_0}{p_a}\right) = \Phi\,(400) = 0.858,$$

$$\left(1 - \frac{l_0}{l_1}\right)^{\gamma - 1} = 1 - \left(\frac{1}{2}\right)^{0.41} - 0.247,$$

$$\frac{(M + M_1)^2}{Mm} = \frac{(5 + 12.5)^2}{5 \cdot 3.65} = 16.78,$$

and obtain

$$\frac{X_{\text{gun}}}{X_{\text{rocket}}} = 5.18$$

if air resistance is neglected.

121 In making this comparison, we have assumed that the payload mass projectile or warhead is the same in both cases (Figure 144a) (*A*). Assuming, however, that the total masses transported are the same, we must replace the term $\frac{(M+M_1)^2}{Mm}$ by $\frac{M}{m}$, the other magnitudes retaining their values. We then obtain

$$\frac{X_{\text{gun}}}{X_{\text{rocket}}} = 0.424.$$

12. The reaction gun

The example considered in the previous section shows that most of the weight carried by the rocket is due to its own mass, and not to that of the warhead.

At the Institute in 1916 I designed a small reaction gun (resembling a rocket) whose shell remains stationary, and from which the payload (projectile) is launched. Figure 144c shows this gun schematically.
122 Bomb (*A*) is ejected by the explosion of gunpowder contained in sheet-metal cylinder (*B*). The gun weighed 7 kg, while the projectiles weighed 3 and 4 kg. Charges of 300 and 400 g black powder respectively shot these projectiles to an average distance of 320 m.

Between the two extremes defined by ordinary and reaction guns lies the recoilless gun, which ejects different masses [of gas] in the direction opposed to that of the projectile.

c) The resistance of fluids and the reaction caused by their discharge

In his paper "Sur la résistance des fluides et la réaction d'une jet," published in "Revue générale de l'aéronautique," No. 6, 1925, as well as in the book "III congrès international de la navigation aérienne," Vol. II, p. 180, Ryabushinskii expounds the theory of the resistance of fluids at different velocities and presents the results of his experiments dealing with this problem during rocket flight. In this sense, this work is a continuation of his "Theory of Rockets."

Of the first part of this work (the resistance of fluids), we shall present only as much as is necessary for the understanding of the second part (the reaction caused by the discharge of fluids). A translation of this second part will be given in full.*

* The same was done in Italy, where this work by D. Ryabushinskii was published in the "Notiziario technico di Aéronautica," No. 8, p. 1. 1927.

1. THE RESISTANCE OF FLUIDS

Let a body have a uniform rectilinear or rotational motion in an unbounded fluid. The curve representing the ratio $\frac{R}{V^2}$ (drag to velocity squared) as a function of the velocity then depends on the shape and dimensions of the body and on the properties of the fluid. However, the general form of these curves, characterized by some singular points, is usually the same. Figure 145 represents such a curve schematically.

The critical velocities V_1 and V_2 may sometimes coincide. At velocities below V_1 the motion is continuous, and its analysis gives an exact solution after integration of Navier's equations.

In this case the experimental results agree with the theory. However, at velocities above V_1 the flow regime and the law governing the drag change abruptly. This is due to the appearance of turbulence which is created by friction between the fluid and the body, and is propagated in the fluid. The next singular point on the curve corresponds to the velocity V_2 at which the flow regime changes again. This change may be quite abrupt in certain cases. This phenomenon is linked to flow separation.

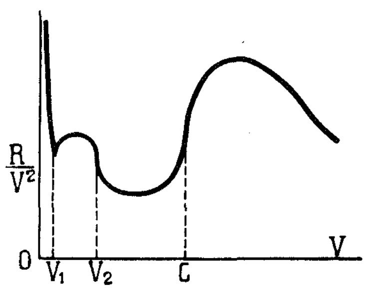


FIGURE 145. Air resistance

123 A third singular point occurs on the curve when the velocity is equal to the speed of sound (C) in the fluid concerned. This point corresponds to an abrupt increase in the drag coefficient.

Following Mach's experiments and the photographs taken by him, several attempts were made to link the theory of drag at high velocities to the theory of shock waves developed by Riemann, Rankine, and Hugoniot. The most important research in this field was done by Sebert, Hugoniot, Wigley, Hadamard, and Lord Rayleigh (cf. "Hydrodynamics," by Sir Horace Lamb, Dover Publishing Co., 1924).

Lord Rayleigh extended Rankine's theory by allowing for friction in order to determine the changes which Laplace's formula $pv^\gamma = \text{const}$ undergoes when a shock wave travels through the fluid. The ratio of the pressure P_2 at the stagnation point to the pressure P_0 corresponding to irrotational flow is then

$$\frac{P_2}{P_0} = \left(\frac{\gamma+1}{2} \cdot \frac{V^2}{C^2}\right)^{\frac{\gamma}{\gamma-1}} \left(\frac{2\gamma}{\gamma+1} \cdot \frac{V^2}{C^2} - \frac{\gamma-1}{\gamma+1}\right)^{-\frac{1}{\gamma-1}} \qquad (1)$$

whence

$$\frac{P_2 - P_0}{\rho V^2} = (\gamma)^{-\frac{1}{\gamma-1}} \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}} \left(1 - \frac{\gamma-1}{2\gamma} \cdot \frac{C^2}{V^2}\right) - \frac{1}{\gamma} \cdot \frac{C^2}{V^2} \qquad (2)$$

Lamb [loc. cit, p. 696] gives some values obtained by means of this formula.

$\frac{V}{C}=$	1	2	3	4
$\frac{p_2}{p_0}=$	1.90	5.67	11.7	20.7

Lamb writes [loc. cit.]: ".... Stanton has measured velocities 2 or 3 times that of sound and found them to agree closely with independent, but more elaborate, experimental investigations."* However, (1) is not completely rigorous and definitive because it is based on certain assumptions which Rankine and Lord Rayleigh had to make due to the difficulty of giving a complete description of all temperature changes occurring in the critical zone *AB* (Figure 144*d*).

2. THE REACTION DUE TO THE DISCHARGE OF A FLUID

I shall present the theory dealing with the pressure at the stagnation point when the flow velocity varies between zero and supersonic values. I shall use the momentum theorem.

Assume that a gas flows out of vessel *A* (Figure 146 *a* and *B*). The vessel is so large that the motion may be considered to be steady. There may or may not be a nozzle. If a nozzle is provided, it is of the convergent-divergent type. The ratio of the pressures inside and outside the vessel thus is

$$> \text{ or } < \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}} = 1.9.$$

Assume also that the angle of divergence of the nozzle is so small that the velocity inside the divergent part of the nozzle can be taken as parallel to the nozzle axis, and that this part is so long that expansion is complete.

124 The pressure in section S' (Figure 146b) is thus equal to the external pressure p_a as is the case in section S_0 (Figure 146*a*). When $\frac{p}{p_a} < 1.9$ S_0 denotes the cross-sectional area of the outlet orifice in the thin wall of vessel *A*, whereas S_0 denotes the area of the throat section in a nozzle when $\frac{p}{p_a} > 1.9$.

On the basis of these assumptions and the momentum theorem, we may write

$$R = (p - p_a)\, S_1 = DVS_0 \tag{3}$$

* [This is copied verbatim from Lamb (cf. "Hydrodynamics," by Sir Horace Lamb, Dover Pub. Co. 1945). The Russian text has a slightly different meaning.]

where D is the mass flow rate per unit area of S_0 (S_0 is the sum of the minimum sections of the stream filaments), and V is the final outlet velocity, which by Saint-Venant's formula is

$$V^2 = \frac{2C^2}{\gamma-1}\left[\left(\frac{P}{P_a}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \tag{4}$$

Here C is the velocity of sound at the external pressure and density of the air.

The value of D is equal to $(\rho_a \cdot V)$ or $(\rho_0 \cdot C_0)$, according to whether $\frac{V}{C} \gtrless 1$.

The density ρ_0 and the flow velocity V_0 are related to the density ρ and the pressure P outside* [sic] the vessel as follows:

$$\rho_0 = \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \rho, \quad C_0 = \left(\frac{\gamma P_0}{\rho_0}\right)^{1/2} = \left(\frac{2\gamma P}{(\gamma+1)\cdot\rho}\right)^{1/2} \tag{5}$$

Inserting (4) and (5) into (3), we obtain

$$\frac{R}{S_1 DV} = \frac{P-P_a}{DV} = \frac{S_0}{S_1} = f\left(\frac{V}{C}\right) \tag{6}$$

where

$$f\left(\frac{V}{C}\right) = \frac{1}{\gamma}\frac{C^2}{V^2}\left[\left(\frac{\gamma-1}{2}\frac{V^2}{C^2}+1\right)^{\frac{\gamma}{\gamma-1}} - 1\right] \tag{7}$$

when $\frac{V}{C} < 1$, and

$$f\left(\frac{V}{C}\right) = \left(\frac{\gamma^2-1}{4\gamma^2}\right)^{1/2}\left(\frac{\gamma+1}{2}\right)^{\frac{1}{\gamma-1}}\left(1+\frac{2}{\gamma-1}\frac{C^2}{V^2}\right)^{1/2}\left[1-\left(\frac{\gamma-1}{2}\frac{C^2}{V^2}+1\right)^{\frac{-\gamma}{\gamma-1}}\right] \tag{8}$$

when $\frac{V}{C} > 1$

The curve $\frac{S_0}{S_1} = f\left(\frac{V}{C}\right)$ is given in Figure 146c.

We introduce the magnitudes S and S' which are determined from the equations

$$\frac{S}{S_1} = \frac{S'}{S_0} = 1; \quad \frac{V}{C} < 1; \qquad \frac{S}{S_1} = \frac{S'\,S'}{S_0\,S_0} = \frac{\rho_0}{\rho_0}\,\frac{C_0}{V}, \quad \frac{V}{C} > 1. \tag{9}$$

125 and rewrite (6) in the form

$$\frac{R}{S\rho_a V} = \frac{P-P_a}{DV} = \frac{S'}{S} = f\left(\frac{V}{C}\right) \tag{10}$$

When $(V:C)<1$, the pressure in the throat (section S_0) (Figure 146a) is equal to the external pressure P_a; when $(V:C)>1$, however, (Figure 146b)

* [Should read inside.]

the pressure in section S_0 is

$$p_a = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}} p \qquad (11)$$

and the gas has to expand further until its pressure is p_a.

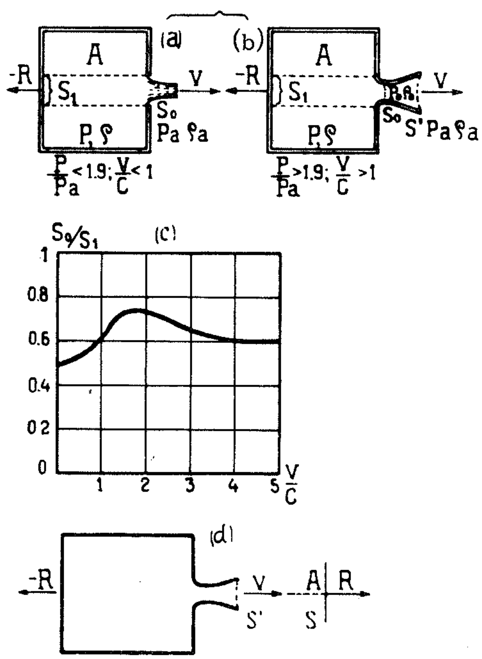


FIGURE 146. Ryabushinskii's theory

We denote as follows from (9), by S' the area of the section where the gas has expanded to the external pressure (Figure 146b), and by S the area defined by the equation

$$\frac{S}{S} = \frac{S_0}{S_1} \qquad (12)$$

Introducing the magnitude S_1, we obtain the reaction R irrespective of whether V is subsonic or supersonic at the external air density ρ_a; $S\rho_a V$
126 is the mass of fluid discharged from the vessel in unit time if there is no flow contraction, i.e., if by (12) and on the basis of the definition of S_1,

$$S_0 = S_1 = S' = S \qquad (13)$$

Letting V tend to zero in (7), we obtain $f(0) = 1/2$. If the fluid is incompressible, we must set $C = \infty$ in (7); we then obtain $f\left(\frac{V}{C}\right) = \frac{1}{2}$, for any velocity V. It may be assumed that in this limiting case the flow rate does not depend on the elasticity of the fluid but, e.g., on the speed of a piston moving in vessel A.

The reaction can be represented as the sum of two terms:

$$R = R_1 + R_2, \tag{14}$$

from which the first one,

$$R_1 = \frac{1}{2} S \rho_a V^2, \tag{15}$$

depends only on the inertia of the fluid, while the second

$$R_2 = \left[f\left(\frac{V}{C}\right) - \frac{1}{2} \right] S \rho_a V^2 \tag{16}$$

determines the increase in the reaction due to the compressibility of the fluid.

Assume that a plane of surface area S is arranged in front of the jet of fluid and perpendicular to the latter.

In the case of the resistance of a medium to the motion of a body (the inverse of the reaction caused by the discharge of a fluid), the drag is referred to the midsection area S of the body if (13) is satisfied and if the flow is irrotational.

Let the fluid impinge on the plane S (Figure 146d) so that the horizontal component of the flow velocity becomes zero. In accordance with the momentum theorem, the force R acting on the plane will be equal and opposite to the reaction on the vessel caused by the discharge. Setting in this case

$$R = (P_2 - P_a)\, S \tag{17}$$

in (10), where P_2 is the pressure acting on S, we may write

$$\frac{P_2 - P_a}{\rho_a V^2} = f\left(\frac{V}{C}\right) \tag{18}$$

and

$$\frac{P_2}{P_a} = 1 + \gamma\left(\frac{V^2}{C^2}\right) f\left(\frac{V}{C}\right), \tag{19}$$

where $f\left(\frac{V}{C}\right)$ is determined from (7) or (8) respectively. The curve representing (19) has a maximum at

$$\frac{V}{C} = 1.74 \tag{20}$$

Equation (17) gives the maximum resistance. In fact (18) or (19) determine only the pressure at the point of symmetry (A) of the plane where $V = 0$ (the stagnation point). If we alter the shape or dimensions of

the obstacle encountered by the jet of fluid but maintain the axis of symmetry of the former coincident with the flow axis, the force which the fluid exerts on the obstacle changes but the pressure at the stagnation point A
127 will still be given by (18) or (19). The pressure determined by (19) is that given by Saint-Venant's formula if $(V:C) < 1$, but not if $(V:C) > 1$.

We can then no longer assume that the process is isentropic. We must in this case allow for shock waves.*

Some values of the ratio P_2/P_a, determined from (19), follow; they may be compared with those obtained from (1) derived by Lord Rayleigh:

$\frac{V}{C}=$	1	2	3	4
$\frac{P_2}{P_a}=$	1.90	5.03	9.45	15.03

By making some simplifying assumptions, we can apply this theory to determine the total drag of a body.**

We shall now describe some experiments carried out by us to study the reaction due to the discharge of gases after the explosion of gunpowder in a gun open at both ends (i. e., a recoilless gun) and in rockets. We shall first derive some formulas which, although approximations, nevertheless give the operating characteristics of such guns and rockets.

Let m be the mass of the propellant, p the energy contained in unit weight of the propellant (specific energy), g the gravitational acceleration, u the absolute gas-outlet velocity, and M the mass of the body propelled at a speed V due to the reaction caused by the discharge of the gas. In this case the total momentum of the system remains constant. Using the conservation of energy principle, we obtain as a first approximation

$$mu = MV \tag{1}$$

$$\frac{1}{2} mu^2 + \frac{1}{2} MV^2 + (1-\varepsilon)\, p m g = p m g \tag{2}$$

The term $(1-\epsilon)\, pmg$ represents that part of the energy contained in the propellant, which is not converted into mechanical work. The efficiency thus is

$$\eta = \frac{\frac{1}{2} MV^2}{p m g} = \frac{\varepsilon}{1+\frac{M}{m}} \tag{3}$$

We assume that the rocket is launched at an angle of 45° and neglect air resistance. The maximum range of the rocket then is

$$X_{max} = \frac{2\varepsilon p m^2}{M(M+m)} \tag{4}$$

If m is small in relation to M, and ϵ is constant, the maximum range of the rocket is proportional to the square of the weight of the propellant

* [It is obvious that the many ambiguities and errors in this section are due to a poorly edited translation of the French original into Russian.]

** Mémoral de l'Artillerie Francaise, No. III, p. 710. 1923.

used, and inversely proportional to the square of the weight of the projectile. The heaviest part of the rocket is its shell. It may be advisable that the shell of the rocket remain at the point of launching, and that only the projectile be fired. This leads us to the design of a gun open at both ends (recoilless gun).

128 It is seen from (3) that the efficiency increases when the ratio M/m is reduced; high-power recoilless guns are therefore preferred unless the coefficient ϵ is excessively small.

Consider now the rocket as a ram for driving piles. The rocket shell may have the form of a cylinder open at both ends and fitted to the pile head. The reaction due to the discharge of the gases after the detonation of the cartridge drives the pile into the ground.

Let **M** be the mass of the pile, V the speed at which it is driven into the ground, R the [dynamic] resistance of the soil (constant in a first approximation), e the depth to which the pile is driven, and t the time that this takes. The remaining symbols have the same meaning as before. Equations (1), (2), and (3) can also be used in this case, but two more equations can be added to them, which are derived from the impulse law and from the kinetic-energy theorem:

$$MV = (R - Mg) \cdot t \tag{5}$$

$$\frac{1}{2} MV^2 = (R - Mg) \cdot e, \tag{6}$$

we then obtain from (5), (6), and (3):

$$e = \frac{\epsilon\, p\, m^2 g}{(R - Mg)(M + m)} \tag{7}$$

$$t = \frac{m}{R - Mg}\sqrt{\frac{2Mpg\epsilon}{M+m}} \tag{8}$$

If m is small in comparison with M, and ϵ is constant, the depth to which the pile is driven will be proportional to the square of the propellant weight. Let S be the cross-sectional area of the pile and b the average [dynamic] resistance of the soil per unit surface area (specific resistance). We can then replace R by bS in the above formulas.

Consider two numerical examples. 1) Let the weight of the pile be $Mg = 200$ kg, the weight of the propellant $mg = 20$ kg, the specific energy of the propellant $p = 300{,}000$ kg m/kg, the cross-sectional area of pile $S = 100$ cm^2, the specific resistance of the soil $b = 100$ kg/m^2, and $\epsilon = 0.1$. Inserting these values into (3), (7), and (8), we obtain

$$\eta = \frac{1}{110};\ e = 5.57\ m,\ t = 0.152\ sec.$$

2) Let the weight of the propellant be 250 g, all other magnitudes having the same values as before. Then

$$\eta = \frac{1}{8010};\ e = 0.000937\ m,\ t = 0.00195\ sec.$$

If we use the same amount of propellent as before, i. e., 20 kg, but divide it into small batches of 250 g each, the pile is driven to a depth of

$0.000937 \cdot 80 = 0.075$ m, instead of 5.57 m when the entire 20 kg are detonated at one time. The difference will, in reality, most probably be considerably less since the [dynamic] resistance of the soil depends on V, but will nevertheless be quite large.

Figure 147 shows a small recoilless gun built in 1916 at the Aeronautical Institute at Kuchino. The length of its steel barrel was 1 m and its bore, 7 cm; the gun rested on a light support. The projectile was a wooden
129 cylinder whose weight and stability were increased by fixing a leaden head to it. Figure 147 shows this cylinder inserted into the muzzle of the gun. The cylinder was ejected by the force of the explosion of gunpowder contained in a sheet-iron cartridge. The cartridge cases were not ejected with great force but fractured and fell to the ground badly damaged. The cylinders were ejected by the reaction force due to the discharge of the gases without the assistance of separate masses, as in the case of the Davis gun.*

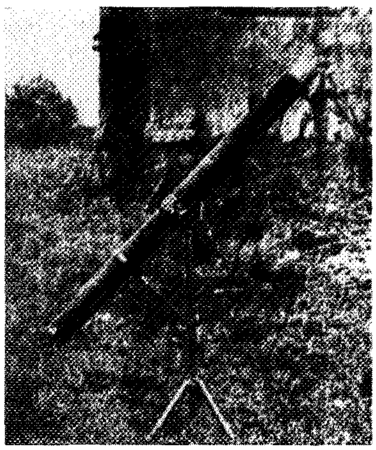


FIGURE 147. Projectile inserted into gun

FIGURE 148. Ryabushinskii's rockets

The gun together with the support weighed 7 kg, while the projectiles weighed 3 and 4 kg. The black-powder charges weighed 300 and 400 g respectively. The average range was 320 m. There was no recoil. The gun neither overturned nor was deflected after firing. This is quite remarkable since the weight of the projectile sometimes exceeded half the weight of the gun.

Further experiments in this direction were carried out by us in 1924 on the beach near Biarritz.

Figure 148 (top) shows a rocket with lateral orifices. The reaction due to the discharge of the gases through these orifices causes the rocket to revolve rapidly about its axis. The flight of such a rocket resembles that of a projectile fired from a rifled gun.

Figure 149 shows a rocket on a tripod of the type used with cameras. The ranges of such rockets were similar to those previously given.

* "La Nature," 2 December, 1916.

Figure 150 shows an installation for pile driving. The pile was 195 cm long and that part of it which was inserted into the steel cylinder was 50 cm long. The pile diameter was 8.8 cm inside this cylinder and 10.5 cm outside it. The internal diameter of the cylinder was 9.3 cm. The pile weighed 12.9 kg. The explosive charge weighed 575 g. The pile was driven to a depth of 60 cm in sand.*

130

FIGURE 149. Rocket on tripod

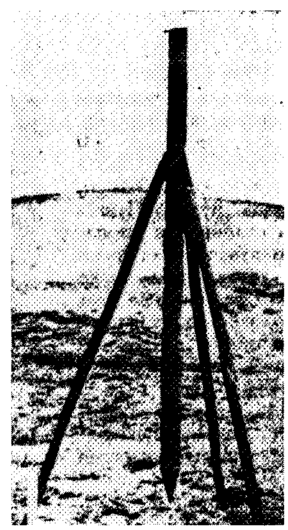


FIGURE 150. Rocket pile driver

Figure 148 (bottom) shows a rocket secured to a disk and provided with lateral ducts; this arrangement permitted the entire system to rotate about an axis perpendicular to the disk. The entire device weighed 533 g. It was projected at an angle of approximately 25° to a distance of 110 m when a 50 g charge was fired; upon landing, it rebounded several times on the moist sand of the beach.

The success of such rockets depends on the resistance of the cartridge with the charge. The detonation velocity must exceed the gas-outlet velocity in the rocket nozzle.

It is interesting to note that when paper cartridges are used, the addition of some sheets to their thickness causes the rockets to fly hundreds of meters instead of dropping to the ground at the point of firing.

* Experiments using dynamite to drive piles had been carried out as early as 1881 by Lt.-Col. Prodanovac in Budapest (cf. "Les explosive modernes" by Paul Chalon, p. 691). The weight of the dynamite charge was very small in comparison with the weight of the pile, and the charge was covered with sand or clay.

131 *Chapter VI*

LARGE-BORE GUNS ON AIRSHIPS. THE WORK OF GIOVANNI PENNA

a) Introduction

Below we give a translation [from the Italian into Russian in the original text] of a paper by the Italian engineer Giovanni Penna. Although, according to its author, this paper deals with guns, it contains the theory of rocket missiles and is in this respect an extension of D. Ryabushinskii's work. Penna's paper appeared in the Italian journals "L'àla d'Italia," 1926, Nos. 2 and 4, and "Rivista Aeronautica," 1926, No. 1. A Russian translation of part of this paper was published in the journal "Voina i Tekhnika," 1927, No. 1.

We have independently translated Penna's paper from the two above-mentioned Italian journals and added to it the critical remarks (published in the "Rivista Aeronautica," 1926, No. 3) by Engineer Crocco, who was influenced by the work of Ryabushinskii and Esnault-Pelterie.

b) Open gun with rocket missile

The use of large-bore guns on airships necessitates guns whose recoil is minimum. Such a gun, open at both ends, was designed by Davis. The charge is located in its center, while the shell is inserted on one side and a bag with shot on the other. This is the counter-shell whose mass is equal to that of the shell. The kinetic energy imparted to the shell upon firing is equal to that imparted to the counter-shell, so that in theory the recoil is zero.

Despite this advantage the Davis gun has the following shortcomings: a) it is necessary to carry on board the airship a useless weight equal to that of the shells; b) ejection of the counter-shell endangers nearby aircraft; c) loading the gun is complicated; d) the energy of the charge is utilized less efficiently than in ordinary guns; e) it is necessary to increase the barrel thickness of the Davis gun in order to have the same gas pressure as in normal guns. The Davis gun must weigh almost twice as much as an ordinary gun to have an equal shell muzzle velocity. Reducing the weight of the Davis gun lowers the muzzle velocity, creating a disadvantage.

To eliminate these shortcomings the author of this paper proposes an open gun with a rocket missile and presents the theory of its firing.

132 All magnitudes are expressed in mks units.

The following notation is used:

t — time;
S — distance;
g — gravitational acceleration;
π — weight of empty missile;
Ω — weight of missile charge;
Q — mean weight of missile $= \pi + \frac{\Omega}{2} + \frac{\omega}{2}$.
ω — weight of gas remaining in combustion chamber at burnout;
C — weight of gas ejected from combustion chamber until burnout;
$c = \frac{C}{Q}$ — charge coefficient corresponding to burnout;
E — rate of gas formation by propellant;
W — linear burning velocity;
A — cross-sectional area of gun bore;
S_m — throat area of nozzle through which gas escapes;
P — pressure inside combustion chamber of missile;
p — external pressure;
R — gas constant;
T — combustion temperature;
ρ — density of gas inside combustion chamber;
f — power of propellant;
u — gas-outlet velocity in exit sections;
v — missile velocity;
q — consumption of propellant per sec [= mass flow rate of gas];
γ — polytropic exponent.

Figure 151a shows rocket missile which is the subject of our investigation. It consists of combustion chamber (*a*), nozzle (*d*), and warhead (*B*).

c) Combustion phases

As in an ordinary gun, ejection of the missile is due to the combustion of an explosive mixture and the formation and discharge of gases which raise the pressure in the combustion chamber. The rate of gas formation (the weight of gas formed in unit time) depends on the shape of the gunpowder grains and on the pressure. At a given pressure the rate of gas formation is constant if the charge consists of thin sheets, spirals, tubes, or rings. Under these conditions, it is most probable that there is a fixed relationship between the mass flow rate q of the gas through the nozzle and the weight of gas formed by the propellant in unit time at constant pressure.

The phenomenon may be separated into 3 phases:

1. The initial phase during which the pressure in the combustion chamber increases from p to P.
2. The combustion phase at constant pressure P.
3. The expansion phase during which the pressure decreases from P to p.

These phases are represented in Figure 151b.

(133)

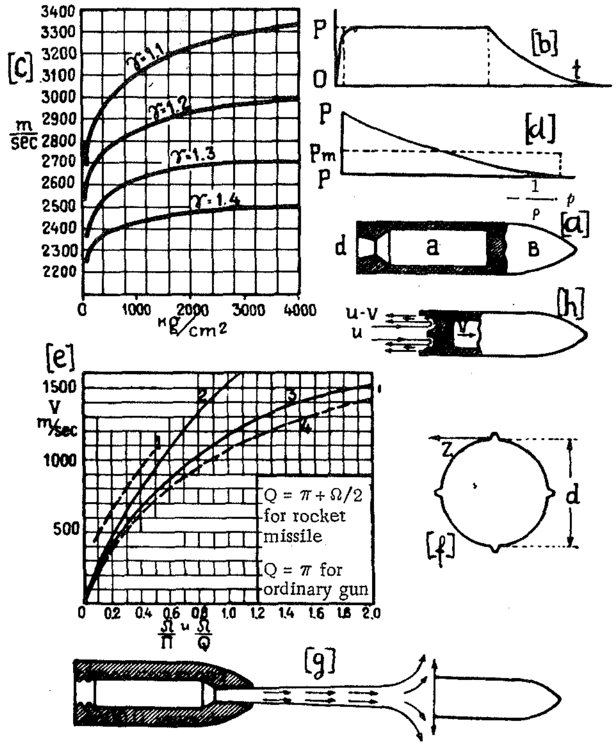


FIGURE 151. Penna's theory:

1 — muzzle velocity of ordinary gun; 2 — muzzle velocity of rocket missile as function of Ω/Q (or of turbo-gun with [relative] efficiency = 1); 3 — muzzle velocity of rocket missile as function of Ω/π; 4 — muzzle velocity of rocket missile at $\omega = \Omega/10$.

Obviously, the first phase is very short if the charge is tightly filled, while the third phase, although long, has a smaller effect than the second phase. We shall therefore first assume that only the second phase exists. The muzzle velocity of the missile will thus be found to be slightly less than in reality. We shall use numerical coefficients corresponding to the
133 real combustion and expansion processes; the correctness of this procedure has been verified by experiments. A short analysis of the third phase will be given later. The first phase is the same as in an ordinary gun, and there is no reason to assume that more energy is gained during it.

d) Determination of the mass flow rate of the gas through the nozzle

The mass flow rate q of the gas through the nozzle is constant during the second phase in which the pressure P in the combustion chamber, the external pressure p, the gas-outlet velocity, and the gas density are constant.

The pressure P in the combustion chamber exceeds the outside pressure multiplied by $\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}}$. We may therefore apply the formula for the

134 discharge of a gas through a nozzle, where the subscript m indicates the throat section:

$$
\begin{aligned}
p_m &= P\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}} \\
\rho_m &= \rho\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \\
u_m &= \sqrt{\frac{dp}{d\rho}} = \sqrt{\frac{2\gamma}{\gamma+1}\cdot\frac{P}{\rho}} \\
q &= S_m \cdot u_m \cdot \rho_m \cdot g
\end{aligned}
\qquad (1-4)
$$

From this we obtain

$$q = S_m\, g\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}\sqrt{\frac{2\gamma}{\gamma+1}P\rho}. \qquad (5)$$

Since

$$\frac{P}{\rho g} = RT, \text{ то } P\rho = \frac{P^2}{RTg}. \qquad (6)$$

Inserting this into (5), we obtain

$$q = S_m \cdot P\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}\sqrt{\frac{2\gamma}{\gamma+1}\cdot\frac{g}{RT}}. \qquad (7)$$

We assume, following Maillard and Le Chatelier, that the specific heat of a gas does not depend on its pressure. We may therefore take the combustion temperature T as constant for any given explosive. Hence,

$$q = S_m \cdot K \cdot P, \qquad (8)$$

where

$$K = \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}\sqrt{\frac{2\gamma}{\gamma+1}\cdot\frac{g}{RT}}. \qquad (9)$$

For ballistite $R = 30.7$, $T = 3{,}281°$.

For values of γ between 1.1 and 1.4, we find that K varies linearly from 0.00622 to 0.00677. This variation is small so that we may assume an average value $K = 0.0065$, whence

$$q = 0.0065\ S_m \cdot P. \qquad (8\ \text{bis})$$

Setting $S_m = 1$ and $P = 1$, we obtain $q = 0.0065$.

If $S_m = 0.0001$ and $P = 10{,}000$, then $q = 0.0065$.

Equation (8 bis) is valid for magnitudes given in cm and kg. This means that 6.5 g of gas per sec pass through each cm².

The power of the explosive is

$$f = R \cdot T \cdot \beta, \qquad (10)$$

where β is the weight of gas produced by 1 kg of explosive.

135 Taking $\beta = 1$ for ballistite, we obtain from (9):

$$K=\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}\sqrt{\frac{2\gamma}{\gamma+1}\cdot\frac{g}{f}} \tag{11}$$

and

$$q=\alpha\cdot S_m P\frac{1}{\sqrt{f}}, \tag{12}$$

where $\alpha=(\gamma g)^{\frac{1}{2}}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$.

Here f is given in kgm and is numerically equal to the pressure created by the combustion of 1 kg of explosives at a constant volume of 1 m^3.

For ballistite $f = 100{,}840$ kgm. The values of f for other explosives can be obtained by multiplying by 10 the values given by G. Bianchi in his work on the theory of explosives, in which he gives f as the pressure, atm (kg/cm^2), created by the combustion of 1 g of the explosive at a constant volume of 1 cm^3.

e) Analysis of the rocket missile during the second phase

Let u be the gas-outlet velocity in the exit section of the nozzle, and r the reaction force caused by the discharge of the gas. Then

$$r=\frac{q}{g}(u-v), \tag{13}$$

with q = const = 0.0065 SP, while u is also constant. When

$$P>p\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma-1}{\gamma}},$$

we have for a perfect gas

$$u=\sqrt{\frac{2\gamma}{\gamma-1}\frac{P}{\rho}\left[1-\left(\frac{p}{P}\right)^{\frac{\gamma-1}{\gamma}}\right]} \tag{14}$$

Since $\frac{P}{\rho}gRT=gf$ and T = 3,281, we obtain from (14):

$$u=994\sqrt{\frac{2}{\gamma-1}\left[1-\left(\frac{p}{P}\right)^{\frac{\gamma-1}{\gamma}}\right]}. \tag{15}$$

Successively using values of γ up to 1.41 and varying P between 4,000 and 100 kg/cm^2, we obtain the values of u shown in Figure 151c. It is seen that u varies inversely as γ when P is given.

At $\gamma = 1$ (isothermic expansion of the gas) the final kinetic energy of the gas is larger than in the case of adiabatic expansion.

The difference between these two values corresponds to the heat absorbed by the gas in order to maintain a constant temperature during its expansion.

Most scientists investigating problems of internal ballistics assume $\gamma = 1.1$ to 1.2.

However, the lack of definitive data permits us to use different values of γ for the expansion of the gas which, in the case under consideration here, differs from that in ordinary guns.

136 The phenomena occurring in these two cases are generally different. Furthermore, the gas in the rocket missile is in contact with the nozzle walls for only a few ten thousandths of a sec, whereas in an ordinary gun this contact lasts during the entire time the shell travels through the barrel. It is therefore possible to assume that in our case $\gamma = 1.41$. Furthermore, the mass of the metal absorbing heat is in our case only 1/100 of that in an ordinary gun.

The gas-outlet velocities obtained for these conditions are less than those observed in reality; at $\gamma = 1.4$ and $p = 1{,}000$ kg/cm², $u = 2{,}430$ m/sec, while at $\gamma = 1.1$ and $p = 1{,}000$, $u = 3{,}100$ m/sec.

Figure 151c shows that the gas-outlet velocity varies only slightly with the pressure when γ is given. In every case, therefore, we may take an average value of u from Figure 151c.

f) Determination of the initial flight speed of the missile

The flight speed of the missile during the second phase at time t computed from the beginning of this phase, which practically coincides with the beginning of combustion, is

$$v = \int_0^t \frac{rg}{\pi'}\, dt, \qquad (16)$$

where π' is the weight of the empty missile together with the weight of the propellant remaining in the combustion chamber at time t. Inserting this value into (13), we obtain

$$r = \frac{qu}{g} - \frac{q}{g} \int_0^t \frac{rg}{\pi'}\, dt. \qquad (17)$$

Since the pressure and thus also u are constant during the second phase, differentiation of (17) yields

$$\frac{dr}{r} = -\frac{q}{\pi'}\, dt. \qquad (19)^*$$

Let τ be the duration of the second phase. The weight of the missile varies linearly from $\pi + \Omega$ to $\pi + \omega$ during the time interval between 0 to τ.

* [There is no formula (18) in the Russian text.]

In integrating (19) we may replace the variable magnitude π' by its mean value Q, we thus obtain

$$\log r = -\frac{q}{Q}\, t + \text{const.} \tag{20}$$

$$r_t = r_0 \cdot e^{-\frac{q}{Q} t}\,. \tag{21}$$

By (13), at $t = 0$, $r_0 = \frac{qu}{g}$, so that

$$r_t = \frac{qu}{g} \cdot e^{\frac{-g}{Q}} \tag{22}$$

137 In this expression qt represents that part of the propellant which has burnt by time t. Inserting this value of r into (16), we obtain

$$v = \frac{qu}{Q} \int_0^t \frac{e^{-gt}}{Q} \tag{23}$$

Integration yields

$$v = u\left(1 - e^{\frac{-qt}{Q}}\right). \tag{24}$$

It follows from this that the missile speed at the end of the second phase and the energy at time τ depend only on the gas-outlet velocity through the nozzle, i. e., on the pressure in the combustion chamber, and on the ratio of the weight of the propellant (burnt up to time τ) to the mean weight of the missile.

Determination of the distance traveled by the missile during the second phase.

The distance traveled by the missile is

$$s = \int_0^t v dt = u \int_0^t \left(1 - e^{\frac{-qt}{Q}}\right) dt. \tag{25}$$

Integration yields

$$\frac{s}{u} = t - \frac{Q}{q}\left(1 - e^{\frac{-qt}{Q}}\right),$$

$$s = tu - \frac{Q \cdot v}{q}\,. \tag{26, 27}$$

At $t = \tau$ we have

$$\tau = \frac{\Omega - w}{q} = \frac{C}{q}$$

whence

$$S = \frac{1}{q}\,(uC - Qv). \tag{28}$$

We denote the ratio $\frac{C}{Q}$ by c. The above formulas may then be simplified as follows:

$$v = u\left(1 - e^{-\frac{q}{Q}t}\right) = u\left(1 - e^{-\frac{C}{Q}}\right) = u\left(1 - e^{-c}\right),$$

$$S = \frac{Q}{q}\,(cu - v). \qquad (29,\ 30)$$

The distance traveled by the missile is thus directly proportional to the weight of the latter and inversely proportional to the consumption of propellant per sec; we have here assumed that C and v are constant during the entire second phase.

Ignoring the ballistic processes during the first and third phase (29) and (30) give us respectively the muzzle velocity of, and the distance, traveled by the missile in a gun open at both ends (the useful length of the gun barrel).

188) Observations on the third phase

The third phase corresponds to the operation of a rocket propelled by compressed air. Such a missile consists of a steel tube closed at one end and having a nozzle at the other end. A stabilizer is fitted to the tail of the missile which contains air at a pressure of up to 40 atm.

In our case the air is replaced by the gas formed by the combustion of propellant at a pressure P and temperature T.

D. Ryabushinskii has given the relevant theory in the 6th Bulletin of the Aeronautical Institute (cf. Chapter V). This theory is based on the laws governing the discharge of gases and gives quite simple results; however, Ryabushinskii did not allow for the decrease in the momentum of the discharged gases, due to the flight speed of the rocket. The differential equations, obtained from those derived by Ryabushinskii, after introducing a suitable correction, are not easily integrated since $\frac{3\gamma - 1}{2(\gamma - 1)}$ is not a whole number. It is therefore easier to represent the function and integrate it graphically.

The derivation may be considerably simplified by replacing the variables u, q, etc., in the preceding equations by their mean values; this yields quite reliable results.

It follows from Figure 151d that the energy contained per unit weight of gas in the combustion chamber at the beginning of the third phase is proportional to the area bounded by the curve and the coordinate axes. This area may be replaced by a rectangle of the same area, whose base is the final specific volume of the expanded gas, and whose height is the mean pressure P_m.

This area is

$$\frac{P_m}{\rho_a \cdot g} = \frac{\gamma p^{\frac{1}{\gamma}}}{(\gamma - 1)\,\rho \cdot g} \cdot p^{\frac{\gamma - 1}{\gamma}}\left[\left(\frac{P}{p}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right] = \int_p^P \frac{dP}{\rho g}, \qquad (31)$$

whence

$$P_m = \frac{\gamma}{\gamma - 1} p \left[\left(\frac{P}{p} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]. \tag{32}$$

Reverting to (5), from which we obtained (8 bis), we can determine the mean mass flow rate of the gas through the nozzle during the third phase:

$$q_m = 0.0065\ S_m \cdot P_m. \tag{33}$$

We insert this value into (13) where u is given by (14) and $P = P_m$. This yields

$$r = \frac{q_m}{g} (u_m - v). \tag{34}$$

Inserting (34) into (17), we obtain

$$v = u_m \left(1 - e^{\frac{-q_m t}{Q}}\right). \tag{35}$$

[cf. (24).]

The product $q_m t$ at the end of the third phase is equivalent to the weight which we have denoted by ω. Equation (35) was derived on the assumption that the missile speed at the beginning of the third phase is zero. This formula is identical with (29). An expression for the distance traveled by the missile can be established by analogy to (30).

139 These formulas may be applied directly to pneumatic rockets. Reverting to the numerical example given by Ryabushinskii in his Bulletin, we obtain a missile speed of 114.2 m/sec instead of 114.5 m/sec.

In the case which interests us, the missile already has velocity v at the beginning of the third phase.

The missile speed at the end of the third phase is determined by a method similar to that used before. This speed is

$$v = u\left(1 - e^{-\frac{\Omega - \omega}{Q_1}}\right) + \left[u_m - u\left(1 - e^{-\frac{\Omega - \omega}{Q_1}}\right)\right]\left(1 - e^{\frac{\omega}{Q_2}}\right), \tag{36}$$

where

$$Q_1 = \pi + \frac{\Omega + \omega}{2}; \; Q_2 = \pi + \frac{\omega}{2}.$$

This expression is similar to (29). The exponent in the first term is much larger in its absolute value than that in the second term, while (u) is far greater than the velocity represented by the second term. We may therefore use the simple formula (29) without introducing significant error in the following numerical example.

h) Numerical example

Let V be the volume of the combustion chamber. According to our adopted notation,

$$C = \Omega - \omega = \Omega - V\rho g = \Omega - V\frac{P}{f}.$$

The following calculation is performed using (36). Let the weight of the missile be $Q_1 = 100$ kg and the weight of the propellant (ballistite) $\Omega = 25$ kg. We set $P = 1{,}000$ kg and obtain $u = 2{,}440$ m/sec from the diagram. We assume $f = 100{,}840$ kgm and a charging density of 1 kg/dm^3. Therefore,

$$V = 25\,dm^3 \text{ and } \omega = V\frac{P}{f} = 2.48\ kg.$$

We obtain from the expression for Q_1:

$$\dot{\pi} = Q_1 - \frac{\Omega + \omega}{2} = 86.26\ kg.$$

The first term in (36) becomes

$$u\left(1 - e^{-\frac{\Omega - \omega}{Q_1}}\right) = 2440\left(1 - e^{-0.2252}\right) = 490\ m/sec.$$

The second term in (36) is

$$(1150 - 490)\left(1 - e^{-0.0275}\right) = 18.5\ m\ sec.$$

This result justifies the neglect of the second term in (36) for tentative computations of rocket missiles.

Figure 151e gives the muzzle velocity of a rocket missile at a pressure $P = 1{,}000$ kg/cm^2 and a charging density of 1 kg/dm^3. This may be admissible when the throat of the nozzle has an adequate cross-sectional area.*

The procedure is similar in other cases.

140 i) Rifling of an open gun firing a rocket missile

Let θ be the slope of the groove whose pitch is constant, Z the sum of the tangential forces whose directions are perpendicular to the axes of the grooves, d the mean diameter across the grooves, M the torque acting on the missile, and φ the coefficient of friction. We then have (Figure 151f):

$$M = Z\frac{d}{2}(\cos\theta - \varphi\sin\theta) = J\frac{d\alpha}{dt} \tag{37}$$

where J is the moment of inertia of the missile with respect to its axis; α is the angular velocity of the missile about its axis.

Furthermore,

$$\alpha = \frac{2}{d}\cdot\frac{dv}{dt}\,tg\theta$$

* It can be shown that at a given charge the ratio of the energy used to propel a rocket missile, to that used to fire a shell of the same weight from an ordinary gun is 0.66. The broken line in Figure 151e represents the experimental muzzle velocity of an ordinary gun. In fact, the efficiency of a rocket missile, as compared with an ordinary gun, is slightly higher than 0.66 if the efficiency of the latter is taken as unity. The corresponding relative efficiency of the Davis gun is approximately 0.5.

We thus obtain from (37):

$$Z = \frac{\varphi . J . dv}{d^2 . dt} \cdot \frac{tg\Theta}{\cos\Theta - \varphi \sin\Theta}, \tag{38}$$

But

$$\frac{dv}{dt} = \frac{rg}{Q_1} = \frac{qu}{Q_1} e^{-c},$$

whence

$$Z = \frac{4 \cdot J}{d^2} \cdot \frac{qu}{Q_1} e^{-c} (\cos\Theta - \varphi \sin\Theta)^{-1} \; tg\Theta.$$

This formula must be used to design the gun. Neglecting the friction of the gases discharged from the missile during its motion in the barrel, an effect difficult to take into account in the analysis, we find that the recoil of a rocket gun is

$$-Z(\sin\Theta + \varphi\cos\Theta).$$

The torque acting on the gun and caused by firing the missile is neutralized by the reaction of the trunnions. This moment acting on the gun is equal and opposite to the torque M given by (37).

The force which we have termed recoil is directed to the front, being caused by the friction between the projections on the missile and the grooves of the barrel. This force is very small, as is seen from the following example. In our case the grooves are of rectangular section, and the steel hoop of the missile has teeth. The recoil can be eliminated completely by providing auxiliary tubes on the missile, which give a recoil of opposite sign; the latter recoil can be computed so as to cancel out the force discussed.

j) Numerical example of the computation of the grooves and of the negative recoil (190 mm bore)

We considered a missile of 190 mm in diameter. Now assume the throat section of the nozzle to have a diameter of 150 mm and an area of $S = 177$ cm^2. This yields a mass flow rate

$$q = 0.0065 \,.\, 177 \,.\, 1000 = 1150 \; kg/sec.$$

The gas-outlet velocity is $u = 2{,}440$ m/sec.

141 The mean weight of the missile is 100 kg, whence $c = 0.2252$.

We take the muzzle velocity of the missile as equal to that of a howitzer, and write

$$arctg\,\Theta = 0.09; \; \cos\Theta = 0.996; \; \sin\Theta = 0.09.$$

The coefficient of friction of steel on steel is 0.15 when the surfaces in contact are well polished.

The moment of inertia of the missile with respect to its axis is $I = 0.063$ kgm[4]. The depth of the grooves is 4 mm, so that $d = 0.194$ m. We thus obtain

$$Z = \frac{4 \cdot 0.063 \cdot 1150 \cdot 2440 \cdot 0.09}{0.194 \cdot 0.194 \cdot 1.252 \cdot 0.983} = 13800 \ kg.$$

The negative recoil is

$$0.15 \cdot 0.996 \cdot 13800 + 0.09 \cdot 13800 = 3260 \ kg.$$

This recoil is still permissible for aircraft weighing 10,000 kg. We have, however, already seen how this recoil can be eliminated.

The torque acting on the gun barrel is

$$M = 13800 \cdot 0.097 \cdot 0.983 = 1330 \ kg \cdot m.$$

This torque can be eliminated by means of the previously mentioned tubes.

We shall now determine the length of the gun barrel so that the second phase ends while the missile is still in the gun.

We find from (30):

$$\frac{100}{1150}(0.2252 \cdot 2440 - 490) = 5.22 \text{ m},$$

The length of the barrel is thus equal to 27.5 calibers, but it should be approximately 30 calibers long in order to provide guidance for the missile at the beginning of the third phase.

k) Notes on shells for ordinary guns

It is known from fluid mechanics that when the gas-outlet velocity is u and the mass flow rate is q, the pressure on an unbounded plane perpendicular to the flow direction is

$$r = \frac{q}{g}(u - v), \tag{40}$$

where v is the velocity at which this plane moves in the direction of u. This makes it possible to apply (13) which is valid for the rocket missile.

Considering the motion of a mass connected to a surface, which has undergone an impact, we may use formulas identical with those given previously. Figure 151g shows an ordinary gun. The theory expounded previously may be applied to this case only if the gas jet remains contracted (its cross section and velocity remaining constant during the whole time it acts on the bottom of the missile), and if the area of the missile bottom is infinitely large or has such a shape that the gas stream is deflected, as shown in Figure 151h.

These conditions are impossible in practice, so that we have to multiply the second term in (40) by a factor which is less than unity.

The efficiency of an ordinary gun is in any case lower than that of a rocket gun.*

* [The footnote in subsection h states the opposite.]

142 l) **Turbo-guns**

Figure 152 (top) shows a projectile in a tube propelled by gases formed outside in another tube.

The gases cannot in this case flow as indicated by the arrows in Figure 151h, and cannot expand radially. A static pressure thus exists in the tube, so that this projectile cannot be considered as a rocket.

We obtain the flow pattern shown in Figure 152 (second diagram from top) if the cross section of the gas jet impinging on the bottom of the projectile is small in relation to the cross section of the tube bore. However, eddies interfering with the regular flow are then present at the boundary between the direct and the reverse stream, so that the theoretical projectile velocity is not attained.

It may be assumed, in the case illustrated in Figure 152 (top), that a static pressure exists inside the tube, which is equal to the dynamic pressure exerted by a gas jet on the base of an isolated projectile.

A gun firing such a projectile thus offers no advantages over an ordinary gun, while its efficiency is less than that of a rocket gun whose efficiency, in its turn, is only 0.66 times that of an ordinary gun.

The recoil of the gun considered is equal to the reaction caused by the discharge of gases from a combustion chamber; this is given by (13) for $v = 0$.

The magnitude of this recoil is of the same order as with an equivalent ordinary gun. In theory the recoil vanishes in the case illustrated in Figure 152 (second diagram from top) when the combustion chamber and the tube are rigidly joined together.

Figure 151e gives an approximate idea of the muzzle velocities obtained with guns firing such projectiles (turbo-guns), as a function of the ratio of the charge weight to the projectile weight. It is found from this diagram that the ratio $\frac{\omega}{\pi}$ must be equal to 0.54 for a turbo-gun in order to obtain a muzzle velocity of 1,000 m/sec. This means that theoretically the charge should amount to 27 kg when the projectile weighs 50 kg. The same muzzle velocity is obtained in an ordinary gun with a 20 kg charge.

Higher pressures than in ordinary guns have to be employed in turbo-guns in order to eliminate the need for large combustion chambers. Inversely, the weight of the chamber has to be increased at low pressures since its volume must be larger than in an ordinary gun.

Lastly, the pressure in the tube must almost equal that in an ordinary gun if the projectile is to move inside the tube (Figure 152, top) so that an efficiency equal to the theoretical one is obtained in practice. In this case the energy losses will be the same as in an ordinary gun.

The turbo-gun therefore offers no advantage over an ordinary gun.

143 m) **Ordinary recoilless guns**

We have already mentioned the Davis gun whose recoil is eliminated by means of a counter-shell having the same momentum as the actual shell. The same result can obviously be obtained with an ordinary gun by utilizing the momentum of some part of the high-pressure gas discharged through orifices in a direction opposite to that of the shell motion.

Let P' be the force acting on the barrel bottom. It will create a reaction P' when the gâs is discharged through the above-mentioned orifices.

Since $P' = AP$, where P is the pressure acting in the barrel [and A the surface area of the barrel bottom], it suffices that the gas inside the barrel escapes through these orifices. The reaction thus obtained is proportional to P, since in practice $u = \text{const}$, its magnitude being

$$AP = \frac{q}{g} \cdot u.$$

Here q is, as we have already seen, proportional to P during the second phase, when the pressure may in practice be assumed to be constant and proportional to $P^{\frac{\gamma-1}{2\gamma}}$ (i. e., proportional to P, since γ differs little from unity, as assumed by all authors) during the third phase.

On the basis of these data it is easy to compute the size of the orifices and the charge necessary for eliminating the recoil, and for obtaining the required muzzle velocity.

We can conclude from the preceding section that the turbo-gun fully corresponds to the case considered here if the effect of the gases on the barrel bottom is excluded. As regards the muzzle velocity, such a gun corresponds to an ordinary one whose barrel has orifices of the required size for the discharge of the gases.

Assuming that when the pressure in the barrel is lowered only a static and not a dynamic force acts on the barrel bottom, we find that the mean pressure necessary for obtaining a predetermined muzzle velocity must be equal to the mean pressure necessary for obtaining the same muzzle velocity in an ordinary gun (when the weight of the shell and the distance traveled by it in the barrel are the same).

Under these conditions the charge must also be larger in a low-recoil gun than in an ordinary one.

The gun barrel must have the same weight as the barrel of an ordinary gun, but its chamber will be heavier, larger, and subjected to a higher pressure than in an ordinary gun.

The gun considered represents an attempt to reduce the recoil. Ballistically, however, it is always possible to design an ordinary gun, which at a smaller charge and the same or even lower pressure will have the same muzzle velocity as a low-recoil gun.

144 **n) Computation of charge for the gun under consideration**

Using the above method, we determined the increase in the charge necessary to eliminate the recoil by testing the 152/45 gun. Its shell weighs 46.5 kg, while the charge weighs 13.9 kg. The muzzle velocity is 830 m/sec at a mean pressure of 1,600 kg/cm^2. We must have the same mean pressure to obtain the same muzzle velocity in a low-recoil gun. The charge in the latter must amount to

$$\Omega' = \Omega + \int_0^t q\,dt.$$

For briefness we may, without introducing an error, compute q by applying the mean-value theorem. We thus postulate that the reaction induced must be equal to that part K of the recoil which we want to eliminate:

$$q_m \frac{u_m}{g} = KP_m A;$$

$$\int_0^t q\,dt = K \frac{P_m A g}{u_m} t.$$

The time t may with sufficient accuracy be determined by assuming that the acceleration of the shell is uniform and equal to

$$\frac{P_m \cdot A \cdot g}{Q}.$$

Let L be the distance traveled by the shell during acceleration. The time taken for this is

$$t = \sqrt{\frac{2L \cdot Q}{P_m A g}}.$$

After the necessary substitutions, we obtain

$$\int_0^t q\,dt = \frac{K}{u_m} \sqrt{2QP_m AgL}.$$

For the 152/45 gun we have $L = 6$ m and $A = 0.01815\ \mathrm{m}^2$. Taking $\gamma = 1.2$ we obtain $u = 2{,}900$ m/sec.

For complete elimination of the recoil ($K = 1$) we must have

$$\int_0^t q\,dt = \frac{1}{2900} \sqrt{2 \cdot 46.5 \cdot 16000000 \cdot 0.01815 \cdot 9.81 \cdot 6} = 13.75\ kg.$$

A muzzle velocity of 830 m/sec is obtained in the ordinary 152/45 gun with a charge of 13.9 kg. The same muzzle velocity is obtained with the gun considered here when the charge weighs 13.9 + 13.75 = 27.65 kg.

The initial velocity of a rocket missile and the muzzle velocity of the turbo-gun will have the same theoretical value of 1,050 m/sec when

$$\frac{\Omega}{\pi} = \frac{27.65}{46.5} = 0.595.$$

145 The recoil can be eliminated in an ordinary gun by connecting the chamber to nozzles pointing to the rear and loaded with explosives which are detonated when the gun is fired.

This method of eliminating the recoil may be useful in some cases. It cannot, however, be employed on light-gun platforms such as motor boats and airplanes.

o) **Closed gun with rocket missile**

Let a rocket missile be inserted into an ordinary gun with closed breech. We assume that the quality of the gunpowder, the shape of the nozzle, and the strength of the missile combustion-chamber walls are such that there is a considerable difference between the pressure in the combustion chamber of the missile and that in the gun barrel. The gas escaping through the nozzle of the missile then gives rise to a reaction force, and its kinetic energy is converted into heat as a result of the impact and eddy formation.

At time t the missile has traveled a distance x in the gun barrel. The gas in the barrel has the same mass as in an ordinary gun of the same power after complete combustion of the charge:

$$\int_0^t q\,dt$$

The work performed by the gas is

$$\int_0^t Ap\,dx,$$

where p is the variable pressure in the gun barrel.

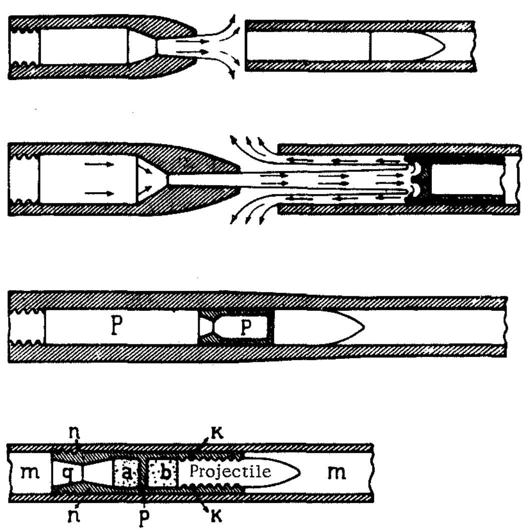


FIGURE 152. Penna's projectile

This would be sufficient for establishing the differential equations necessary for solving this problem. However, analytic integration of these equations is very difficult, since no data are available on the pressure distribution in the gun barrel while the missile travels in it.

We shall therefore consider only an approximative theory based on results obtained in investigations of the free flight of projectiles.

The p-x diagram of our gun will be similar to that of an ordinary gun; only the position of the pressure maximum will be different. As a first approximation we assume that in our case the mean pressure is the same as in an ordinary gun when the weights of projectiles and charges are respectively the same.

The difference between the pressures in the combustion chamber of the missile and in the gun barrel (which should be as large and long as possible, depending on the quality of the gunpowder) has some mean value corresponding to some averaged gas-outlet velocity and mass flow rate through the nozzle. Let F be the average force acting on the missile (Figure 152, second diagram from bottom).

We then have

$$F = Ap + \frac{q_m \cdot u_m}{g} - \frac{q_m}{g}\int_0^t \frac{Fg}{Q}\,dt \tag{41}$$

Integrating this expression according to the method used to derive (22) from (17), we obtain

$$F = \left(Ap_m + \frac{q_m\, u_m}{g} \right) e^{\frac{-q_m t}{Q}} \tag{42}$$

Substituting this value of F in

$$v = \frac{g}{Q}\int_0^{-t} F dt.$$

and integrating, we obtain

$$v = \frac{g}{q_m}\left(Ap_m + \frac{q_m\, u_m}{g} \right)\left(1 - e^{-\frac{\Omega}{Q}}\right) \tag{43}$$

where $q_m \tau = \Omega$ and τ is the time taken by the missile to travel through the barrel.

Assume for the sake of simplicity that the acceleration of the missile is uniform. We then have

$$\tau = \frac{\Omega}{q_m} = v\,\frac{Q}{Fg}.$$

Substituting for F from (42), we obtain an equation of the first degree in q_m, which yields

$$q_m = \frac{\Omega g A p m^{-\frac{\Omega}{Q}}}{-\Omega u_m e^{-\frac{\Omega}{Q}} + vQ} \tag{44}$$

p) **Numerical examples**

Equations (43) and (44) are obviously only tentative since they were derived on the basis of approximations; they do indicate, however, the maximum possible initial velocity of the missile. These formulas enable us to approximately determine the dimensions of the nozzle for different weights of the rocket missile and charge.

The results have been verified experimentally.

We consider again the 152/45 gun with reduced recoil. The data* referring to it are as follows:

$$\Omega = 13.9;\ A = 0.01815;\ P_m = 16000000;\ Q = 46.5 + \frac{13.9}{2} = 53.45.$$

$$\frac{13.9}{53.45} = 0.26;\ e^{-0.26} = 0.772;\ 1 - e^{-0.26} = 0.228;\ \gamma = 1.2.$$

We assume that the quality of the gunpowder and the strength of the missile combustion chamber are such that the permissible difference between the pressures in the missile combustion chamber and in the gun barrel is 1,000 kg/cm², whence $P_m = 2{,}600$ kg/cm².

From (44) we obtain $q = 900$ kg/sec. According to (1):

$$P_m = \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}} p_m.$$

whence

$$u_m = \sqrt{\frac{2.4}{0.2} \cdot \frac{26000000}{26.3}\left[1 - \left(\frac{16}{26}\right)^{\frac{0.2}{1.2}}\right]} = 975\ m/sec.$$

$$\text{where } \rho_m = \frac{P_m}{gRT} = \frac{26000000}{9.81 \cdot 100800} = 26.3$$

From (43) we obtain

$$v = \frac{9.18}{900}\left(290000 + \frac{900 \cdot 975}{9.81}\right) 0.228 = 944\ m/sec.$$

The missile velocity is thus 14% higher, and its energy 30% greater, than when the same charge is fired in an ordinary gun.

This advantage becomes even greater when the pressure difference is increased beyond 1,000 kg/cm².

The theory expounded enables us to determine the dimensions of the nozzle in the missile.

q) Remarks on the discharge exponents and coefficients

In the above calculations we did not employ the contraction coefficient for the discharge of a gas, nor Zeuner's discharge coefficient. We have therefore neglected the third phase which has a considerable influence on the muzzle velocity. Zeuner's coefficient could not be used due to the lack of experimental data on its value even at small pressure differences. The data which interest us can be obtained only experimentally.

* [All magnitudes are given in the mks system.]

In any case, the results obtained appear to be sufficient for estimating the magnitudes considered, the more so since the results were verified experimentally.

148 r) Determination of the maximum pressure in the combustion chamber of a rocket missile

It may happen that a rocket missile is charged in such a way that the rate at which the charge is completely converted into gas is equal to the mass flow rate through the nozzle. It is also possible that the charging density is numerically equal to the specific weight of the explosive, i.e., that the combustion chamber is completely filled with the explosive so that there is no free space accessible to the gas; the latter must then leave through the nozzle as soon as it is formed. This hypothetical case can occur only at the beginning of the combustion, when the charging density is 1.6 for ballistite; the maximum pressure may then be predicted in the following way.

The rate E at which gas is formed from the gunpowder grain is proportional to its instantaneous surface area σ, the density δ of the explosive, the linear burning velocity ω, and the instantaneous pressure to the nth degree:

$$E = \sigma \cdot \delta \cdot w \cdot P^n.$$

Let y be the ratio of the instantaneous thickness of the grain to half the minimum dimension of the grain, while a, h, and μ are characteristics of the grain shape, v_0 is the initial volume of the grain, and l_1 is half its minimum dimension. We then have

$$\sigma = \frac{v_0}{l_1} a (1 - 2hy + 3\mu y^2) \tag{46}$$

We may introduce this expression into our formula. Let the charge of weight Ω contain N grains; thus

$$N = \frac{\Omega}{v_0 \delta}. \tag{47}$$

The overall rate at which the gas is formed is thus

$$E_t = \frac{\Omega}{l_1} a w P^n (1 - 2hy + 3\mu y^2) \tag{48}$$

The mass flow rate through the nozzle is

$$q = KS_m P \tag{8}$$

Equating E_t to q, we obtain a formula determining the pressure for the hypothetical case where the chamber volume contracts during combustion so that the charging density remains constant:

$$P = \left[\frac{\Omega a w (1 - 2hy + 3\mu y^2)}{l_1 K S_m}\right]^{\frac{1}{1-n}}$$

It is sufficient for us to know the maximum pressure in the combustion chamber in order to determine the power of the missile. We have $\mu = 0$ for a grain having the common shape of a string or rod of rectangular section.

This is usually the case. The pressure will then be maximum at the beginning of the process when $y = 0$, all other conditions being the same. This maximum pressure is

$$P_{max} = \left(\frac{\Omega a w}{l_1 K S_m}\right)^{\frac{1}{1-n}} * \qquad (50)$$

when the charging density is 1.6.

149 If the charging density is less than 1.6, the maximum pressure will be less than the value given by (50). This necessitates the introduction of a correction factor which allows for the different charging density. This is confirmed by experiments. The relative charging density is here understood to be the ratio of the weight of the charge contained in the combustion chamber to the weight of the charge which would completely fill the combustion chamber. We assume for the sake of simplicity that the charging density is a linear function. Comparison of experimental results with those obtained by using the following formula yields a value which differs from that given in works on internal ballistics of ordinary guns.

The formula of the author of this paper is

$$P_{max} = \left(\frac{\Omega a \Delta w}{l_1 K S_m}\right)^{\frac{1}{1-n}} * \qquad (51)$$

The symbols used in this formula have the following meanings:

Ω — weight of charge, kg;
Δ — relative charging density;
w — linear burning velocity, which is approximately 0.002 m/sec at $P = 1$;
l_1 — half the minimum thickness of the original grain, m;
K — 0.0065 on the average;
S_m — cross-sectional area of nozzle throat, cm^2;
a — has the following values for different grain shapes:

strings or square rods . . . . $a = 2$
twin strips . . . . $a = 1.5$
triple strips . . . . $a = 1.33$
quadruple strips . . . . $a = 1.2$
tenfold strips . . . . $a = 1.1$
lamellas . . . . $a = 1$

n = 0.56.

* It follows from this formula that the value of the exponent $n = 1$, used by most authors in order to simplify the formula for the rate of gas formation, is not correct. In fact, from $n = 1$ follows $P \quad \infty$, which is impossible. It is seen from this formula that $P \quad \infty$ when $S_m \quad 0$, which is also impossible (explosion in a closed space).
In this case we must replace (8) in the computations by an expression depending on the characteristic equation of the gases formed by the combustion, in which the volume of the propellant enters.

Inserting these values into (51), we obtain

$$P_{max} = 0.067 \left(\frac{\Delta \Omega a}{l_1 S_m}\right)^{2.28} \qquad (52)$$

In the particular case

$$\Delta = 0.6,\ \Omega = 0.1\ kg,\ a = 2,\ l_1 = 0.0005\ m,\ S = 2.5\ cm^2,$$

this yields

$$P = 2140\ kg/cm^2.$$

s) Ordinary shells fired without recoil by a light gun with the usual muzzle velocity

The preceding also indicates that it is possible to obtain muzzle velocities of 300—400 m/sec without large charges. However, the following suggestion may be of great value in the arming of airships.

150 Is it possible in practice to fire ordinary shells without a large recoil from light guns with muzzle velocities of 700—800 m/sec?

Ordinary shells have the following advantages over elongated projectiles with their own combustion chambers:

1. More accurate bore.
2. More accurate trajectory.
3. Larger effect on impact since in the rocket missile the combustion chamber, which moves together with the missile, absorbs part of the kinetic energy unproductively.

The purpose indicated may be attained by designing a recoilless gun in the following way (Figure 152, bottom). This gun has a barrel which is open at both ends ($m-m$).

Tube ($n-n$) with partition (P) in its center can move inside the barrel. Charge (a) and nozzle (q) are arranged in the rear of the tube behind the partition. The tube has guiding grooves on the outside, so that it rotates while traveling in the barrel. Charge (b) is arranged in front of the partition behind the projectile which also has grooves causing it to rotate when it is ejected from the tube by the explosion of charge (b). Firing is carried out as follows:

Charge (a) is detonated first, so that inside the barrel the inner tube moves to the right like a rocket missile. The second charge (b) is detonated when the tube reaches the end of the outer barrel. The projectile is then ejected from the tube, which is returned by the recoil to its initial position as smoothly as possible.

Application of this principle to ordinary guns will make it possible to fire projectiles over hundreds of km. However, priority should be given to maximizing the muzzle velocity in order to obtain a flat trajectory and to increase the effect of the force.

t) Remarks on the external ballistics of projectiles fired from airships

Firing a projectile at a high altitude (from an airship) presents a more difficult problem than firing it from the ground. This is due to mobility of the airship along the three coordinate axes and its oscillations about the latter, without mentioning drift of the airship, caused by the wind. Computation of the trajectory of a shell is difficult even when it is fired from an ordinary gun on the ground; the relevant differential equations have no exact solution.

Even A. Siacci had to leave some of these problems unsolved.

In our case, however, it might be possible to solve these equations using the method of Prof. E. Pascal who built an integraph and suggested a procedure for plotting the trajectory. Such an instrument, supplementing the firing table, might make it possible to solve this problem.

u) Conclusion

On the basis of what has previously been stated, it may be concluded that it will be possible in the very near future to set up guns on airships, capable of firing projectiles weighing up to 1,000 kg, from great heights, at muzzle velocities of 400 m/sec or more. It will be impossible to provide a defense against these projectiles with the ordinary means available on land or water.

151 v) Engineer G. A. Crocco's observations on Penna's work

Engineer G. A. Crocco published a paper in "Rivista Aeronautica," No. 3, 1926 in which he referred to a difference in the conclusions reached by Penna and by himself. In Crocco's view, however, this difference is in Penna's favor.

The contents of Crocco's paper follows.

Consider Penna's rocket missile, using the following notation:

r — reaction;
q — mass flow rate of propellant, kg/sec;
g — gravitational acceleration;
u — gas-outlet velocity;
v — missile velocity;

$m = \frac{q}{g}$;

M — mass of missile with propellant at time t;
M — the same, at time $t + dt$;
$-dM = mdt$ — mass discharged during time interval dt.

Evidently, $M' = M + mdt$.

To determine the reaction we write down the momentum of the system at time t and $t+dt$:

1. At time t: $Mv = (M+mdt)\,v$
2. At time $t+dt$: $M\,(v+dv)+mdt\,(v+u)$

These two quantities must be equal, whence

$$Mv+mvdt = Mv+Mdv+mvdt+mudt$$

or

$$Mdv+mudt=0 \tag{1}$$

where the sign of u is opposite to that of v.

Equation (1) shows that there exists a reaction r due to which there is a considerable increment dv in the velocity of the mass M. This reaction is

$$r=-mu \tag{2}$$

This quantity differs from that obtained by Penna in his equation (13), since it does not depend on v.

This result, identical with Ryabushinskii's conclusions, is not unexpected. The mass mdt moves in space with the absolute velocity $u+v$ but, since it already had the velocity v along the missile trajectory, it has acquired a velocity u relative to the missile, on which alone the reaction depends.

In fact, the reaction r depends on the resultant of the pressure in the combustion chamber, which is not equilibrated due to the presence of the nozzle through which the gas can escape.

This causes a force propelling the missile. This force is obviously independent of the missile velocity v, which may therefore be ignored.

152 An altogether different case is presented by a machine which hits the mass of the surrounding medium. If this mass is fixed in space and the machine has a velocity v, the reaction is in this case reduced by mv.

On the other hand, in the case of a rocket missile, where the discharged mass is contained in the missile and already has a velocity v at time t, this reduction does not occur.

If u = const, r = const. The velocity of the missile is then simply determined from the equation

$$Mdv=-mudt=udM$$

whence

$$v=-u\log\frac{M_0}{M}.$$

This expression takes the place of equation (24) obtained by Penna. It yields a larger initial velocity and thus supports Penna's conclusion, since it leads to more favorable results in his numerical examples.

We note in conclusion that the formulas given by us yield an apparently paradoxical result, namely that the missile velocity v may be equal to or even exceed the gas-outlet velocity. If we select the mass ratio in such a way that $\log \frac{M_0}{M} = 1$, i.e., if $M_0 = 2.718\, M$, we obtain $v = -u$. The propellant then accounts for 63.1% of the total weight of the missile. In theory we can obtain any velocity v if u is given. However, the mass M_0 will then increase considerably and the final mass of the missile will be very small in comparison with its initial mass.

153 *Chapter VII*

THE ROCKET MISSILE OF ANTONIO DE STEFANO

General Antonio De Stefano published a paper in "Rivista di Artiglieria e Genio" of September and October 1926 (p. 1611) under the title "Il proietto a reazione."

The following is a translation of this paper. *

Present-day rockets have a low accuracy. Although gunnery experts have proposed various methods of increasing their accuracy, attempts in this direction have been unsuccessful.

Rotation of a projectile increases its accuracy, but this was not achieved earlier in the case of rockets.**

At present there also exist means to launch rotating rockets having a suitable shape; these are called rocket missiles.

A missile is fired from a rifled gun with open breech. The missile is propelled in- and outside the gun by a charge located in the missile itself. This idea is not new. It was applied, e. g., by Companelli and Leggiardo. The latter employed the rocket principle in experiments with a 75 mm gun. The recoil was reduced by drilling holes in the breech block in order to let the gas escape, but the result was an extremely low muzzle velocity. Increasing the charge also increased the recoil, while increasing the number of holes in the breech block reduced the muzzle velocity. In this way one arrives at a point where an increase in the charge endangers anybody standing behind the gun.

In this paper on rocket missiles I shall discuss the results to be expected in practice, the required weight of the entire missile and of the propellant, the optimum rifling, the velocities obtainable, etc.

I shall consider only the case already discussed by Penna and Crocco, when combustion in a rocket missile takes place entirely or almost entirely in the gun barrel, so that we need not allow for the effects of drag and gravity on the velocity imparted to the missile by the reaction caused by discharge of the gases.

Missile velocity. Consider a rocket missile consisting of an ordinary shell and a tube with a nozzle, containing the propellant tightly packed in the rear of the shell.

Let gM be the weight of the entire missile, i. e., together with the propellant, and let gm be the weight of the gas ejected per sec. We count

* It was translated by E.V.Agokas and appeared in "Voina i Tekhnika," No.4, 1927. We also translated this paper. However, since Agokas was the first to publish a translation, we present the latter with some small corrections, alterations, and remarks.

** The author [apparently De Stefano] evidently refers only to artillery rockets, since ordinary rotating rockets had already been designed (e.g., according to Goddard's patent).

the time from the instant at which the propellant is ignited, denoting by v the missile speed at time t and by u* (considered positive in the direction in which the gases escape) the gas-outlet velocity relative to the missile.

The momentum of the missile minus the mass mdt of the propellant transformed into gas during the time interval dt is $(M-mt-mdt)\,v$ at time t and $(M-mt-mdt)\,(v+dv)$ at time $t+dt$. A quantity mdt of propellant is transformed into gas during the time interval dt; the velocity of this mass is v at time t and $v-u$ at time $t+dt$

If no external forces act on the missile or on the gas, i. e., if we neglect drag, gravity, and secondary effects, we obtain $(M-mt-mdt)\,(v+dv) - (M-mt-mdt)\,v$ for the missile and $m\,(v-u)\,dt - mv\,dt$ for the propellant [as the changes in momentum during the time interval dt].

Thus,

$$(M-mt-Mdt)(d+dv)-(M-mt-mdt)\,v+m\,(v-u)\,dt-mv\,dt=0.$$

Hence, canceling out and neglecting infinitesimal quantities of higher order, we obtain

$$(M-mt)\,dv=mudt.$$

Integration between the limits O and t yields

$$v=-u\log_e\frac{M-mt}{M} \qquad (1)$$

We denote by Θ the angle which the tangent to the missile trajectory makes with the horizontal at time t if drag and gravity have to be taken into account. We then obtain two equations for the projections of the forces on the two coordinate axes:

$$(M-mt)\,d\,(v\cos\Theta)-mu\cos\Theta dt=-(M-mt)\,f(v)\cos\Theta\,dt \qquad (2)$$

$$(M-mt)\,d\,(v\sin.\Theta)-mu\sin\Theta\,dt=-(M-mt)\,f(v)\sin.\Theta\,dt-g\,(M-mt)\,dt \qquad (3)$$

Multiplying (2) by v sin Θ and (3) by v cos Θ, and subtracting one equation from the other, we obtain

$$gdt=-\frac{vd\Theta}{\cos\Theta} \qquad (4)$$

Inserting this into (2), we obtain the equation of the hodograph:

$$gd\,(v\cos\Theta)+\frac{mu\,vd\,\Theta}{M-mt}=vf\,(u)\,d\Theta, \qquad (5)$$

which differs from the equation of the ballistics of an ordinary shell in that the term

$$\frac{muvd\,\Theta}{M-mt}.$$

has been added.

* In his paper, A. De Stefano denotes this velocity sometimes by U and sometimes by u, but we, like Agokas, shall use the symbol u constantly.

155 This term vanishes when $u = O$, in which case (5) reduces to the ballistics equation of an ordinary shell.

We insert the expression found for dt into the equations

$$dx = v \cos.\Theta dt \qquad dy = v \sin \Theta dt.$$

and obtain

$$gdx = -v^2 d\Theta \qquad gdy = -v^2 \, tg\, \Theta d\Theta. \tag{6}$$

Equations (6) and (4) are identical with the ballistics equations of an ordinary shell, but the values of x, y and t are different at the same parameters determining the missile trajectory, so that the velocity v given by (5) will also differ.

After considering this problem in its most general formulation, we shall now discuss a particular case.

We introduce the following notation:

A — cross-sectional area of nozzle in which the gas-outlet velocity is u;
u — gas-outlet velocity;
δ — density of gases at instant at which they pass through the nozzle [section of area A];
δ_0 — density of propellant;
δ_1 — density of gases in combustion chamber;
q — fraction of propellant burnt at time t;
ω — weight of propellant;
W — volume of combustion chamber of rocket missile;
α — covolume of propellant;
f — power of propellant;
P — pressure at time t;
γ — adiabatic exponent;
w — burning velocity of propellant grain at unit pressure;
$2l_1$ — grain thickness;
ψ — fraction of grain thickness, burnt at time t;
T — combustion temperature;
R — gas constant.

Pressure in combustion chamber. The weight of the gas discharged through the nozzle from the beginning of burning to time t is

$$Ag\int_0^t \delta u \, dt,$$

In Nobel's equation this has to be deducted from the weight ωq of the propellant burnt, since it no longer affects the pressure [in the combustion chamber]. We thus obtain

$$P = f\frac{\omega q - Ag\int_0^t \delta u \, dt}{W - \alpha\left(\omega q - Ag\int_0^t \delta u \, dt\right) - \frac{\omega}{\delta_0}(1-q)} \tag{7}$$

When the final pressure is atmospheric, the gas-outlet velocity is given by

$$u^2 = \frac{2P \cdot v_0 \gamma}{m(\gamma - 1)} \left(1 - \frac{1}{P^{\frac{\gamma - 1}{\gamma}}}\right)$$

156 where v_0 is the specific volume (after deduction of the covolume) of the gas, and $m = \frac{1}{g}$ is the mass of this gas in the combustion chamber.

Neglecting the covolume, we have

$$m = \delta_1 \, v_0 \qquad \frac{P}{\delta_1} = gR\,T_0$$

In writing the last formula we assume that the gas has temperature T_0. in the combustion chamber, thus neglecting a slight expansion during which a small amount of work is performed. On the other hand, assuming the gas to expand adiabatically during its discharge, we obtain

$$\delta = \delta_1 \frac{1}{P^{\frac{1}{\gamma}}} = \frac{P^{\frac{\gamma - 1}{\gamma}}}{gRT_0}$$

The gas-outlet velocity is

$$u = \sqrt{\frac{2P\gamma}{\delta_1(\gamma - 1)} \left(1 - \frac{1}{P^{\frac{\gamma - 1}{\gamma}}}\right)} = \sqrt{2gR\,T_0 \frac{\gamma}{\gamma - 1}\left(1 - \frac{1}{P^{\frac{\gamma - 1}{\gamma}}}\right)} \tag{8}$$

whence

$$u\delta = \sqrt{\frac{2\gamma}{gRT_0(\gamma - 1)} \left(P^{\frac{\gamma - 1}{\gamma}} - 1\right) P^{\frac{\gamma - 1}{\gamma}}}$$

The fraction of the propellant burnt is

$$q = ay\,(1 - \lambda y + \mu y^2) \tag{9}$$

We assume that the burning velocity is proportional to the first power* of the pressure (the unique value of this exponent has not been determined experimentally). We thus obtain

$$y = \frac{W}{t_1}\int_0^t P\,dt \tag{10}$$

Inserting this value into (9) and the values of δu and q into (7), we obtain a differential equation from which we can determine P as function of t.

Granularity of propellant. Care must be taken that P is never greater than a given value P_m, so that the permissible stresses in the combustion-chamber walls are not exceeded. The missile velocity can be maximized by maintaining P close to this highest permissible value P_m during burning

* Agokas translated this as "initial power."

of the propellant. It follows from (1) that the missile velocity varies directly with u, while (8) shows that u increases with P.

It is necessary that P increase as rapidly as possible to P_m and that this value be maintained up to burnout. The gas remaining in the combustion chamber then escapes when the pressure drops rapidly.

The value of P can be computed from (7, 8, 9, 10) for any instant. However, this value slightly affects the missile velocity at the beginning
157 and end of burning. The condition that the weight of gas discharged at P = const be equal to the weight of gas formed, yields

$$\omega = \frac{dq}{dt} = A g \delta u. \tag{11}$$

or

$$\frac{a \omega W}{l_1} P\left(1 - 2 \frac{\lambda w}{l_1} \int_0^t P dt + 3 \frac{\mu w^2}{l_1^2} \left[\int_{t_0}^t P dt\right]^2\right) = A g \delta u.$$

Here t_0 is the instant at which this condition is first satisfied. For this to be independent of time it is necessary that $\mu = \lambda = 0$. This is the case with lamellas and long tubes with holes. For such tubes we also have $a = 1$.

Nozzle section. From the last equation we obtain

$$A = \frac{\omega W P_m}{g l_1 \delta u} \tag{12}$$

if $P = P_m$ = const. The value of l_1 is determined from (17) which follows.

However, in reality P is not constant, and there is no explicit relationship between the gas-outlet volocity u and the mass flow rate of the gas. This is seen from (7) which indicates that the free space in the combustion chamber increases as the propellant is burnt. This causes a slight reduction in the missile velocity.

Applying the above formulas in practice, we conclude that the propellant must continue to burn outside the gun, since otherwise A would have to be far larger than is possible.

Weight of rocket missile. Mass flow rate. Duration of burning.

Let s be the distance traveled by the missile, setting $s = 0$ at $\tau = 0$. We then obtain from (1):

$$\frac{ds}{dt} = - u \log_e \frac{M - mt}{M}.$$

Integration yields

$$s = \frac{uM}{m} \int \log_e \frac{M - mt}{M}\, d\frac{M - mt}{M} = \frac{u}{m}(M - mt)\left(\log_e \frac{M - mt}{M} - 1\right) + \frac{uM}{m} =$$
$$= \frac{uM}{m}\left\{\frac{M - mt}{M}\left(\log_e \frac{M - mt}{M} - 1\right) + 1\right\}. \tag{13}$$

In general the initial velocity will be v and the total distance traveled, L.
We obtain from (1):

$$mt_1 = M\left(1 - e^{-\frac{v}{u}}\right). \tag{14}$$

Here t_1 is the time required for the missile to attain the velocity
158 From (13) we have

$$m = \frac{uM}{L}\left\{1 - \left(\frac{v}{u} + 1\right) e^{-\frac{v}{u}}\right\} \tag{15}$$

whence

$$t_1 = \frac{L}{u} \quad \frac{1 - e^{\frac{-v}{u}}}{1 - \left(\frac{v}{u} + 1\right) e^{\frac{-v}{u}}}. \tag{16}$$

We note that $gmt_1 = \omega$. Hence, (14) determines what part of the missile weight is accounted for by the propellant.

Grain thickness. The thickness of a lamella or tube of gunpowder is

$$l_1 = wP_m t_1 \tag{17}$$

Combustion-chamber volume. The value of W is arbitrary, as is seen from the following consideration: Whatever the value of W, the weight of the gas formed during combustion will be equal to the weight of the gas discharged (cf. (11)) when P attains the value P_m (cf. (12)). The pressure therefore cannot exceed this value.

The value of W affects the time (determined from (7)) needed for the gas to attain the pressure P_m.

Total weight of missile. Let P_m be the pressure in the combustion chamber, D the diameter of the missile, which is equal to the outer diameter of the tube forming the combustion chamber, D_1 the internal diameter of the combustion chamber. We then have

$$\frac{D}{D_1} = \sqrt{\frac{m\theta + (m-1) P_m}{m\theta - (m+1) P_m}}. \tag{18}$$

[where θ is the elastic limit of the material, and m is here Poisson's ratio].

Taking $m = 3$, we obtain a wall thickness which exceeds the value ratio].

Let l be the length of the tube containing the propellant, taking the specific weight of steel as 7.8. The tube will then weigh

$$7.8 \, \frac{\pi}{u} \, (D^2 - D_1^2) \, l.$$

[if all dimensions are in cm].

Let p be the weight of a shell fired from a modern gun, gM the total weight of the missile, and $gM\left(1 - e^{\frac{-v}{u}}\right)$ the weight of the entire propellant charge. We then have

$$7.8\,\frac{\pi}{4}\,(D^2-D_1^2)\,l+p+gM\left(1-e^{\frac{-v}{u}}\right)=gM.$$

The space inside the tube is $\frac{\pi}{4}\,D_1^2\,l$. We assume that only part of it (e.g., 4/5) is taken up by the propellant whose specific weight is 1.6. We then obtain

$$1.6\,\frac{\pi}{5}\,D_1^2\,l=gM\left(1-e^{\frac{-v}{u}}\right),$$

whence

$$l=\frac{5gM\left(1-e^{\frac{-v}{u}}\right)}{1.6\,\pi D_1^2}$$

159 Inserting this value of l into the preceding equation, we obtain

$$\frac{7.8}{1.6}\cdot\frac{5}{4}\cdot gM\left(\frac{D^2}{D_1^2}-1\right)\left(1-e^{\frac{-v}{u}}\right)+p+gM\left(1-e^{\frac{-v}{u}}\right)=gM,$$

whence

$$gM=\frac{p}{e^{\frac{-v}{u}}-6.1\left(1-e^{\frac{-v}{u}}\right)\left(\frac{D^2}{D_1^2}-1\right)}=\frac{p}{\left(6.1\frac{D^2}{D_1^2}-5.1\right)\left(1-e^{\frac{-v}{u}}\right)+1} \qquad (19)$$

The value of $\frac{D}{D_1}$ is obtained from (18) and that of (u) from (8). Hence, (19) determines the total weight gM of the missile.

The derivative (with respect to P) of the denominator in (19) is

$$-6.1\left(1-e^{\frac{-v}{u}}\right)\frac{d\frac{D^2}{D_1^2}}{dP}+\frac{ve^{\frac{-v}{u}}}{2u^3}\left(6.1\,\frac{D^2}{D_1^2}-5.1\right)\frac{du^2}{dP}$$

Since $1-e^{\frac{-v}{u}}$ and $6.1\,\frac{D^2}{D_1^2}-5.1$ are both positive, $\frac{d\frac{D^2}{D_1^2}}{dP}$ is also positive by (18), while according to (8) $\frac{du^2}{dP}$ is negative*, it follows that the entire derivative is negative. The denominator thus decreases, and gM increases when P is increased.

Hence, P should be minimized in order to reduce the weight of the missile.

A reduction of P entails a decrease in u.** This is very important, since it follows from (8) that u is large even at very low pressures (cf., e.g., Penna's work and his diagrams).

Application. We shall apply the theory expounded to some examples. Let us determine the weight of the propellant of a rocket missile with an initial velocity of 500 m/sec, an outer diameter of 75 mm, and weight of 6.5 kg.

* [This conclusion is wrong since $\frac{du^2}{dP} > 0$.]

** [This again contradicts the above conclusion.]

Let the maximum pressure in the tube filled with the propellant be $P_m = 100$ atm, the yield point of the steel of the tube, $\Theta = 40$ [kg/mm^2], $L = 1.5$ m, $u = 2{,}200$ m/sec. We then obtain from (19):

$$gM = 8{,}85 \qquad \omega = gmt_1 = 1{,}787.$$

Thus the propellant charge must weigh 4 times as much as in an ordinary gun for the same effect to be obtained.

However, if we compute the cross-sectional area A for this case, we find that all the gas formed during combustion of the entire propellant cannot escape in the short time in which the missile travels in the gun barrel.

We have

$$A = \frac{\omega WP}{gl_1\delta u}$$

since by (17) $l_1 = \omega Pt_1$ and $\omega = gmt$, we obtain

$$A = \frac{m}{\delta u} \tag{20}$$

160 If P is referred to m^2 we obtain

$$\delta = \delta_1 \frac{10000^{\frac{1}{\gamma}}}{P^{\frac{1}{\gamma}}}, \quad \delta_1 = \frac{P}{gRT_0},$$

as before. Setting $R = 30$, $T = 3{,}200$, $P_m = 1{,}000{,}000$, $\gamma = 1.4$, we obtain $\delta = 0.037$.

From (15) we find $m = 26.6$, whence $A = 0.325$ m^2. This means that the nozzle in the tube containing the propellant must be much larger than the maximum possible value of $\frac{\pi}{4} D_1^2$.

Evidently, L has to be increased, i.e., the propellant must continue to burn after the missile has left the gun. We determine the value of L from (20), setting $A = \frac{\pi}{4} D_1^2$.

[Using (15)], we obtain

$$L = \frac{M}{A\delta}\left[1 - \left(\frac{v}{u} + 1\right)e^{-\frac{v}{u}}\right] = 113.5\ m$$

The propellant must continue to burn until the missile has covered a distance of more than 100 m.

We obtain $m = 0.356$ at this value of L.

It is thus incorrect to assume a value of γ less than 1.4, or increase P_m when A is excessively large, since δ and u change little in this case, while M varies in the same sense as δ. The value of gM soon becomes negative and tends to infinity when P_m is increased.

In our case the weight of the missile becomes infinitely large at $P_m = 750$ atm. Beyond a certain limiting pressure P, the wall thickness becomes so large that it is no longer possible to place the propellant charge, whose weight is $\omega = gM\left(1 - e^{-\frac{v}{u}}\right)$, inside the tube, and the missile weight must again be increased since the tube has to be lengthened. Hence, when the propellant must continue to burn during free flight, we have to know whether that part of the propellant which burns inside the gun can impart to the missile the necessary rotational velocity.

We can obtain $\frac{M-mt}{M}$ from (13) and v from (1). Computation yields a very small velocity.

Conditions are not more favorable if we want to impart a velocity of 1,500 m/sec to the same missile. The latter must weigh 19 kg and the propellant charge, 7.84 kg; however, A then assumes an impossible value. On the basis of the preceding we find that the propellant must continue to burn for a distance of almost 1.5 km after the missile has left the gun, while the missile velocity inside the barrel will be very small.

Consider a 381 mm gun firing a shell weighing 885 kg at a muzzle velocity of 700 m/sec. A rocket missile similar to the 75 mm one will weigh 1,380 kg, with a propellant charge of 375 kg. Its muzzle velocity will be very small, and the propellant will continue to burn over a distance of 1.5 km during the missile flight.

161 **Conclusions.** The above results lead to the conclusion that it is impossible, at least in the cases considered, to fire a missile in such a way that the propellant has burnt completely when the missile leaves the gun barrel. It is also impossible to impart to the missile the required rotation, due to the low speed at which it leaves the muzzle.

The rotation can be imparted to a missile launched from the ground or at sea by the ejection of a propellant charge which normally will not weigh much.

Other means have to be employed if the missile is to be launched from an airplane.

In conclusion we note that if it is found during trials that the accuracy is not excessively low, such a missile may often be of considerable use despite its comparatively large weight, length, and propellant consumption.

THE ROCKET IN INTERPLANETARY SPACE

Of all the various methods of travel in interplanetary space proposed by the many inventors, rocket propulsion has attracted the greatest attention, i. e., flight by means of the reaction created by the discharge of gases from the machine. This method has been investigated from the theoretical aspect and has been shown to be quite feasible. Although a number of projects for the creation of suitable machines had been proposed, by the time of this writing not a single space flight had been carried out, even though there is reason to assume that such spaceships were being built in some countries.

The following is a presentation of the ideas of various scientists on the design and construction of interplanetary spaceships. However, the latest works of Oberth, Hohmann, Esnault-Pelterie, Goddard, and Tsiolkovskii are, in view of their importance, given separately in two further books.

The first to prove that rocket engines could be used for interplanetary flight was Isaac Newton who, in the introduction to his third law, stated that it would be possible to fly in space using reaction engines.

In Vienna in 1891 Dr.Franz von Hoefft applied the rocket principle to a flying machine. Air was aspirated at the nose and ejected at the stern. In 1895 he employed the same principle in the plan of an interplanetary spaceship. He also invented a solenoid gun for launching such a spaceship.

Prof. Nernst, Wiecherts, and Scharpeller later showed that it is possible to use the radiant energy in space for the propulsion of an interplanetary spaceship. Sargent of the USA took up the problem of interplanetary communication in France.

a) **Ganswindt's rocket spaceship**

The "Berliner Lokal-Anzeiger" of 27 May 1893 (No. 245) referred to a report given the previous day by the inventor Hermann Ganswindt in the "Philharmonie" [a concert hall in Berlin] on his project of a spaceship for interplanetary travel, e. g., to Mars or Venus, and also for flight over the earth's poles. According to the newspaper the spaceship was to be designed as follows: "Its main part consists of a steel cylinder to which are secured steel pipes containing compressed air for breathing. The passengers are located in a heated compartment of the cylinder. A rocket engine is suggested for propulsion. Space flight should be faster than the motion of the stars." The newspaper gave no further details.

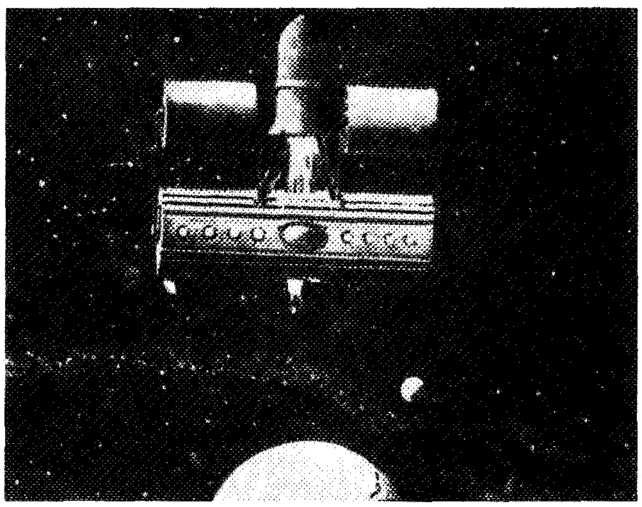


FIGURE 153. Ganswindt's spaceship

In 1899 Ganswindt presented a drawing of this spaceship (Figure 153) in his book "Das jüngste Gericht: Erfindungen von Hermann Ganswindt" (second enlarged edition published in Schöneberg near Berlin). He also gave the following additional information on this spaceship:

"The steel cylinder (gondola) should have the minimum possible diameter for carrying just 2 passengers and the necessary supplies. On top of the first cylinder and parallel to it is placed a second cylinder containing pipes filled with compressed air to be supplied as required to the passenger compartment in the gondola. Heating is provided by utilizing the heat contained in the discharged gas. The detonations are effected by means of dynamite cartridges located in the upper steel cylinder."

Assuming a gas-outlet velocity of 1,000 m/sec, Ganswindt thought that the cylinder containing the propellant would, due to its large mass, acquire a velocity of only 50 m/sec, while the gondola, suspended elastically from the cylinder, would attain a speed of approximately 20 m/sec. The upper steel (164) cylinder was to act like a flywheel, storing energy during successive detonations of the dynamite cartridges, entraining the spaceship with increasing velocity until the latter was sufficient for overcoming the attraction of the earth. Then like a celestial body, the spaceship would continue to fly without further detonations. The flight direction was to be changed by turning the upper cylinder, and the gas was to be ejected in the opposite direction [i.e., to the front] during landing.

FIGURE 154. H. Ganswindt

H. Ganswindt (Figure 154) was born on 12 June 1856. Being a typical innovator, he invented various parts for bicycles which he built himself. He also submitted designs of airplanes, helicopters, and airships (1883).

164 The same Berlin newspaper printed the following: "The legendary Icarus did not die; he reappears under different names in various centuries. He has now returned under the name of Hermann Ganswindt who, like his ancestor, attempted to fly. . . . "

Ganswindt's project was attacked by Prof. Roman Baron Gostkowski of Vienna in the Viennese newspaper "Die Zeit," No. 304, Vol. XXIV (pp. 53–55). Under the title "Ein moderner Ikarus," he subjected Ganswindt's project to sharp criticism and proved its impossibility. Gostkowski, however, made some arithmetical mistakes, and when they are corrected, the results are even more unfavorable. Gostkowski also mentioned that Ganswindt had submitted his plans to the Russian and German emperors, stating that his spaceship would be able to reach Mars or Venus within 22 hours. Except to point out the errors we shall not consider Gostkowski's computations in detail.

In the same review which we will presently summarize, Loos referred to some strange remarks, made by Gostkowski, on investigations reportedly carried out in the second half of the 17th century. The results of these investigations were supposed to have shown that the more rarefied the air, the more difficult it is to ignite gunpowder (Schiesspulver), and that in 1817 Munte had observed that gunpowder does not explode in a vacuum.

Engineer Ludwig Loos published an article in "Die Zeit" of 25 August 1900, Vol. XXIV, p. 118, in which he examined Gostkowski's conclusion that interplanetary flight according to Ganswindt's plan was impossible, and revealed the mistakes in Gostkowski's computations.

The essence of Loos' observations is as follows:

1. For the spaceship to be able to fly around the earth like a satellite, as proposed by Ganswindt, it is necessary that its weight be balanced by centrifugal force; for this the speed of the spaceship must be approximately 8 km/sec. Assuming the spaceship to weigh 250 kg, such a speed can be attained by performing work equal to 800 million kgm, obtainable from 2,800 kg gunpowder if energy losses during the explosions are neglected. The same amount of propellant is needed for landing. Six tons of propellant are required altogether, which have to be lifted to the limits of the earth's atmosphere; a further 7 tons of gunpowder are needed for this. To decrease the propellant required, Loos suggested that the ship be launched from a high mountain and that it be built of aluminum rather than steel, to reduce the weight.

2. Much attention has to be paid to the strength of the spaceship, since certain parts of it are subjected to high stresses.

165 3. A better propellant would be detonating gas (a mixture of hydrogen and oxygen), each kg of which yields more than 1,333,000 kgm work.

On 23 September 1926, Ganswindt wrote to me that his spaceship was to be lifted to the upper layers of the atmosphere not by a rocket but by an airplane, and was to land in a glide without using propellant.

Finally, in a second letter sent to me on 12 October 1926, Ganswindt explained that a) the propellant (dynamite cartridges) was to be located in two lateral cylinders on top, rotating like the cylinder of a revolver and containing several hundred thousand cartridges to be fed automatically into the central steel cylinder at whose upper end they were to be successively detonated; b) the products of combustion were to be discharged through a pipe passing through the passenger gondola. Part of the gas was to heat the gondola.

b) The work of K. Tsiolkovskii, Ya. Perel'man, and others

The first person in Russia to prove that man could penetrate into interplanetary space using rockets, and to expound the theory of such flights, was a teacher of physics in Kaluga, named Konstantin Eduardovich Tsiolkovskii.

His first study appeared in 1903 under the title "Issledovanie Mirovykh Prostranstv Reaktivnymi Priborami" (Investigations of Cosmic Space Using Reaction Devices). This paper appeared in "Nauchnoe Obozrenie," 1903, No. 5, p. 45. He later developed his ideas on interplanetary flight in articles published in other journals and in monographs. These studies are important not only from the scientific and technical, but also from the historical aspect; we shall therefore devote a separate book to them and only mention them here.

In 1907 the Swedish astronomer Birkeland carried out experiments using a model of a rocket spaceship propelled in vacuum by means of hydrogen and oxygen.

In 1913 the French engineer Esnault-Pelterie published his book on the theory of rocket flight to other planets.

The eighth book of this series contains a complete translation of this work, and for this reason we only mention it here.

In October 1916 the Pulkovo astronomer G. Tikhov submitted a report in Petrograd on reaction-propelled interplanetary spaceships, in which he referred to the work of C. A. and V. Bjerknes (father and son), A. Korn, and A. Baricelli.

A gifted Russian popularizer of the idea of interplanetary travel was Ya. Perel'man, who described in his books the ideas of various scientists on space flight, criticized their projects and presented an attractive picture of future flight to the moon and other planets.

Problems of interplanetary flight were discussed by Ya. Perel'man in the following works:

1. "Zavtrak v Nevesomoi Kukhne" (Breakfast in a Celestial Kitchen) published in "Priroda i Lyudi" 1914, p. 381.
2. "Mezhplanetnye Puteshestviya" (Interplanetary Travel), Petrograd, 1915, first edition.
3. "Zanimatel'naya Fizika"* (Physics for Entertainment), Petrograd, 1916, Vol. II, p. 21.
4. "Puteshestviya na Planety" (Travel to the Planets), Petrograd, 1919, 2nd edition.
5. Ibid., 3rd edition.

166 6. "Mezhplanetnye Puteshestviya" (Interplanetary Travel), Leningrad, 1923, 4th edition.

7. Ibid, 5th edition.
8. "Polet na Lunu" (Flight to the Moon), Leningrad, 1925.
9. "Proekty Signalizatsii na Mars" (Projects of Signaling to Mars) in "V Masterskoi Prirody," 1926, No. 2, p. 50.
10. "Problemy Zvezdoplavaniya" (Problems of Celestial Navigation) in "Vestnik Znaniya," 1928, pp. 552, 594.

* [This book has been published in English under the name "Physics for Entertainment" by Izdatel'stvo "Mir", Moscow.]

Yakov Isidorovich Perel'man (Figure 155) was born on 22 November 1882 in Bialystok, Grodno Province, to a Jewish family. His father was a bookkeeper and his mother a primary-school teacher. He received his secondary education at the Bialystok high school and his higher education at the St. Petersburg Forestry Institute where he finished in 1909, obtaining the title of First-grade Forestry Scientist. However, he worked very little in forestry, if we disregard his services in 1917 as managing secretary of a section of the Special Committee on Fuel. In order to save fuel for lighting he, among others, proposed (and as was instituted upon his initiative) the introduction of daylight saving time (advancing the clock by one hour) in Russia. He began his literary activities as a pupil of the 6th grade on 23 September 1899 in "Grod. Gubernsk. Vedomosti" (Grodno Province Sheets) by publishing his first article "Po Povodu Ozhidaemogo Ognennogo Dozhda" (On the Occasion of the Expected Rain of Fire) (when an abundant fall of November meteorites (Leonides) was expected, which in wide circles was linked to the "end of the world"). This article was signed "Ya. P."

FIGURE 155.
Ya. Perel'man

In 1901, while a student, he became a permanent contributor to "Priroda i Lyudi," continuing until publication ceased in 1918. During these 17 years he published in this journal, under various pseudonyms, about a thousand articles, notes, and translations on various subjects. In 1906 he became a member of the editorial staff, managing the journal himself after the death of the editor in 1913. At the same time he also published articles in other periodicals, amongst them the "Pedagogicheskii Sbornik."

In 1918 he became one of the most active collaborators of the "Pedagogicheskaya Mysl'," in which he published a series of interesting and instructive articles, surveys and reviews. From 1919 onward he edited the journal "V Masterskoi Prirody," and in 1924 he took charge of the scientific department of the "Vechernyaya Krasnaya Gazeta."

He began to teach physics in 1919 at various educational institutes, such as the Pskov Institute of National Education, the Petrograd Workers Polytechnicum, the Zinov'ev University and the Leningrad Electrotechnicum.

He wrote 30 books on different subjects, of which 1,300,000 copies were printed altogether. His most important books were: Zanimatel'naya fizika (1913 g.) (Physics for Entertainment (1913)), Fizicheskaya khrestomatiya (A Textbook on Physics), Novyi zadachnik po geometrii (Problem Book on Geometry), Prakticheskie zadachi po geometrii (Practical Problems in Geometry), Zanimatel'naya geometriya (Geometry for Entertainment), Zanimatel'naya arifmetika (Arithmetic for Entertainment), Tekhnicheskaya geometriya (Technical Geometry), Tekhnicheskaya fizika (Technical Physics), Metricheskaya sistema (The Metric System), Mir planet (The World of the Planets), Polet na lunu (Flight to the Moon), and Mezhplanetnye puteshestviya (Interplanetary Travel) in 5 editions.

In all his works he developed new subjects, displayed a scientific approach, originality, clarity of ideas, liveliness of explanation, lucidity of style, and tried to make the instruction interesting.

We should also mention Alexander Alekseevich Rodnykh (Figure 156), the indefatigable compiler of the bibliography on the history of Russian

167 aviation, who also collected rare photographs and drawings dealing with the development of reaction engines in Russia. Six of these drawings were placed at our disposal by A. Rodnykh.

In 1919 Prof. Goddard published his paper "A Method of Reaching Extreme Altitudes" in the USA, in which he described his experiments on the operation of rockets, and also gave an analysis and the theory of their flight.

Since a translation of Goddard's work will be given by us in the seventh book, we only mention it here. Goddard was assisted in his work by Jenkins.

Figure 157 shows schematically a rocket-propelled spaceship suggested by the Austrian scientist F. A. Ulinski (1920). A compartment in the form of a rocket is located in the nose of the machine from which gas is ejected. The recoil thus induced propels the spaceship in a direction opposed to that of the gas jet. Ulinski, however, assumed that the relationship between the reaction obtained and the weight of the entire spaceship together with the fuel was so unfavorable that it would hardly be possible to reach the upper limit of the terrestrial atmosphere, not to mention the danger inherent in such a device.

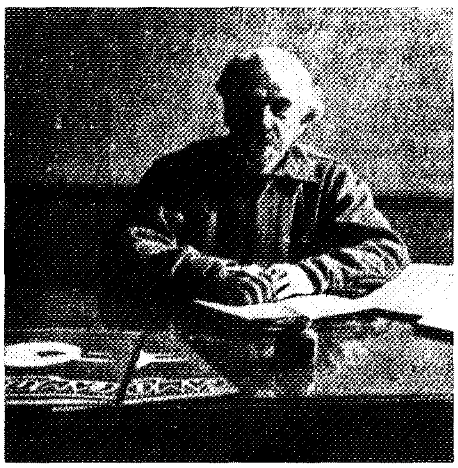


FIGURE 156. A. Rodnykh

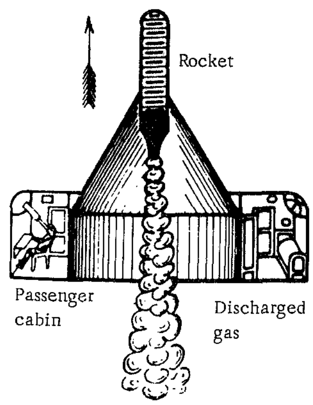


FIGURE 157. Ulinski's interplanetary rocket

In 1920 A. Scherschevsky reported to the Scientific Aeronautical Association in Berlin on interplanetary communication and on Tsiolkovskii's work.

In 1924 Prof. V. Vetchinkin submitted a report in Moscow on an interplanetary spaceship and on the design of a reaction-propelled, unmanned spaceship. J. Roberts in the U. K. worked in the Air Ministry on the problems of a reaction-propelled airplane. On 29 April 1927 M. Valier reported to the Scientific Aeronautical Association in Berlin on space flight. This report led to a discussion in aeronautical periodicals (Manigold in "Z. F. M." 1927, No. 11, and A. Scherschevsky in "Flugsport," 1927, p. 388).

Lastly, we should mention the interest shown in problems of space communication by the German professors Hopf, Mises, Prandtl, and Einstein.

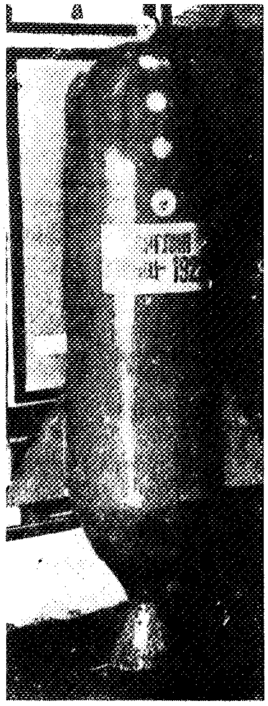
168 

FIGURE 158. Welsh's rocket ship

WELSH'S ROCKET SHIP

In 1922 in England, Welsh proposed a rocket ship (Figure 158) which was to be propelled by means of melonite detonating in compressed air. The rocket ship was to land by means of a parachute. A model and a description of this machine were shown at the exhibition of interplanetary machines held in Moscow in 1927.

L. GUSSALLI'S PROJECT OF ROCKET FLIGHT TO THE MOON

The Italian engineer Luigi Gussalli, in his book "Si puo già tentare un viaggio d'alla terra alla Luna?" Milan 1923, presented a plan of a rocket flight from the earth to the moon and made the following suggestions: The rocket should consist, e.g., of 27 sections, each containing 300 g of propellant. These sections were to be combined into 4 groups (Figure 159). The flight was to be carried out in 3 long and 6 short intervals, according to the table given in Figure 159.

Assuming 2 passengers with a combined weight of 150 kg, the load per section would be 150/27 = 5.5 kg at takeoff, but only 3.75 kg after the first interval, due to the reduced gravitational attraction of the earth.

Two passengers might be carried to the moon by means of a group of similar rockets connected as shown in Figure 159. One rocket would contain the passengers and another the propellant. Alternatively, one large rocket might be built. Each "train" was to carry a propellant reserve for the return trip from the moon to the earth. Less propellant would be needed on the return trip than on the voyage to the moon, since it would be easier to take off from the latter due to its smaller gravitational attraction, while a metal parachute could be used for landing on the earth.

Gussalli proposed that takeoff from the earth and rapid acceleration to the required flight speed be facilitated by launching the rocket with a catapult; he also referred to Drouet's method of employing a centrifugal machine, but did not recommend it. Gussalli proposed, as an engine for his rocket, the double-reaction turbine described on p. 75. Gussalli recommended that an experimental rocket be launched first, and only then a group of rockets or one large rocket.

In his work Gussalli defined the operating principle of a reaction engine
as follows: a certain mass is ejected from it at a high velocity, thus
169 causing a reaction which propels the larger mass of the engine in the
opposite direction at a lower speed.

In addition, he presented the following theory of Maurice Deprez:

"Irrespective of the nature of the operation of the reaction engine, the maximum recoil is obtained when the gas-outlet velocity is equal to twice the flight speed of the machine."

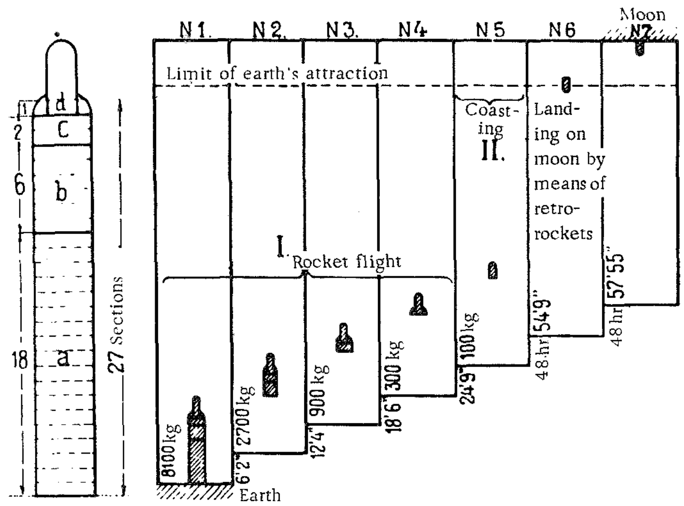


FIGURE 159. Gussalli's scheme for flight to the moon

TABLE.

Long intervals	Short intervals (propellant consumption)	Propellant weight, kg		Duration of interval	Time elapsed from takeoff to end of interval
		at beginning of interval	at end of interval		
Rocket flight from earth to an altitude of 5,780 km	1. Consumption of 2/3 of propellant = 5,400 kg	27 × 300 = 8,100 kg	2,700 kg	6' 2"	6' 2"
	2. Consumption of 2/3 of 2,700 = 1,800	2,700	900	6' 2"	12' 4"
	3. Consumption of 2/3 of 900 = 600	900	300	6' 2"	18' 6"
	4. Consumption of 2/3 of 300 = 200	300	100	6' 3"	24' 9"
Coasting	5. Coasting	100	100	48 hr 30'	48 hr 54' 9"
Landing on moon by means of retro-rockets	6. Landing by consumption of 100 kg propellant .	100	0	3' 46"	48 hr 57' 55"

170 He also mentioned the necessity of equipping the rocket with rudders and described their operation as follows:

"When the gas jet impinges at a high velocity on the rudder turned to a transverse position, it exerts a large pressure on it since high-velocity gas has a high energy; the gas jet thus acts like a solid bar. The properties of such jets have been studied by Bernhard Brinson and by Lord Kelvin."

We shall now present some of our own views on the flight of rockets and artillery projectiles, developing the ideas of Gussalli and of the German astronomer Max Valier.

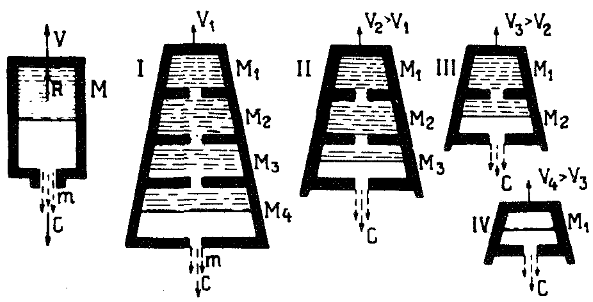
c) Brief theory of rockets

A rocket is propelled by the reaction or recoil caused by the discharge of gas.

Let an explosion cause a mass m of gas to be ejected each second at a velocity c from a rocket (Figure 160). The recoil R imparts a velocity v to the rocket which together with the unburnt propellant has a mass M. The law stating that the total momentum of the system remains constant yields the fundamental equation of rocket motion

$$m \cdot c = Mv \qquad (1)$$

Let a given mass of gas be discharged each sec at a constant velocity. The left-hand side of (1) then is constant, whereas M on the right-hand side will decrease, since the mass of unconsumed propellant continuously decreases; hence, v must increase.



FIGURES 160 and 161. Rocket-flight theory

Rockets are built in several stages in order to maximize the velocity v. These stages are discarded as the propellant contained in them is consumed, so that the remaining mass M is greatly reduced during the flight. The velocity v therefore increases.

Figure 161 shows a four-stage rocket. The masses of the stages are $M_1 - M_4$ respectively.

171 At the beginning of motion, when the propellant in the first stage is being used, we have

$$mc - (M_1 + M_2 + M_3 + M_4)\, v_1$$

After separation of the first 3 stages, we obtain

$$mc = M_1\, v_4,$$

where v_4 is much greater than v_1.

Figure 161 illustrates how the stages separate successively.

The higher the speed at which the rocket moves away from the earth, the lower will be the velocity, relative to the earth, of the gas discharged.

Figure 162 shows schematically the relationship between the velocities of the gas and of the rocket during ascent from the earth. The rocket is shown in 5 positions. In the first position its velocity is still zero, whereas that of the gas is v_1 relative to both the earth and the rocket. In the fifth position the speed of the rocket equals the gas velocity relative to it, v_p . The gas-outlet velocity relative to the rocket remains the same as before, but becomes zero relative to the earth. It would thus appear to an observer that the gas cloud is stationary in the air, while the rocket continues to climb. The velocity of the rocket relative to the earth gradually increases in the intermediate positions, while the velocity of the gas relative to the earth gradually decreases.

Let us determine the relationship between the velocity v of the rocket and the velocity c of the gas. Let m be the mass of the rocket which during a time increment increases its velocity by dv, due to the discharge of a mass dm of gas.

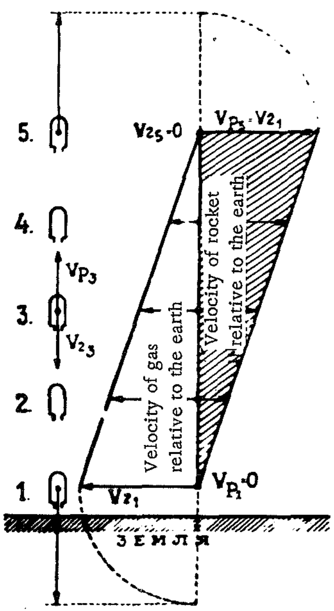


FIGURE 162. Rocket-flight theory

By analogy to (1) we thus have

$$cdm = mdv$$

whence

$$v = c \ln \frac{M_0}{M_n} \qquad (2)$$

where M_0 is the initial mass of the rocket, and M_n its end mass.

It follows from (2) that if we wish to impart to the rocket a speed which is n times the gas-outlet velocity ($v = nc$), the ratio of the initial to the end mass must be given by

$$\ln \frac{M_0}{M_1} = \frac{v}{c} = n,$$

whence

$$\frac{M_0}{M_1} = e^n$$

The ratio of the initial to the end mass is
172 thus the nth power of the base of the natural logarithms ($e = 2.71828 \cong 2.72$). If $n = 1$, i.e., $v = c$, we have

$$\frac{M_0}{M_1} = 2.72.$$

Thus the initial mass of the rocket must be 2.72 times its end mass if a flight speed equal to the gas-outlet velocity is to be attained.

For

$$v = 2c. \quad M_0 = 7.4\ M_1$$
$$v = 3c. \quad M_0 = 20.1\ M_1$$
$$v = 4c. \quad M_0 = 54.6\ M_1$$
$$v = 5c. \quad M_0 = 148.4\ M_1$$
$$v = 10c. \quad M_0 = 22026\ M_1$$
$$v = 30c. \quad M_0 = 11 \cdot 10^9 M_1.$$

It follows from (2) that the gas-outlet velocity c and the ratio of the initial to the end mass should be maximized. In practice, however, these magnitudes cannot be increased infinitely. Thus, if detonating gas is used as propellant, v may be 12,000 m/sec when the gas-outlet velocity is 5,000 m/sec and $\frac{M_1}{M_0} = 12$. However, due to the small specific weight of the mixture forming the detonating gas, the rocket must have a large volume, i. e., either a large cross-sectional area, which increases the drag or great length, which increases the danger of its breaking apart.

The speed required for interplanetary travel may be attained rapidly if the rocket is unmanned. In this case, however, it must have the optimum acceleration, so as to leave the gravitational field of the earth as quickly as possible without excessive increase of drag. The danger to human beings, caused by high accelerations, should be kept in view if the rocket is to be manned. The acceleration should in this case not exceed 40 m/sec^2.

Valier gave the following data for interplanetary rockets:

1. For flight from the earth to the limits of the solar system: $c = 4{,}000$ m/sec, $v = 19{,}000$ m/sec, a multistage rocket being used. During flight from the earth to the limit of the earth's gravitational field $\frac{M_0}{M_1} = 12.1$; thereafter part of the shell separates and for the remainder of the rocket $\frac{M_1}{M_1'} = 43.1$.

2. For flight from the earth to Jupiter $v = 172$ c.; $\frac{M_0}{M_1} = 4.7 \cdot 10^{12}$.

3. For flight to Mars the amount of propellant carried must be 1.5 times as much as for flight to the moon.

We shall now continue our comparison between a shell fired from a gun and a rocket.

The shell has its maximum velocity in the muzzle; thereafter its velocity decreases. By detonations a rocket can acquire any speed desired within certain limits. Initially, in the lower layers of the atmosphere,
173 where the drag is large, the rocket may travel slowly in order to save propellant; further up, where the density of the air is low, the rocket should develop a high speed. It is, however, generally best to impart to the rocket the maximum possible speed so that it leaves the earth's gravitational field as soon as possible, since any delay causes a waste of propellant.

Oberth tried to find a compromise between these two requirements by selecting a so-called optimum speed which the rocket should maintain at any given time as long as it travels within the atmosphere; this optimum speed is determined from the condition that propellant consumption be minimum.

In the case of a manned rocket, the flight speed is subjected to the restriction that the acceleration must not exceed a value which can be tolerated by human beings. This value is approximately 30 m/sec^2 (maximum 45 m/sec^2).

During a perpendicular ascent, the acceleration is added to the gravitational acceleration (9.81 m/sec^2), so that the safe acceleration is in this case *only* $30 - 9.81 = 20.19$ m/sec^2.

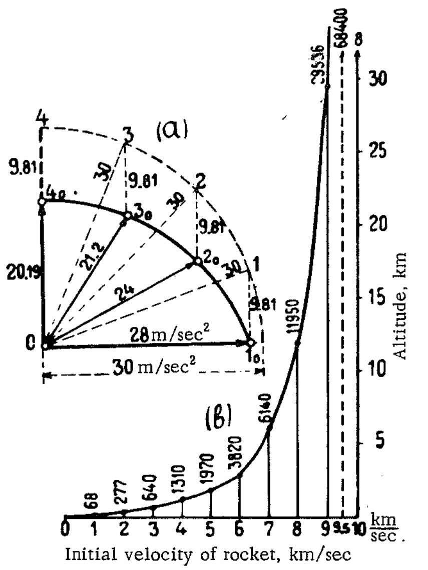


FIGURE 163. Rocket-flight theory

For the sake of safety, it is therefore better at first not to ascend vertically but at a slope. Figure 163 shows the influence of the inclination on the acceleration to which a person is subjected. The maximum total acceleration has been taken as 30 m/sec^2.

174 An acceleration of 28 m/sec^2 is permissible during horizontal flight (0-1_0) which, when added vectorially to $g = 9.81$ m/sec^2, yields the safe limit of 30 m/sec^2.

The permissible acceleration is 24 m/sec^2 when the flight direction corresponds to ray 0-2_0, and 21.2 m/sec^2 in the direction of ray 0-3_0.

We can calculate what height the rocket attains at an initial acceleration of 30 m/sec^2 until a certain speed v_1 is reached. Taking this value as the initial velocity of free flight (coasting), we can then determine the remaining height up to the point at which the rocket begins to descend to the earth. Thus, assuming an initial coasting speed of 1,000 m/sec, we obtain:

1. Distance traveled from the earth ($v = 0$) to a height where $v_1 = 1{,}000$ m/sec:

   $h_1 = \frac{1}{2} \cdot 30\ t^2$, where t is obtained from the equation $1{,}000 = 30\ t$;

   $h_1 = \frac{1}{2} \cdot 30 \cdot \frac{1000^2}{30^2} = 16{,}666$ m $= 16.666$ km.

2. The additional height h_2 gained during coasting (assuming as an approximation that $g_1 = 9.81$ at altitude h_1) is

$$h_2 = \frac{v}{2g} = \frac{1000^2}{2\ 9.81} = 50.9\ km.$$

The total altitude thus is $H = h_1 + h_2 = 16.666 + 50.9 \cong 68\ km$.

Figure 163*b* shows the results of similar computations carried out for rockets having initial coasting speeds v_1 between 1 and 10 km/sec.

The ordinates represent the altitude (in km) which can be attained by the rocket. At greater altitudes h_1, the gravitational acceleration g is [approximately]

$$g = g_1 \frac{h_1^2}{h_2^2}.$$

175 For comparison Figure 164 presents, after Valier, the flight of a rocket (curve *ABE*) and that of a shell fired from a gun (curve *CBE* when the resistance of the air is taken into account, and curve *DBE* when it is neglected).

The ordinates represent the speed of ascent in m/sec, while the abscissas represent the altitude of the projectile expressed in earth radii.

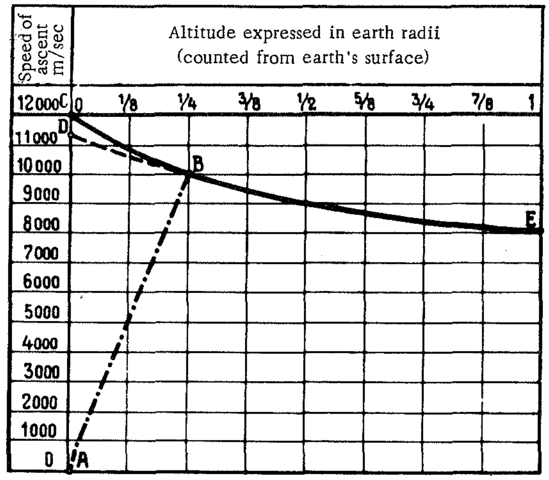


FIGURE 164. Theory of flight of rockets and shells

The rocket at first ascends at a uniform acceleration of 30 m/sec^2 until its speed reaches $v_b = 10{,}000$ m/sec; this occurs at an altitude h_1 determined from the previous formula:

$$h_1 \quad \frac{1}{2}\cdot 30\,t^2;\ t = \frac{10000}{30} = 333 \text{ sec};\ h_1 =$$

$$-\ \frac{1}{2}\cdot 30\,\frac{10000^2}{30^2} = 1{,}666.6\ \ km \cong 1/4 \text{ radius of earth}$$

This speed and altitude are represented on the diagram by point ***B***. The rocket then begins to coast at a gradually decreasing speed. Thus, at a height $h_2 = r$, measured from the surface of the earth, its speed is given by

$$v_2^2 = v_1^2 - 2g_1h_1^2\left(\frac{1}{h_1} - \frac{1}{2r}\right)$$

where

$$g = \frac{9.81\cdot r^2}{\left(r + \frac{1}{4}r\right)} = 6.28\ \ m/sec^2;\ h_1 =$$

$$6371 + 1{,}666.6 \cong 8037\ km;\ 2r = 6371\times 2 =$$
$$12742\ km.$$

Substituting these values, we obtain

$$v_2^2 = 10000^2 - 2.6.28\cdot 8037\left(\frac{1}{8037} - \frac{1}{12{,}742}\right)$$
$$\cong 8000\ km.,$$

which corresponds to point ***E*** on the diagram.

The curve ***EB***, continued to the left, intersects the y-axis at a point which corresponds to the muzzle velocity of a shell of equal weight. However, allowing for the resistance of the air, the muzzle velocity has to be increased by the amount ***DC*** to 12,000 m/sec.

SPACESHIP WITH RETRO-ROCKETS

Landing on a celestial body having no atmosphere, e. g., the moon, is possible only by using retro-rockets.

Figure 165 represents the simplest case of a manned rocket-propelled
176 machine which rises from the earth to a height of 1,000 m and then lands using retro-rockets. The machine contains two rockets, one for takeoff and one for landing. Each rocket burns for 10 sec, the acceleration attained being 2 g. The entire propellant charge (gunpowder) weighs 40 kg. At first the machine ascends to a height of 500 m in 10 sec, after which it coasts at a gradually decreasing velocity to its maximum altitude $H = 1{,}000$ m. It then descends in free fall to a height of 500 m in 10 sec and is finally braked during the last 10 sec of its return to earth. The respective accelerations are: $b - g =$ 1) $2g - g = +g$; 2) $0 - g = -g$; 3) $0 - g = -g$; 4) $2g - g = +g$. The acceleration is represented on the diagram by the stepped curve. The velocity is $v = (b-g)t$; it is represented on the diagram by the angular line ($v = 0$ at t = 0.20, and 40 sec). The flight altitude is represented by the curved line.

(175)

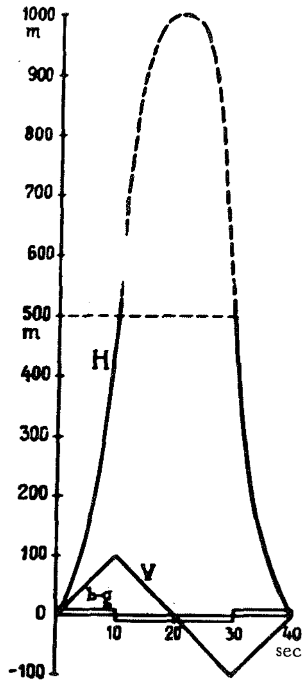


FIGURE 165. Landing by means of retro-rockets

d) **The work of Oberth, Valier, and Condit**

The first edition of Hermann Oberth's book, "Die Rakete zu den Planetenräumen," appeared in Munich in 1923 (a second edition was published in 1925, and a third in 1929). This book contains a computation of the flight of a manned rocket in interplanetary space and gives several variants of its design. Book 7 of this series contains details of Oberth's work, so that here we shall only briefly discuss his results.

From his computations Oberth found that a manned rocket must fly for 332 sec (at an acceleration of 30 m/sec^2) in order to pierce the double armor of the earth's gravitational field and the resistance of the air. During this time the rocket attains an altitude of 1,653 km and a speed of 9,960 m/sec. At this height the computed speed already exceeds the speed corresponding to the parabolic law, and further acceleration becomes superfluous. The force of gravity to be overcome by the rocket during these 332 sec corresponds to g = 9.81 m/sec^2 initially, and to 6.17 m/sec^2 at the end (8 m/sec^2 in the mean). This causes a loss in speed of 2,656 m/sec, whereas the speed lost due to drag is only 200 m/sec.

In the ideal case the force acting on the rocket should impart to it a speed of 9,960 + 2,656 + 200 = 12,816 m/sec. This speed can be attained within 5/6 of the time mentioned (i. e., after 260 sec) if the rocket has a curved instead of a vertical trajectory. In this case the speed lost due to gravity will be only 2,000 m/sec instead of 2,656 m/sec, and in the ideal case the force acting on the rocket would impart to it a speed of about 12,100 m/sec.

178 A higher acceleration is possible if the rocket is unmanned. It may then fly faster and will lose only 800 m/sec in overcoming gravity and drag. Without this loss it would attain a speed of 10,932 m/sec according to the parabolic law at a height of 280 km, where the gravitational acceleration is 8.996 m/sec^2. The speed imparted to the rocket in the ideal case will thus be $10{,}923 + 800 = 11{,}723$ m/sec.

Popularization of the problem of interplanetary travel by means of rockets was undertaken in 1924 by Max Valier (Figure 166) in his book "Der Vorstoss in den Weltenraum — Eine Wissenschaftliche Gemeinverständliche Betrachtung" (second edition in 1925, third edition in 1928). In this book Valier reviewed the various methods of launching a missile into space (gun, centrifugal machine). He gave preference to the rocket and, using Oberth's work as a foundation, made some suggestions on the development of airplanes equipped with rockets.

FIGURE 166. M.Valier

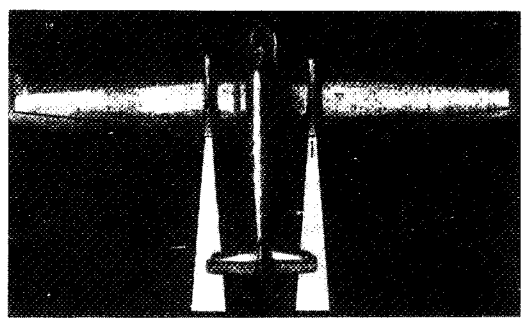


FIGURE 167. Airplane with propeller and 2 rockets, after Valier

Max Valier was born in 1895 in Bozen (Tirol) [now Bolzano in the Italian Region of Alto Adige]. He was educated in a high school run by Franciscans; he finished in 1913. By this date he was already considered an expert mechanic and while still at school had published articles in 20 journals. He then began to study astronomy, mathematics, physics, and chemistry, in Innsbruck (Austria). In 1915 he was drafted into the [Austro-Hungarian] army and served in a gas battalion. Flying as a pilot he once crashed from a height of 4,000 m, but was saved. In 1921, while living in Munich, he began to write books.

179 We present several of Valier's drawings which show airplanes developed by him.

Figure 167 shows an airplane with a propeller, large wings, and 2 rockets; Figure 168 shows an airplane with a propeller, a smaller wing area, and

(177)

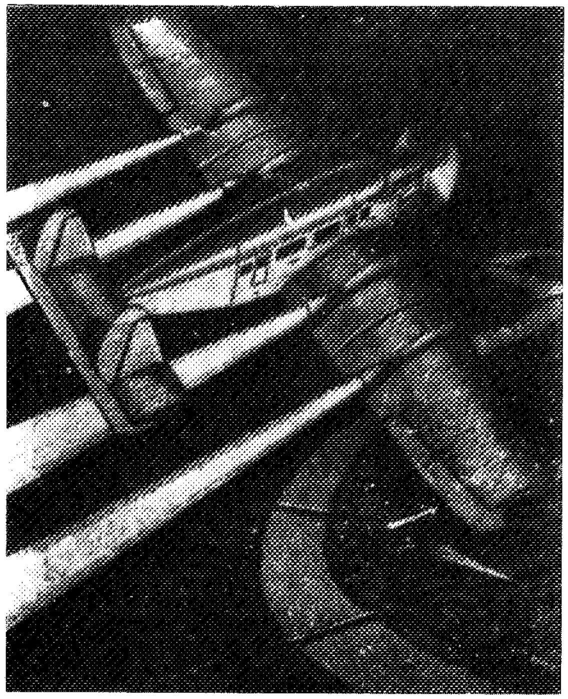


FIGURE 168. Airplane with propeller and 4 rockets

(178)

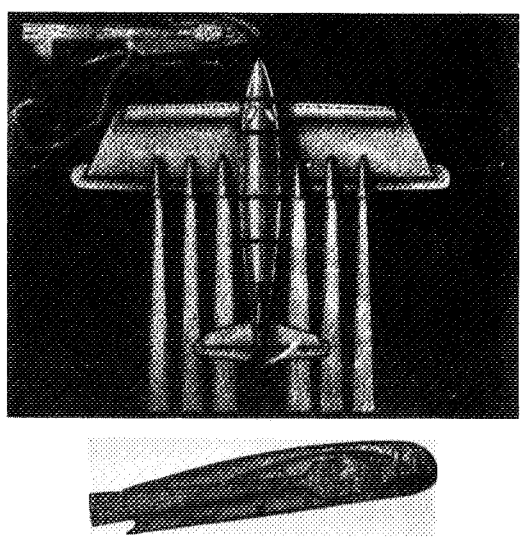


FIGURE 169. Airplane with extensible wings and 6 rockets, after Valier

4 rockets, while Figure 169 shows an airplane without propeller, with small
182 extensible wings and 6 rockets. Figure 170 is a longitudinal section of a similar airplane; Figure 171 shows a rocket plane with twin fuselage; Figure 172 shows a space rocket, and Figure 173 shows a spaceflight station on the moon, where energy supplies can be replenished by solar batteries. Figure 174 shows a spaceship landing on earth.

(179)

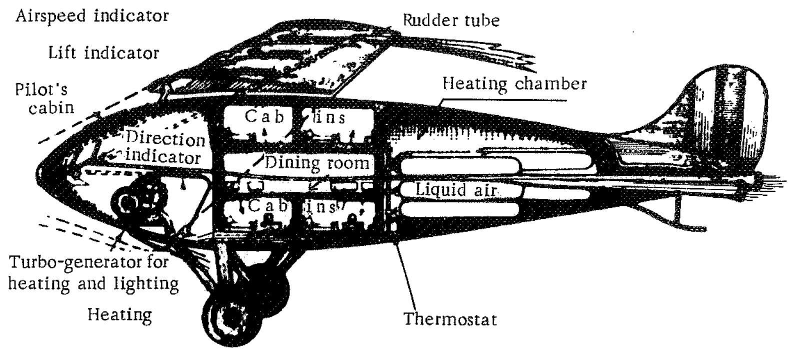


FIGURE 170. Section of plane designed by Valier

(179)

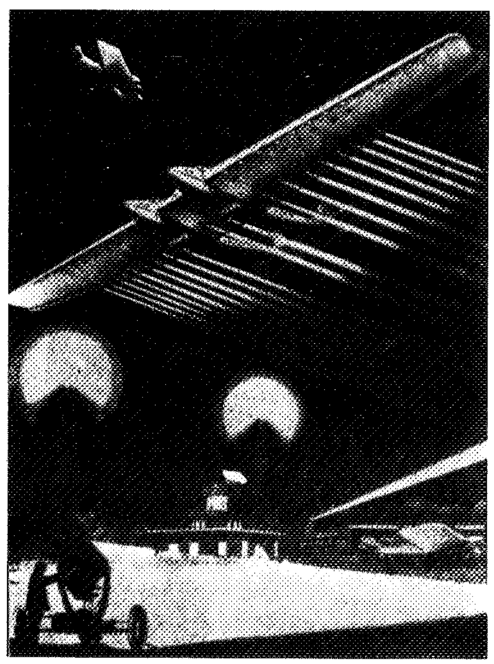


FIGURE 171. Rocket plane designed by Valier

(180)

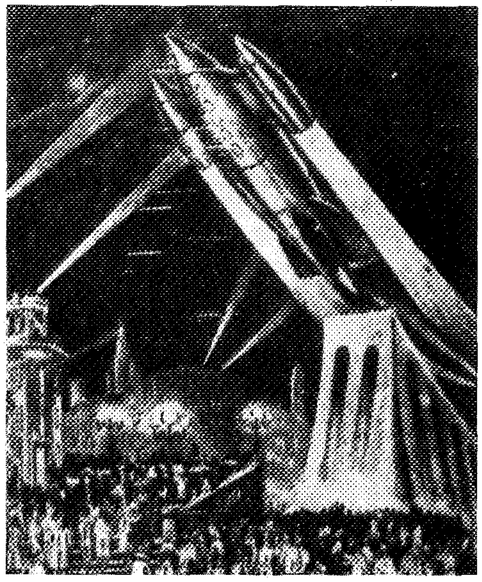


FIGURE 172. Space rocket, after Valier

(180)

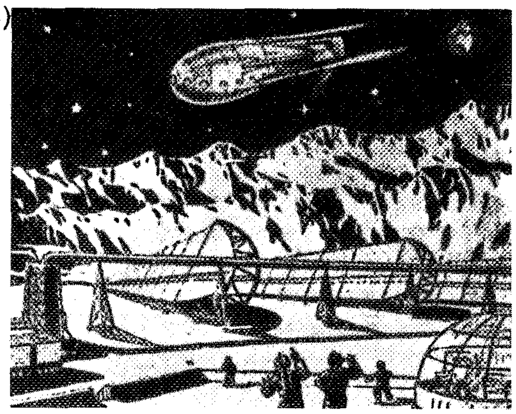


FIGURE 173. Space flight station on the moon

(181)

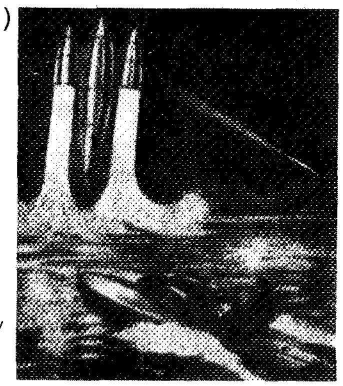


FIGURE 174. Spaceship landing on earth

Developing Oberth's ideas, Valier wrote:

183 Assuming that the gas attains a velocity of 4,000 m/sec during its expansion and that the final rocket speed is 19 km/sec, we find that for Oberth's hydrogen-burning rocket the ratio of the mass of the full rocket to that of the empty rocket is 43.1. At this mass ratio it will be possible to reach the limits of the solar system. A mass ratio of 12.1 is sufficient to reach the limits of the earth's gravitational field.

Takeoff and landing on Jupiter require a flight speed which is 172 times larger than the gas-outlet velocity; the ratio of the mass of the full rocket to that of the empty rocket must be $4.7 \cdot 10^{12}$. However, the amount of propellant required for flight to Jupiter and back without landing is only 1.5 times larger than that required for flight to the moon.

Valier's computations showed that a rocket can attain a speed equal to the gas-outlet velocity if the weight of the propellant carried by it amounts to 63.21% of its total weight. A rocket speed equal to twice or three times the gas-outlet velocity can be attained if the weight of the propellant carried amounts to 86.46 or 95.2% respectively, of the total weight of the rocket. The remainder of the rocket would thus account for only 13.5 or 5% of the total weight. With gunpowder, which yields a gas-outlet velocity of only 2,500 m/sec, the weight of the propellant would be very large [referred to the total weight of the rocket]. Use of a mixture of hydrogen and oxygen as propellant (c = 5,000 m/sec) would reduce the weight of the rocket but, on the other hand, would be dangerous, difficult to adjust, and increase the cost. For these reasons Valier suggested that trial flights, first carried out to heights of 250—300 km, would be less difficult from the technical aspect.

(181)

FIGURE 175. Separation of space rocket from first stage

Figures 175—179 show various stages of a future manned rocket flight to the moon. Figure 175 shows the instant the spaceship separates from the first stage (auxiliary airplane) which had lifted it to an altitude of approximately 6 km; from this point the rocket continues to fly independently by burning its own propellant.

(182)

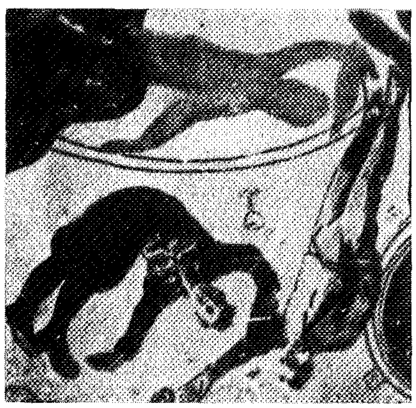


FIGURE 176. During gravity-free flight

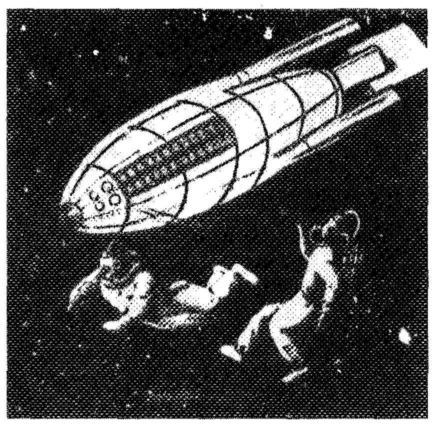


FIGURE 177. During gravity-free flight

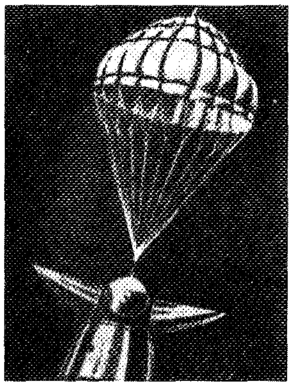


FIGURE 178. Landing by parachute

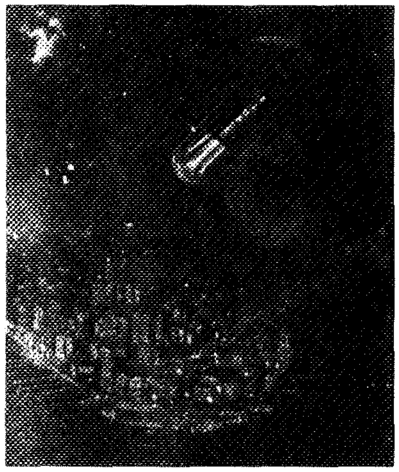


FIGURE 179. Landing by parachute using retro-rockets

Figure 33 shows the rocket coasting between the earth and the moon under
84 the influence of gravity. Figure 32 shows the passenger cabin with the parachute (on top); the passengers are being subjected to an acceleration of 4.5 g as the rocket gathers speed. Figure 176 shows people floating about inside the cabin when there is no gravity (no acceleration). Figure 177 shows that during gravity-free flight the passengers may safely move outside the rocket in spacesuits. Lastly, Figures 178 and 179 show the rocket landing upon return, using first a parachute and then retro-rockets.

THE COST OF A ROCKET SPACESHIP

"Die Rakete" of 15 December 1927 stated that the cost of a rocket spaceship weighing one ton and intended for flight to the moon would be about 3,350,000 marks, i.e., only a little more than a Zeppelin airship. However, reduction of the cost might be achieved by reducing the weight of the shell and combustion chamber.

Work on the design of a 2 m-diameter rocket was also carried out in Denmark in 1925.

CONDIT'S SPACESHIP

Certain newspapers reported on a rocket spaceship designed by Robert Condit, a professor of chemistry (U S A), in which he proposed to fly to Venus (1926).

LABADIÉ S SPACESHIP

The French inventor J. Labadié proposed the spaceship shown in Figure 180. It was to consist of 3 parts. The upper part contained a telescope and an apparatus for regenerating air for breathing. The
(184) central part contained an electric motor and the combustion chamber, while the lower part contained the nozzle.

In one of his designs the rocket had 8 nozzles and an elongation of 1:4 [sic], while another design included 6 nozzles.

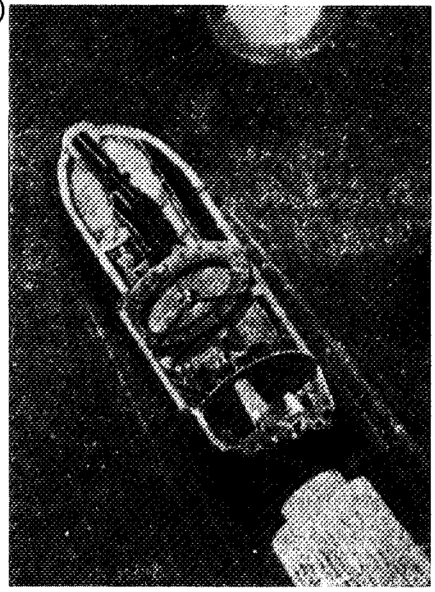


FIGURE 180. Labadié's spaceship

RANDOLPH'S ROCKET SPACESHIP

185 Figure 181 shows part of a section of Randolph's rocket spaceship. It contained several thousand cylindrical reservoirs with separate nozzles. These were to operate successively, from the bottom. Two retro-rocket engines for landing on Mars and on the earth are shown above and below the central cabin. The cabin also contained the propellant tank of the rocket controlling the flight direction and 2 gyroscopes ensuring stability during flight.

The passenger cabin could rotate around the compartment containing the gyroscopes, thus inducing artificial gravity forcing the passengers against the outer wall of the cabin. Figure 181 also shows the trajectory of the spaceship between earth and Mars. Its weight approximated that of an ocean-going vessel.

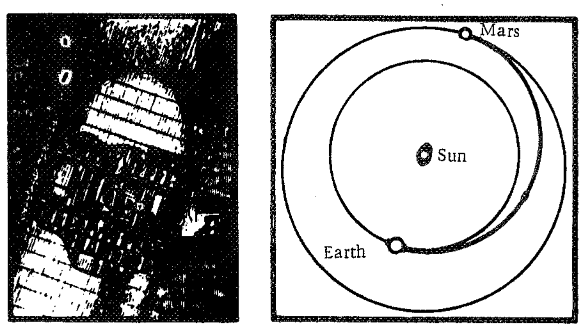


FIGURE 181. Randolph's spaceship and its trajectory during flight to Mars

GUIDO VON PIRQUET'S WORK

A thorough investigation of the flight paths of interplanetary spaceships was carried out by Engineer Guido von Pirquet (cf. his paper in "Die Rakete" of 1928).

Engineer Guido von Pirquet was born in 1880 at Hirschstetten Castle (now within the city limits of Vienna) into a family of landowners. He was educated first at high school and then at the Technical Colleges of Vienna and Graz (Departments of Mechanical Engineering). His hobby was astronomy. He was a member of the Technical Experimental Committee, Vice-President of the Austrian Association of Inventors, and Secretary of the Society for the Exploration of the Upper Layers of the Atmosphere and Interplanetary Communication in Vienna.

e) Winged rocket designed by Tsander

The Russian engineer F. A. Tsander published an article in "Tekhnika i Zhizn'", 1924, No. 13, p. 15 and No. 12, describing an interplanetary rocket with wings (overall view on the cover). The article was accompanied by a schematic drawing. We reprint here this article in which Tsander
186 demonstrated the advantages of his project over those of Tsiolkovskii, and replied to Ya. Perel'man's objections.

"Having become interested in the mathematical and design investigations concerning interplanetary travel, I have carried out computations on this problem for several years, coming to the conclusion that at the present state of technology it will, in all probability, be possible within the next few years to fly to other planets.

I have worked out the following principal directives:

1. For flight in the upper layers of the atmosphere and for landing on planets having an atmosphere, it will be advantageous to use airplanes as structures maintaining the spaceships in the atmosphere. Airplanes capable of landing in a glide when the engine is stopped are much better than the parachutes suggested for reverse landing on the earth by Oberth in his book "Rocket to a Planet."

The use of a parachute makes impossible the free selection of the landing site or continued flight in the case of a temporary engine stoppage, so that it should be employed only in the case of unmanned flight. That part of the rocket which is controlled by a person must be provided with an airplane. Landing on a planet with a sufficiently dense atmosphere by means of retro-rockets, as proposed by Tsiolkovskii, is less advantageous than using a glider or airplane with engine, since a rocket consumes much propellant during landing; such a landing would cost tens of thousands of rubles even when only one person is carried. On the other hand, landing by means of an airplane would cost only some tens of rubles, and would not cost anything if gliding were employed. The computations show clearly that it is possible to land safely on the earth from a slow glide.

2. The flight speed should be low near the ground, and should gradually be increased as altitutde is gained and the density of the air decreases.

3. Propulsion in the lower layers of the atmosphere should be provided by a special high-pressure engine using fuel and liquid oxygen. The engine should drive a propeller with either adjustable or ordinary [fixed] blades. In the latter case the engine should be designed in such a way that it can operate at a low speed on the ground, its speed being gradually increased as altitude is gained. The engine and propeller may be replaced by a rocket designed for flight in the atmosphere, the reaction propelling the machine in the desired direction.

The term "rocket" should here be understood as a nozzle similar to those fitted in turbines: the products of combustion enter through its throat at a high pressure. The gas particles rebound from the nozzle walls and expand rapidly, attaining a velocity of 4 to 5 km/sec in the direction of the nozzle axis. A rocket designed for flight in the atmosphere aspirates air from the surroundings into the nozzle. This air is mixed with the products of combustion, so that the velocity of the whole mass of gas in the rocket is reduced. The mass of the gaseous mixture to be accelerated is thus larger and the efficiency higher than with an ordinary rocket. The efficiency of the latter is very low at flight speeds up to 400 m/sec.

187 4. At flight speeds above 400 m/sec propulsion should be either by an air-breathing or by an ordinary rocket.

5. During rocket flight it is necessary to pull in part of the lifting surfaces: propeller, engine, and similar parts of the airplane, melting them in a special vessel or boiler and ejecting the molten metal in order to assist the rocket. The airplane should be designed accordingly. It should be equipped with cables and other devices permitting all necessary movements. The computations indicate that the weight of such a machine will only slightly exceed that of an ordinary airplane.

6. At speeds close to 8 km/sec it will be best to leave the terrestrial atmosphere at a small inclination to the horizontal, since in this case the centrifugal force developed during flight around the earth's sphere will balance the force of gravity; the machine, left to itself, will not fall back to earth. If it is already outside the atmosphere, it will perpetually circle round the earth like the moon. The air, which creates lift in the case of an airplane, would in the case considered only slow down the machine. Lifting surfaces are quite superfluous during interplanetary flight and are used again only during landing in an atmosphere.

7. A speed of 11.18 km/sec must be attained if it is desired to fly to other planets. Rockets may be used in this case, but it would probably be better to fly using mirrors or screens of very thin sheets. The screens must rotate about their axis for the sake of rigidity. A mirror requires no fuel but may be used as propellant in the rocket if necessary. In addition to these advantages, it does not induce high stresses in the material of the spaceship and weighs less than a rocket together with the propellant required for it. On the other hand, it is more easily damaged by meteors than a rocket.

8. The screens may most probably be replaced by a ring in which an electric current flows. Iron filings located inside the ring would be maintained near the plane of the latter by electromagnetic forces. The iron filings should also carry electrostatic charges so that they remain at a certain distance from one another.

At the enormous distances encountered in interplanetary space, small forces induce comparatively large flight velocities. Sunlight exerts such a pressure on the mirror, screen, or iron filings.

9. Huge concave mirrors, built in interplanetary space and rotating together with guiding telescopes around a planet, collect sunlight and direct it toward the spaceship flying to another planet. This will impart to the spaceship a velocity many times higher than that imparted by a rocket.

10. Several interplanetary spaceships can be built on the basis of these considerations.

The results of my computations are as follows:

It is possible to eliminate the huge carrier rocket. Tsiolkovskii proposed the use of rockets combined with airplanes for interplanetary travel.* In
188 this case the force developed by the rocket supports the entire weight of the spaceship and accelerates it. Such a rocket is called a lifting rocket. On the other hand, the rocket designed by me rests in an airplane; the force developed by it must support only 1/3—1/7 the weight of the spaceship. Such a rocket is much easier to construct than the huge rocket proposed by Tsiolkovskii. The stresses in the material will be much smaller in my rocket than in a lifting rocket.

Moreover, use of the structural material of the airplane as propellant reduces the stresses in the spaceship since it is thus possible to replace part of the liquid propellant by solid structural material. The concomitant increase in the amount of structural material will make it possible to distribute the loads over larger cross sections of the girders. It is thus practically possible, by using the material as propellant, to reduce the weight of the spaceship [at takeoff] from 10 to 0.5 t (the weight of a small airplane). This ensures that the large velocities necessary for overcoming the gravitational attraction of the earth are attained. Use of the structural material as propellant also eliminates the need for employing high-power explosives.

The large acceleration in a lifting rocket causes the large apparent increase in weight, which forces the pilot to lie in a bath filled with liquid during the acceleration period. This is not necessary in my rocket since its acceleration is far smaller, and as a result the period of acceleration may be much longer than in a lifting rocket.

Both engine and rocket in the spaceship designed by me can be easily stopped and restarted during flight, so that this spaceship is very suitable
189 for experiments in which the flight altitude and speed are gradually increased.

The combination of a rocket with an airplane and the use of the structural material of the latter as propellant also eliminate the requirement of a sufficiently powerful explosive as mentioned by Ya. Perel'man.

No powerful explosive is needed in my rocket since it weighs only $\frac{1}{30}-\frac{1}{10}$ as much as the lifting rocket mentioned by Perel'man.

The obstacles to interplanetary travel, cited by Perel'man, are thus eliminated.

* In his letter to me dated 14 February 1927, F.A.Tsander writes that in this sentence the editor of the journal deleted the words "but not," i.e., "but not combined with airplanes." In other words, Tsander claims priority for the idea of winged rockets. However, reaction-propelled flying machines with wings had already been proposed earlier, e.g., by Lorin and Melot in France.

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(188)

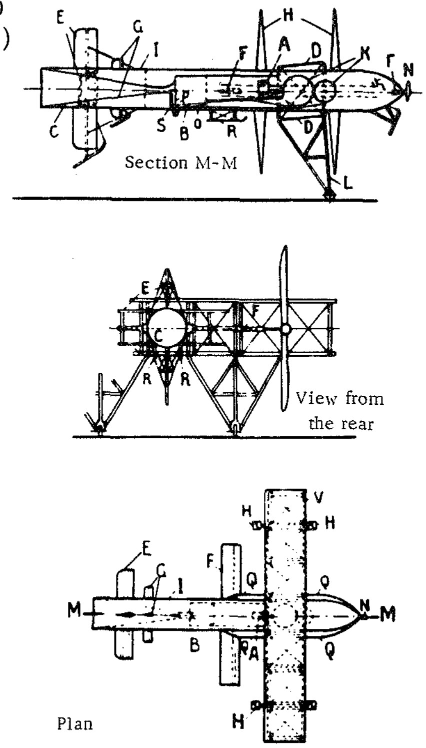

FIGURE 182. Tsander's rocket (schematic)

Figure 182 shows schematically the winged rocket designed by Tsander. No details of it are given. It may be assumed that two airplanes were to be combined with the rocket. One of them was a large biplane with four lateral propellers, elevator ***E***, rudder E_1, and undercarriage ***L***. After takeoff all these parts were to be pulled in and burnt. The return was apparently to be effected by means of the small monoplane ***F*** with undercarriage ***R***, rudder ***G***, and propeller *N* at the nose.

A drawing and a model (Figure 183) of Tsander's rocket were shown at the 1927 Exhibition of Interplanetary Machines in Moscow. It was stated that he had worked on it since 1922. The rocket was to ascend to a height of 7 km using wings. Thereafter the wings were to be pulled in and the rocket engine was to begin operating by burning the aluminum in pure oxygen. Landing was to be effected in a glide, as with an airplane. An engine consuming 1 g fuel per hp [sic] was to be used during takeoff and landing.

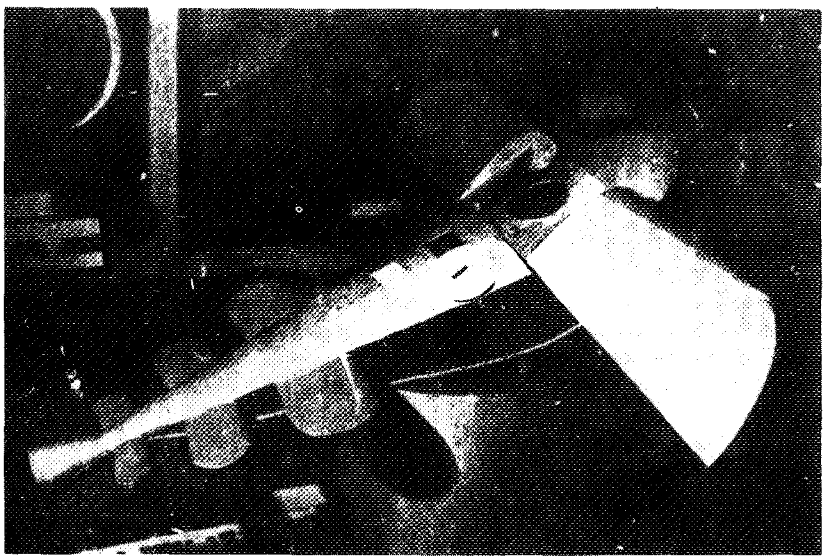

FIGURE 183. Tsander's rocket

Tsander's valuable contributions in the field of interplanetary communication make it desirable to know more about his work and his life. Upon my request Tsander was kind enough to send me his picture (Figure 184), taken on 28 March 1927, together with his autobiography which follows.

AUTOBIOGRAPHY OF FRIEDRICH ARTUROVICH TSANDER, MECHANICAL ENGINEER

I was born on 23 August 1887 in Riga, Latvia. My father was a physician of Russian citizenship, and a great lover of natural sciences. When I was a child, he and I often visited the Zoological Museum in Riga, where he was working at that time. The various exotic animals, in particular the birds, together with the stories he related which suggested that life in unknown forms might be found on other planets as well as on meteorites like those kept in the museaum, aroused in me, at a very early age, the wish to fly to the stars. As a boy, I was especially inspired by books and stories on astronomy and interplanetary travel.

FIGURE 184. F. A. Tsander

In 1905 I finished high school in Riga as best student of my class. From then until 1907 I studied at the Technical College of Danzig, Germany [now Gdansk, Poland] in the Department of Mechanical Engineering. From 1907 until 1914 I was a student at the Riga Polytechnical Institute, also in the Department of Mechanical Engineering, where I finished in June 1914, with distinction.

In 1908 I was twenty-one years old, officially an adult. I obtained a substantial sum of money and the first thing I bought was an astronomical telescope with an objective diameter of 4" and a length of approximately 1.5 m. At this time we, the students, organized the "First Russian Student Association for Aeronautics and Flight Technology" at the Riga Polytechnical Institute. I often mentioned to my friends that we should work on problems of flight to other planets. During the famous opposition of Mars in 1909, I often showed the planets and star clusters to my friends with the aid of my telescope.

In 1908 I made my first attempts in the field of interplanetary communication. I carried out some computations on the discharge of gas from a vessel, the work necessary for overcoming the attraction of the earth, and other subjects.

From 1914—1918 I worked in the rubber industry, first in Riga and later in Moscow, in order to gain knowledge of the manufacture of rubber articles,
191 rubber being a good vacuum seal.

Between 1915 and 1917 I carried out my first experiments on greenhouses of aircraftlike lightness, which might be used during flights to other planets. I achieved some success in raising vegetables (peas, cabbage, etc.) in flower pots filled with crushed charcoal, which is two or three times lighter than earth, instead of soil or sand. As fertilizer I used night soil.

After September 1917, when our plant ceased to work, I resumed my computations on flights to other planets, proceeding from the analysis of the flight of a special high-altitude airplane propelled by an airscrew. In order to impart a higher speed I added a rocket to the engine of this plane, and performed the relevant computation in that year. Thereafter I calculated the trajectories, flight durations, and speeds necessary for spaceships flying to other planets, as well as making other computations.

In February 1919, with great expectations, I started to work as Chief of the Technical Office at the No. 4 ("Motor") Government Aircraft Plant in Moscow. I began to use all my spare time to design an airplane capable of leaving the earth's atmosphere and attaining cosmic speeds, and also designed an engine for it.

At the end of 1920 I submitted a report on my engine to the Provincial Conference of Inventors in Moscow. The A. I. Z. (Association of Inventors) was approached, and much was said about my project of an interplanetary airplane spaceship. Lenin promised his support.

I then carried on my work more intensively, wishing to submit a project developed as far as possible. From the middle of 1922 until the middle of 1923, I worked at home in order to speed up the job. However, I got into financial straits and had to sell my astronomical telescope. Students at the Military Academy in the Kremlin became interested in it and bought it for the club of the V.Ts.I.K. (All-Union Executive Committee), thus enabling me to continue my work. My friends in the "Motor" plant also supported me, paying me an additional salary; this was the first sacrifice made for interplanetary communication.

Thereafter I began to work again, this time as consultant to the No. 4 ("Motor") Government Aircraft Plant, which in 1925 was renamed after Frunze.

192 In January 1924 I gave the first lecture on my interplanetary spaceship to the theoretical section of the Moscow Association of Friends of Astronomy. This lecture was a success.

In the fall and winter of 1924—1925, I delivered further public lectures in the form of debates, with great success. I thus gave 3 lectures in Moscow and one each in Leningrad (where the debate was chaired by Prof. Glazenapp), Kharkov, Saratov, Tula, and Ryazan. Later, I also gave lectures at the 2nd Aircraft Plant in Moscow.

I first published a paper in the "Tekhnika i Zhizn'", 1924, No. 13, under the title "Perelety na Drugie Planety" (Flights to Other Planets), which contained a short summary of my principal work.

In 1924 I took part in organizing in Moscow the Association for the Study of Interplanetary Communication, and was chosen a member of its Presidium. After a lecture given in Moscow by Prof. Lapirov-Skoblo, a list of members of the Association was set up. Approximately 150 persons registered within a short time. We gave lectures to the Association, which temporarily had its quarters in the M.O.N.O. Astronomical Observatory at No.13, 6 Lubyanka. The chairman of the Association was the writer Kramarov. Members also included such personalities as F. E. Dzerzhinskii, K. E. Tsiolkovskii, and Ya. I. Perel'man.

However, the lack of published material and of spare time did not permit us to work intensively. After existing for approximately one year the Association temporarily became inactive. The files and the library were handed over to the V.N.O.* in Moscow, which at the time took upon itself the initiative to open it.

I was married in fall 1923 to A. F. Milyukova. The children, although much loved (I had given them astronomical names, the daughter being called Astra and the son, Merkur), considerably slowed down the work.

At present I am preparing for print a book of approximately 500 pages, containing my computations on interplanetary communications. The calculations partly deal with a field not yet touched by other authors.

In fall 1924 I submitted to the Air-Force Academy in Moscow a summary of a lecture cycle which I proposed to give to the students of this institution. The lectures were not held then, but in the current year I have been invited to give them to the students of the senior courses. We hope that these lectures will lead to an increase in the number of people working in this field.

As far as I know I was the first to make the following suggestions:

1. To provide rockets with wings for flight in the atmosphere, for attainment of cosmic speeds of approximately 8 km/sec in the upper layers of the atmosphere, and also for landing in a glide upon return from interplanetary space to the earth or some other planet possessing an atmosphere.

2. To equip such an airplane rocket with engines for flight in the lower layers of the atmosphere, where the efficiency of rockets is very small due to the low flight speed. The engines should be of special design, it being best if they are designed to operate for half an hour without breakdown.

3. To simultaneously use rocket propellants giving solid and gaseous products of combustion. The first kind of propellant (particularly because
193 methods, proposed by others, of assembling rockets involve enormous initial weights and are therefore not cheaper but more dangerous than my airplane rocket, since the design of pure lifting rockets has not yet been studied) may consist of parts of the interplanetary spaceship, e. g., girders, surfaces, etc., made of alloys of aluminum, magnesium, lithium, etc. These parts become superfluous because of the weight reduction due to consumption of part of the propellant. It is thus an advantage that we can build a very strong spaceship capable of carrying a sufficient amount of propellant.

4. To use combinations of rockets and concave mirrors concentrating the sunlight inside the spaceship in order to increase the gas-outlet velocity, i. e., the power of the rocket during flight in interplanetary space.

5. To use a ring (solenoid) in which an electric current flows, and the pressure of the solar radiation on a cloud of iron filings maintained inside the ring by the electric current for propulsion in interplanetary space. It is an advantage that meteors passing through this cloud will scarcely affect the flight.

6. To concentrate the sunlight in parallel beams by means of huge convex and concave mirrors designed as described under point 4, in order to obtain high speeds and permit flights to other solar systems (at present this is the only possible method which offers hope for such flights).

* [Military Scientific Organization].

7. To use a sphere made of very thin metal sheets, charged by the earth's electricity and repelled from it by electrostatic forces, for the purpose of interplanetary flight. This is possible if the earth carries an electric charge.*

8. To circle round a planet in- or outside its atmosphere in order to increase the flight speed (obtaining energy gratuitously during flight to other planets); to accelerate the interplanetary spaceship when its flight speed is high (for the same purpose).

9. To deflect meteors by means of electrostatic energy emitted by the spaceship as cathode rays in the direction of the meteors, the spaceship being located inside an electrically charged sphere.

I have several other suggestions to make on the design of interplanetary spaceships, their engines, rockets, etc., as well as other proposals which I have not yet worked out sufficiently.

Moscow, 12 March 1927. Signed: F. A. Tsander

THE WORK OF AL'KO AND S. DE STEFANO

Some short notes on rocket flight in interplanetary space were published by Al'ko in "Tekhnika i Snabzhenie Krasnoi Armii." In particular, No. 159, 1924 contains the following report:

94 DETERMINATION OF THE GUNPOWDER CHARGE NEEDED FOR PROPELLING A MASS OF ONE KILOGRAM TO THE MOON BY MEANS OF A ROCKET (NEGLECTING DRAG)

The work which has to be performed in overcoming gravity is $6.3 \cdot 10^6$ kgm.

The work developed by 1 kg of gunpowder equals 429,000 kgm.

The rocket must carry the charge with it. Let x be the weight of the charge, which decreases to zero during burning. Its mean weight thus is $x/2$ kg. Thus lifting a weight of 1 kg requires a charge weighing $\frac{6.3 \cdot 10^6}{429 \cdot 10^3} \cong 14.7$ kg. Assuming the rocket efficiency to be approximately 1/3, we obtain $3 \cdot 14.7 \cong 45$ kg $= x$.

Lifting a charge weighing x/2 requires an additional $45 \cdot 45/2 \sim 1{,}015$ kg of gunpowder, so that the total amount of gunpowder required is $1{,}015 + 45 =$ $= 1{,}160$ kg.

WEIGHT OF A ROCKET FOR FLIGHT FROM THE EARTH TO THE MOON AND BACK

The Italian General Antonio De Stefano found on the basis of his computations that carrying a cabin containing one person and weighing 0.3 *t*

* This had already been proposed by Yamato in 1924.

altogether, to the moon and back to the earth, would require that the spaceship with the propellant weigh 150 t at takeoff from the moon. The spaceship would have to weigh 75,000 t in order to carry these 150 t from the earth to the moon at a gas-outlet velocity of 2,000 m/sec. The spaceship would have to weigh 120 t at takeoff from the earth and 6 t at takeoff from the moon in order to carry a payload of 0.3 t to the moon and back to the earth at a gas-outlet velocity of 5,000 m/sec.

f) Hohmann's spaceflight project

In his book "The Attainability of Celestial Bodies" (Munich, 1925) the German engineer Walter Hohmann investigated the possibility of rocket flight in interplanetary space, in particular to the moon, Venus, and Mars. He also studied the conditions under which a rocket missile could land upon return to the earth.

We shall subsequently present the principal results of his investigations. A complete translation of his book will be given in a separate volume.

His book contains 5 chapters:

1. Takeoff from the Earth
2. Landing on the Earth
3. Free Flight in Space
4. Flying Around Other Celestial Bodies
5. Landing on Other Celestial Bodies.

Takeoff from the earth: Hohmann investigated the influence of varying the acceleration of the rocket missile during takeoff, allowing for gravity at different gas-outlet velocities. The results of his calculations are given in Table 1 reproduced below, in which, however, drag has been neglected.

In establishing this table Hohmann assumed that the gravitational acceleration of the earth is constant, being equal to $g_m = \frac{2g_0 + g_1}{3}$, where g_0 is the gravitational acceleration on the surface of the earth, and g_1 is the gravitational acceleration at a distance r_1 from the center of the earth.

He furthermore assumed the mass discharged at any instant to be proportional to the residual mass of the missile, the gas-outlet velocity being taken as constant.

The final speed v_1 given in the table corresponds to the case where acceleration of the missile ceases at a distance r_1 from the center of the earth, without the missile returning to the earth under the effect of gravity.

Hohmann assumed that the maximum acceleration tolerable for human beings is 30 m/sec^2. He also assumed a gas-outlet velocity of 2,000 m/sec; the ratio of the initial to the end mass of the missile (at the end of acceleration) is then 825 according to the table, if drag is neglected.

The takeoff conditions change when drag is taken into account. The acceleration is then reduced by approximately 2.4 m/sec^2 and will thus be 30 − 2.4 = 27.6 m/sec^2. This also increases the ratio of the initial to the end mass of the missile, which for different accelerations and gas-outlet velocities is given in Table 2.

TABLE 1. Flight from earth, neglecting drag

Acceleration of missile, m/sec^2		15	20	25	30	40	50	100	200
Distance r_1 from center of earth, km		10,600	9,510	8,860	8,490	7,950	7,640	7,000	6,680
Flight speed v_1 at end of gas discharge, m/sec		8,660	9,150	9,470	9,680	10,000	10,200	10,650	10,890
Flight duration t_1 until end of gas discharge, sec		1,192	762	565	448	319	248	117	57
Ratio of initial to end mass (at burnout) of missile ($\frac{m_0}{m_1}$) at gas-outlet velocity C.	C = 1,000 m/sec	58,700,000	4,160,000	1,545,000	675,000	346,000	240,000	120,300	89,130
	C = 1,500 "	149,000	25,000	12,000	7,750	4,950	3,840	2,400	2,000
	C = 2,000 "	7,570	2,010	1,160	825	587	495	347	299
	C = 2,500 "	1,270	438	282	216	164	143	108	95.5
	C = 3,000 "	388	159	110	88	70	62	49	44.7
	C = 4,000 "	87.3	44.8	34.1	28.7	24.2	22.	18.7	17.2
	C = 5,000 "	35.7	20.9	16.7	14.6	12.8	11.9	10.4	9.8
	C = 10,000 "	6.0	4.6	4.1	3.8	3.6	3.5	3.2	3.1

TABLE 2. Flight from earth, allowing for drag

Acceleration, m / sec^2		30	100	200
Takeoff duration, t/sec		456 instead of 825	123 instead of 117	64 instead of 57
Gas-outlet velocity C, m/sec	C = 2,000	933 " 825	468 " 347	602 " 299
	C = 2,500	235 " 216	138 " 108	166 " 95.5
	C = 3,000	95 " 88	60 " 49	71 " 44.7
	C = 4,000	30 " 28.7	22 " 18.7	25 " 17.2
	C = 5,000	15 " 14.6	12 " 10.4	13 " 9.8

Hohmann uses the value 933 in his further computations.

Landing on the earth. To facilitate landing on the earth Hohmann proposes that the missile, re-entering from space at a speed of 11.1 km/sec, be equipped with a braking surface retarding its flight in the terrestrial atmosphere, and that landing itself be effected spirally and not radially, thus describing gradually decreasing ellipses about the earth. Their perigees would be at an altitude of 75 km, the flight speed being gradually reduced until it was sufficiently low to allow for a safe landing on the earth from a glide.

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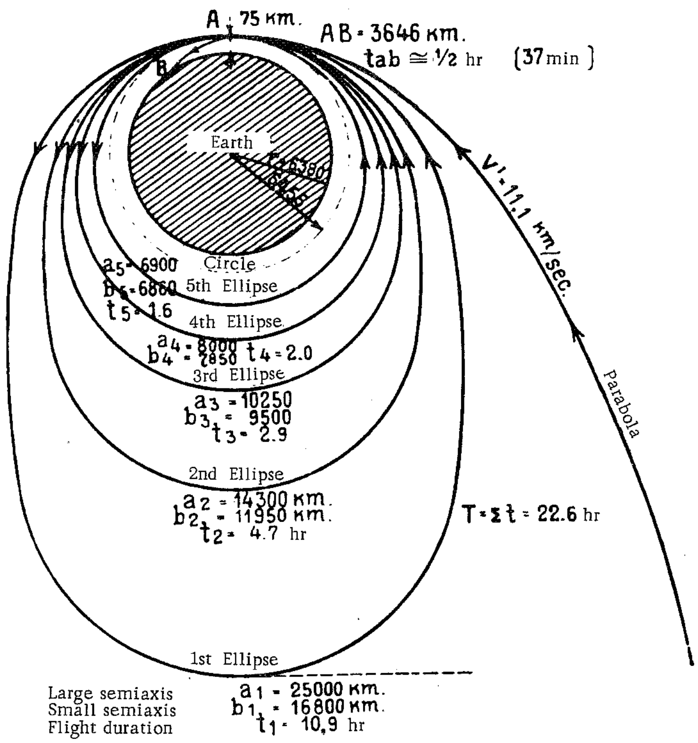

FIGURE 185. Landing of rocket missile on earth, according to Hohmann

Figure 185 shows these ellipses. The flight speed of the missile at point A, at an altitude of 75 km, is as follows for the different ellipses:

Parabolic approach, v' . .	11.1 km/sec
1 ellipse	10.4 "
2 "	9.8 "
3 "	9.2 "
4 "	8.6 "
5 "	8.1 "
Circle	7.85 "

The last speed value corresponds to motion of the missile around the earth in a circle, drag being neglected. Thereafter the flight goes over into a glide extending over a distance AB equal to 3,646 km.

Figure 185 gives the dimensions of the ellipses and the durations of flight along them. The entire landing procedure takes 22.6 hr.

Hohmann also considered the direct transition from a parabola to a circle at an altitude of 75 km. For this it is necessary to travel in the
198 terrestrial atmosphere over a distance of 2,000 km in 3.63 min at a decreasing speed. Landing is effected in a glide, as described before when the speed has been reduced to 7.85 km/sec, corresponding to free flight along a circle. However, this involves a large deceleration and heating of the missile. The danger caused to the walls of the missile by heating due to friction with the air may, according to Hohmann, be eliminated by means of external fins which increase the heat-transmission surface. This also raises the number of turns made about the earth, namely for a speed

from	11.1 — 7.85	km/sec	6	turns
"	7.85 — 4	"	3.5	"
"	4 — 0	"	0.5	"
		Total	10	"

It is in this case assumed that the entire energy lost during braking is converted into heat and absorbed by the missile. In reality the number of turns will be somewhere between 5 and 10.

Free flight in space: On the basis of the computations performed by Hohmann in the first chapter of his book, he determined the speed v_1 (at the end of gas discharge) at which the missile moves away from the earth without returning to it. Return to the earth necessitates corrective bursts during free flight, which alter the flight speed. Thus, the missile can be prevented from flying farther than 800,000 km from the earth, and will return to it directly if the speed is reduced before this point. The weight of propellant needed for this is 0.11 times the weight of the missile. The latter will not return to the earth but continue to fly around it in an ellipse if the course is corrected at a distance of 800,000 km from the earth, by using an amount of propellant whose weight equals 0.09 times the weight of the missile; the corresponding change in speed is 0.09 km/sec.

Space flight with return to the earth along an ellipse will take place as follows:

1. Termination of the acceleration of the missile at an altitude of 8,490 km (cf. Table 1 for an acceleration of 30 m/sec^2).
2. Flight from this point until the return begins at a distance of 800,000 km from the earth. The duration of this stage is 349 hr.
3. Return flight along an ellipse from a distance of 800,000 km to an altitude of 6,455 km (beginning of braking). The duration of this third stage is 354 hr.

The total flight duration thus is

Ascent during 8 min ≅	0.2	hr
Free flight: 349 + 354 = ...	703	"
Landing	22.6	"

Total approximately 30.2 days, i. e., about 1 month.

199 Weight and shape of missile.

Assuming a flight duration of 30 days, Hohmann determined the weight of the cabin and of the supplies necessary for two persons, as follows:

Weight of missile head calculated for flight lasting 30 days:

		kg
a)	Two persons together with clothing and personal requirements	200
b)	Food and water for two persons at 4 kg/d per person for 30 days:	240
c)	Kerosene for heating the missile for 30 d and for heating the liquid oxygen $(1.7 + 0.3 = 2\ kg/d)$	60
d)	Oxygen for breathing for two persons at 0.6 kg/d per person and for burning kerosene at 2.7 kg oxygen/kg kerosene $(2 \cdot 2.7 + 2 \cdot 0.6 = 6.6\ kg/d)$ for 30 days	200
e)	Vessels for the storage of liquid oxygen and supplies at 0.4 and 0.2 times the respective weights: $200 \cdot 0.4 + (240 + 60) \cdot 0.2$	140
f)	Braking surfaces (6 m^2), lifting surfaces (59 m^2), rudder (5 m^2), nose surface (10 m^2) at 3 kg/m^2: $6 + 59 + 5 + 10 = = 80\ m^2,\ 80 \cdot 3$	240
g)	External shell of missile (14.45 m^2) at 50 kg/m^2.	780 [sic]
h)	Propellant for course corrections	200
	Total . .	2,260 [sic]

Assuming that three course corections will be necessary after the end of acceleration, during each of which 1/10 of the entire weight will be consumed, we obtain the weight of the missile head after the end of acceleration as $2{,}260 \cdot 1.1^3 = 3{,}000$ kg.

At the beginning of the landing glide upon return to the earth the weight will be

$$3{,}000 - 740 - 240 - 60 - 200 = 1{,}760\ \text{kg}.$$

Figure 186a shows the entire missile with its head (on top) and the propellant charge (shaped like a tower becoming wider toward the bottom).

Figure 186b shows the missile head separately with two persons. Its nose points downward. Lastly, Figure 186c shows the missile during reentry from interplanetary space into the terrestrial atmosphere. The drawing shows the open parachute (F_1), the lifting surface (F_0), and the rudder (F). The dimensions are indicated on the drawing.

The following data were assumed as given when determining the dimensions of the rocket:

Weight of missile head with payload, as shown above: 3,000 kg = 3 t.

Specific weight of propellant: 1.5 t/m^3.

Acceleration during ascent: 30 m/sec^3.

Gas-outlet velocity: $c = 2{,}000$ m/sec.

Ratio of initial to end mass (cf. Table 1): 933.

The shape of the propellant charge was found by assuming a uniform compressive stress of 1.85 kg/cm^2 in all cross sections.

Total weight of missile at takeoff = $3 \cdot 933 = 2{,}799$ t.

200

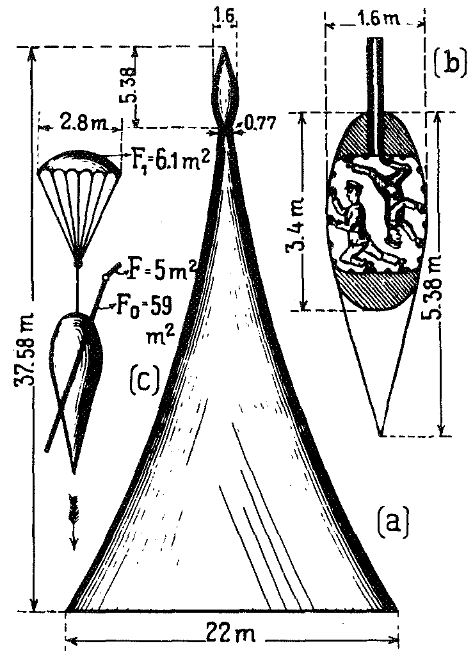

FIGURE 186. Hohmann's rocket

Turning of missile head during flight (Figure 186b).

Changing the flight direction of the missile head necessitates turning the latter in such a manner that the nozzle points exactly the other way. Hohmann proposed that a person inside the missile head should for this purpose move in a suitable direction while clutching a handrail secured to the inner face of the wall. The missile would then turn in the opposite sense until it was in the desired position. It would then be possible to adjust the speed as required by means of corrective bursts.

FLIGHT AROUND OTHER CELESTIAL BODIES

a) **Flight around the moon** is possible by coasting, as described before, after attaining a distance of 800,000 km from the earth; this figure is almost 3 times the distance between the moon and the earth. The flight should be timed so that at the maximum distance of the missile from the earth the moon passes between the latter and the sun. The flight should be directed toward the sun, so that the illuminated earth and moon can be seen.

b) **Flight around Venus**. If the missile, after reaching a distance of 800,000 km from the earth, changes its speed by some other value than the 0.09 km/sec necessary for return to the earth, it will either approach the
201 sun or increase its distance from it, depending on the sign of the change. Thus, if the speed is reduced by 2.4 km/sec the missile will describe an ellipse which is tangent to the orbit of Venus. For this it is necessary to

use an amount of propellant whose mass is 3.65 times the mass of the missile at that instant (at $C = 2{,}000$ m/sec).

Return to the earth must be in accordance with the rotation of the earth and Venus around the sun. Two possibilities exist in this case: 1) to fly to the orbit of Venus, become its satellite, circle around it several times, and having spent there some time, return along an elliptic arc to the earth. This requires 2.15 years, the ratio of the initial to the end mass of the missile being 83,000; 2) to fly to Venus, return to the earth's orbit, intersect it and continue further, and then return to the earth's orbit along a tangent to the point at which, according to the computations, the earth should be at the time of landing. This requires 1.58 years, the ratio of the initial to the end mass of the missile being 82,000 (at $C = 2{,}000$ m/sec).

c) **Flight around Mars** is similar to flight around Venus. It is only necessary to increase, instead of decreasing, the flight speed at a distance of 800,000 km from the earth. The duration of the flight will be approximately 1½ years. The weight of the entire missile at takeoff from the earth (assuming the missile head and payload to weigh 16.72 *t* at takeoff) will be

at $C = 2$	km/sec	567,000 *t*
" $C = 2.5$	"	69,500 "
" $C = 3$	"	17,600 "
" $C = 4$	"	3,150 "
" $C = 5$	"	1,130 "

LANDING ON OTHER CELESTIAL BODIES

a) **Landing on Venus.** Flying from the earth to Venus and landing on the latter requires 176 days. The weight of the missile with the propellant will be as follows:

Initial weight of missile head (crew, head, stores) . . . . . . 7 *t*
Weight at landing on Venus . . . . 3.5 *t*
Initial weight of entire missile

at $C = 2$	km/sec	54,800 *t*
" $C = 2.5$	"	8,800 "
" $C = 3$	"	2,800 "
" $C = 4$	"	620 "
" $C = 5$	"	260 "

However, if it is necessary to carry propellant also for the return to, and landing on the earth, the initial weight of the entire missile will be

at $C = 2$	km/sec	670,000,000 t
" $C = 2.5$	"	17,000,000 "
" $C = 3$	"	1,600,000 "
" $C = 4$	"	74,000 "
" $C = 5$	"	1,240 "

b) **Landing on Mars.** Flying from the earth and landing on Mars requires 265 days.

Weight of missile head at takeoff from earth . . . . 9 *t*
" " " " " landing on Mars . . . . 3.2 *t*

202 The weight of the entire missile at takeoff from the earth will be:

Gas-outlet velocity	For flight to Mars only, *t*	For return flight to earth (propellant stored on Mars), *t*
C = 2 km/sec	875,000	1,430
C = 2.5 "	76,500	515
C = 3.0 "	15,000	265
C = 4 "	2,200	118
C = 5 "	690	71

c) **Landing on the moon.** Flying from the earth to the moon requires 15 days.

Initial weight of missile head with stores . . . . 2.6 *t*.

Initial weight of the entire missile at takeoff from the earth will be:

Gas-outlet velocity	Flight to moon only	Flight from moon to earth (propellant stored on moon)	Flight from earth to moon carrying propellant for return to earth
C = 2 km/sec	8,250 *t*	8.9 *t*	28,000 *t*
C = 2.5 "	1,610 "	6.9 "	4,250 "
C = 3 "	555 "	5.9 "	1,250 "
C = 4 "	144 "	4.8 "	890 "
C = 5	64 "	4.3 "	700 "

d) The ease with which takeoff is possible on the moon offers the advantage of using it as a station during flight to other planets. The following table gives the initial weight in tons of the missile for flight from the moon.

Gas-outlet velocity (C) km/sec	Circular flight moon – Venus – Mars without landing on these planets	Flight moon – Mars with landing on latter	Flight moon – Venus with landing on latter	Flight moon – Mars with landing on latter, propellant for return stored on moon	Flight moon – Venus with landing on latter, propellant for return stored on moon
C = 2.0	2,070	3,190	200	75,000	290,000
C = 2.5	780	860	99	11,800	36,300
C = 3	417	370	67	3,600	9,900
C = 4	194	136	38	850	1,780
C = 5	124	76	29	360	680

The various results obtained by Hohmann are compared on p. 198.

203 THE RESULTS OF ESNAULT-PELTERIE'S COMPUTATIONS

In his book "L'exploration par fusées de la très haute atmosphère et la possibilité des voyages interplanétaires," Paris, 1927, p. 29, Esnault-Pelterie computed $\left(\frac{M_0}{P}\right)$ the ratio of the initial to the end mass (payload) of a spaceship. He assumed that a manned missile flies at a constant acceleration until it attains an altitude y_c at which its speed is v_c, the time elapsed being t_c. He considered 3 values each of Γ and of the drag coefficient.

He gave the following values of $\frac{M_0}{P}$ for different gas-outlet velocities v and accelerations Γ:

Γ	k	y_c km	v_c m/sec	t_c sec
10 g	0.1	637	10,660	120
2 g	0.5	3,185	9,133	750
1.1 g	0.91	5,800	8,080	36'40"

v m/sec	$\Gamma = 1.1\ g$	$\Gamma = 2g$	$\Gamma = 10g$
2,000	143,000	1,574	358.5
2,500	13,270	361.3	110.6
3,000	2,700	135.2	50.5
3,500	883	67.1	28.8
4,000	378	39.7	18.9
4,500	196	26.3	13.6
5,000	115	19.1	10.5
6,000	52.2	11.6	7.10
7,000	29.7	8.19	5.37
8,000	19.4	6.30	4.35
9,000	14.0	5.13	3.69
10,000	10.7	4.36	3.24

In "Z. F. M.," 1928, pp. 319, 367, H. Senftleben developed the theory of the takeoff of rockets in airless space and determined the conditions under which propellant consumption is minimum.

g) Comparison of the work of K. Tsiolkovskii, Esnault-Pelterie, Oberth, Goddard, and Hohmann

We have presented the theoretical studies of different scientists concerning the flight of rockets in interplanetary space. It is therefore of interest to compare the assumptions on which their computations are based, as well as the results obtained when these assumptions are more or less the same. These data have been tabulated on p. 200.

Comparison of results obtained by Hohmann for various cases of rocket flight

Route	Permissible acceleration during flight, m/sec^2	Flight duration	Initial weight of missile head
Takeoff from earth and flight to infinity, neglecting drag	15	1,192 sec	1 t
	20	762 "	
	25	565 "	
	30	448 "	
	40	319 "	
	50	248 "	
	100	117 "	
	200	57 "	
The same, allowing for drag	30	456 "	1 t
	100	123 "	
	200	64 "	
Flight from earth to a distance of 800,000 km and return to earth (flight around moon)	30	30 1/5 days	3 t
Takeoff from earth, flight around Venus, landing on earth	30	2.15 years	1 t
	30	1.58 "	1 t
Takeoff from earth, flight around Mars, landing on earth	30	1.5 "	16.72 t
Flight from earth to Venus and landing on Venus	30	176 days	7 t
Flight from earth to Venus and back, carrying propellant for return trip	30		2 persons with supplies
Flight from earth to Mars and landing on Mars	30	265 "	9 t
Flight from Mars to earth (propellant stored on Mars) and landing on earth	30		
Flight from earth to moon and landing on moon	30	15 "	2.6 t
Flight from moon to earth and landing on earth (propellant stored on moon)	30		2.6 t
Flight from earth to moon, landing on moon, return to earth (propellant stored on earth)	30		2.6 t
Flight from moon around Venus and Mars without landing on them, return to moon	30		2 persons with supplies
Flight from moon to Mars and landing on Mars	30		the same
Flight from moon to Venus and landing on Venus	30		"
Flight from moon to Mars, landing, and return to moon (all propellant stored on moon)	30		"
Flight from moon to Venus, landing, and return to moon (propellant stored on moon)	30		"

x x

Initial weight of entire missile at various gas-outlet velocities C, m/sec							
1	1.5	2	2.5	3	4	5	10
58.700,000	149,000	7,570	1,270	388	87.3	35.7	6.0
4,160,000	25,000	2,010	438	159	44.8	20.9	4.6
1,545,000	12,000	1,160	282	110	34.1	16.7	4.1
675,000	7,750	825	216	88	28.7	14.6	3.8
346,000	4,950	587	164	70	24.2	12.8	3.6
240,000	3,840	495	143	62	22.2	11.9	3.5
120,300	2,400	347	108	49	18.7	10.4	3.2
89,130	2,000	299	95.5	44.7	17.2	9.8	3.1
		933	235	95	30	15	
		468	138	60	22	12	
		602	166	71	25	13	
		2,799					
		83,000					
		82,000					
		567,000	69,500	17,600	3,150	1,130	
		54,800	8,800	2,800	620	260	
		670,000,000	17,000,000	1,600,000	74,000	1,240	
		875,000	76,500	15,000	2,200	690	
		1,430	515	265	118	71	
		8,250	1,610	555	144	64	
		8.9	6.9	5.9	4.8	4.3	
		28,000	4,250	1,250	890	700	
		2,070	780	417	194	124	
		3,190	860	370	136	76	
		200	99	67	38	29	
		75,000	11,800	3,600	850	360	
		290,000	36,300	9,900	1,780	680	

Author	Tsiolkovskii	Valier	Esnault-Pelterie	Goddard		Oberth (allowing for safe landing)	Hohmann (allowing for safe landing)	
Permissible gas-outlet velocity, km/sec . . .	5.7	4.0	65.3	3.63	2.134	3.0	5.7	2.0
Permissible acceleration in flight, km/sec^2 . . .	100		10.8	45.7	45.7	40	100	30
Ratio of initial to end weight of missile for following routes: Takeoff from earth and flight to infinity	9			43.5	6.02	approx. 200	~10	933
Takeoff from earth and landing on moon . . .	9	12.1						8,250
Takeoff from earth and becoming its satellite .	5							
Takeoff from earth, circling moon, landing on earth	<9					approx. 200		933
Takeoff from earth for flight to outer planets (Mars)	>9							875,000
Takeoff from earth for flight to inner planets (Venus)	21							54,800
Takeoff from earth, flight to Mars, return to earth	21							
Takeoff from earth and flight to another solar system	10,000							
Takeoff from earth, flight to moon, landing, and return to earth using retro-rockets . .			1.43					

h) **Design of large rockets in Russia**

Rumors about the designing of a large rocket at the Air-Force Academy in Moscow have appeared in various publications. We present 3 of these reports.

1. R. Lademann stated in "Die Luftwacht," 1928, p. 372, that Prof. Vetchinkin in Moscow presented plans of unmanned and manned rockets in 1925 and 1926.

2. "Illustrierte Flugwoche," 1926, p. 596.

The Association for Interplanetary Flight at the Air-Force Academy (Petrovskii Palace, Leningrad Chaussee, Moscow) is doing research, and designing an experimental model of an unmanned rocket. The propellant is to be liquid hydrogen and oxygen. The rocket head carries an explosive which emits a strong flash, in accordance with Goddard's suggestion. This flash should be observed when the rocket lands on the moon. An important part of this work is provided by Prof. V. P. Vetchinkin. The rocket is to be about 60 m long with a diameter of approximately 8 m. It is to be built of boiler plates welded together electrically.*

207 3. Some details on the rocket missile built in Moscow between 1922 and 1926 were given by M. Kol'tsov in his paper "Vokrug sveta za Poltinnik" (Around the World for 50 Kopeks) published in "Aviatsiya i Khimiya," 1927, No. 1.

He describes this missile in the form of an imaginary report in the provincial press:

The construction of a missile for interplanetary travel has been completed at the Moscow airport. The missile has an old-fashioned shape and is 107 m long. Its shell is made of fire-resistant light alloy. It contains a cabin with a reservoir for compressed air, as well as waste-air purifier. The missile tail contains the propellant mixture. Flight will be according to the rocket principle... After entering the gravitational field of the moon the rocket will approach its surface at a terrific speed; to reduce the speed the travelers must effect small bursts with the rocket.

Construction of the rocket has already taken 4 years. Italian engineers were engaged for this purpose. The work is being carried out under the direction of Tsiolkovskii and Engineer Tsander...

This report has been copied from the "Karel'skaya Kommuna."

i) The First World Exhibition of Interplanetary Machines and Mechanisms in Moscow (68 Tverskaya St., April to June 1927)

The First World Exhibition of Interplanetary Machines and Mechanisms was held in Moscow between April and June 1927 by the Association of Inventors.

The organizers of the exhibition were O. Kholoshchev, I. Belyaev, A. Suvorov, G. Polevoi, and Pyatetskii. Despite financial and other difficulties they managed to collect interesting and valuable material for this exhibition, obtain information from many Russian and non-Russian researchers concerned with interplanetary communications, and process and present this information interestingly and clearly to the general public in the form of diagrams, models, drawings, etc. Moreover, after the exhibition had been closed, the organizers published, as an account of it, a very elegant album with pictures of the exhibits, descriptions of the latter, and reviews by visitors.

In view of the great interest value of this account, we present a description and some of the contents of this album, a copy of which was kindly put at my disposal by the Association.

The material sent to me includes the following:

1. A letter from the Association.
2. A poem by Sergeevich, dedicated to the inventors.
3. Greetings to the Circle for the Exploration and Conquest of Space, by Academician Grave.
4. An album with 45 photographs of exhibits.
5. A short description of the designs of interplanetary spaceships.
6. Some reviews by visitors to the exhibition.

The contents of this material follows.

* Cf. also notes on this rocket in vol. No. 1 of our work "Mezhplanetnye Soobshcheniya." Mechty, Legendy i Pervye Fantazii" (Interplanetary Flight and Communication: Dreams, Legends, and Early Fantasies), Leningrad, 1928, p. 12.

208 1. **Letter from the Association**

A. I. Z.
Association of Inventors
Technical Sector No. 285
68 Tverskaya St., Moscow
Tel. 95-98
16 January 1928

Dear Comrade Rynin,

We are sending to you, as historian of interplanetary travel, a small album with photographs from the Exhibition of Interplanetary Machines and Mechanisms which closed after having been open to the public for 2 months. However, there remains an interplanetary section which organizes groups for the study of these problems.

The exhibition was not particularly large and did not receive any special support by the authorities responsible for information, who claimed that this matter was still premature and problematical and would stir up the masses and to a certain degree the press, which until now had not seriously treated the problems of interplanetary technology.

The many people who visited the exhibition showed great interest in these problems and offered valuable suggestions concerning further developments in this field. This was a result of the simple and clear explanations given by the guides at the exhibition (as can be judged from the reviews, some of which we are sending to you as additional information), and by a series of lectures held on this subject in Moscow and other cities of the USSR. We can supply you with copies of the reviews of the lectures should you so desire. The album has been supplemented by a brief explanation of all the projects of the various inventors. Please inform us if this is not sufficient, and we shall try, to the best of our ability, to supply the information in which you are interested.

We can also send you Tsiolkovskii's publications, especially his latest works, should you not be in possession of them.

If it is not inconvenient for you, please inform us what you have accomplished in this field. Surely, you possess much material on these subjects. When you finally publish your esteemed work, it will no longer be science fiction but active realism, almost an everyday occurrence.

This long cherished idea is not far from being realized, and the inventor will again show that only he can do for civilization that which advances humanity. We send you a poem dedicated to the inventor, composed by us.

With interplanetary greetings
A. I. Z. Planner: Ibtsabi

Stamp.

The stamp has 3 concentric circles containing the following words:

Outer circle: Association of Inventors to Inventors (in Russian and English).

Center circle: Asociacio de la inventistoj la inventistoj [same meaning in Esperanto]

× 21 + 0 XV 105 5 + 2 XV 105 (in AO language)

Inner circle: Concentration point of all-inventiveness of the earth's meridian of all inventors.

2. **Poem by Sergeevich**

"Dedicated to the Inventor"

Inventor, up, up
You must invent everything,
Amongst cultural lull
You are on the right path. . . .
It would be a defeat,
As you would be the first to realize,
If between you and the planets
Somebody, something, somewhere were to stand.
You are ultraidealistic
You must recreate everything,
With your inventiveness
You will conquer the Universe.
Forward, forward, with a free body,
Free heart and mind,
And let your brave inventions
Change everything around you.
Let skyscrapers rise,
Over oceans throw bridges. . . . . . .
And let all worlds hear about this
That all this has been created by you alone. . . .
You make distances vanish,
You make day and night vanish,
You will change everything in the Universe
And drive nature away.
When the motto of your dreams
Will fuse with the right to possess everything
You will be emperor of the conquests
And will be able to fly anywhere. . . .
You will be invaluable,
All the worlds will know you,
You are a citizen of the Universe
And will conquer all.

3. **Greetings from Academician Grave to the Circle for the Study and Conquest of Space**

(This letter will be reproduced in the third book in connection with projects for utilizing radiant energy in space). *

4. **Album with 45 photographs of exhibits**

The album contains the following photographs:
1. The surface of the moon with view of the earth
2. The organizers of the exhibition
3. A foreign transcription
4. The corner of the AO language (principles of a new language proposed by the Association)

* N.A.Rynin "Mezhplanetnye Soobshcheniya. Luchistaya Energiya v Fantaziyakh Romansistov" (Interplanetary Flight and Communication: Radiant Energy—Science Fiction and Science Projects). Soikin's Publ. House, 1929.

5. Press reviews of the exhibition and of the AO language
6. The astronomical part
7. Aviation and aeronautics
8. Overall view of some parts
9. Scientific-fantastic and scientific-realistic part
10. Planning and invention (theoretical part)
210 11. Period of invention and design
12. Period of invention and design, and Fedorov corner
13. Corner of Jules Verne and Wells
14. Corner of Kibal'chich (USSR), student and national liberator
15. Corner of inventor Tsiolkovskii (USSR), from right
16. The same, from left
17. Bust of Tsiolkovskii
18. Corner of inventor Goddard (USA)
19. Corner of inventor Oberth (Austria and Germany)
20. Corner of inventor Max Valier (Germany)
21. Publications and illustrations of inventor Max Valier (Germany)
22. Model of rocket invented by Max Valier (Germany)
23. Models of rockets invented by Esnault-Pelterie (France), Welsh (U.K.), and Graffigny (France)
24. Model of rocket invented by Ulinski (Austria)
25. Corner of inventor Polevoi (USSR)
26. Model of rocket car and scheme of space station designed by Polevoi (USSR)
27. Cross section of Polevoi's rocket car
28. Model of rocket invented by Fedorov (USSR) (closed)
29. The same (open)
30. The same, schematic longitudinal section
31. The same, engine compartment
32. The same, temperature regulator
33. Corner of inventor Krein
34. Model of rocket invented by Tsander (USSR)
35. Corner of inventor Tsander (USSR)
36. Overall view of spacesuit (suit for traveler in interplanetary space)
37. Caricatures of inventions (man riding on rocket)
38. Mountains and craters on moon
39. Sun eclipse seen from moon
40. Rocket passing through star clusters
41. Rocket passing through spiral nebulas
42. Rocket passing through a meteor stream
43. Rocket passing through cosmic radiation
44. Telegraphy by interplanetary ships from space to earth by means of radio waves and sunlight
45. Enigmatic phenomena occurring in upper layers of atmosphere.

5. Short description of interplanetary spaceships design

The exhibits are described briefly. Since we have given details of the latter at various places in this book, we shall only list these descriptions and indicate some special points. *

* N.Rynin,"Kosmicheskie Korabli v Fantaziyakh Romanistov" (Spacecraft in Science Fiction), P.Soikin's Publishing House, 1928.

1. Scientific-fantastic period (Jules Verne and Wells).
2. Scientific-realistic period (Kibal'chich).
3. Planning and invention period (theoretical) (Tsiolkovskii's work).
4. Invention and design period (Goddard).

211 An assessment of the various types of "rockets", and of the methods of launching them is given, the danger of lifting by airship is demonstrated, and hope is placed in the electrochemical method of using propellants (splitting of atoms) [this would now be termed "use of nuclear energy"]. The different types of propellant (liquid, solid, and liquid in combination with solid) are compared. Various engine types are described, such as turboprop and turbojet engines.

Machines designed by Tsiolkovskii, Ulinski, Graffigny, Fedorov, Esnault-Pelterie, Polevoi, Oberth, Goddard, Valier, Welsh, Tsander, and Krein are described. It is mentioned that Goddard launched a rocket to a height of 15 km.

The description ends with the greeting

"With interplanetary greetings
The Interplanetary Section of the
Association of Inventors."

6. Some reviews of visitors to the exhibition

Almost all reviews are favorable to the exhibition, express interest in the idea of interplanetary travel, and only indicate regret that the premises were small. We give the contents of some reviews chosen at random.

1. Excursion of the local trade union of the Apakovsk Tramways:
   "Having seen the exhibition, we can state that it is useful, but we find that its premises are too small and that insufficient means were made available for its establishment. In addition, a number of visitors, acquainted with Tsiolkovskii's work, consider it necessary to increase his pension. We, together with the Donbas workers, consider it necessary to supplement the exhibition not only with models but also with originals, e. g., telescopes, etc. We would consider it desirable if the lecturer would use Russian instead of foreign words in his explanations."
2. Prof. Orlov:
   "I have looked at the exhibits with great interest."
3. Electrical Engineer Mal'tsev:
   "The exhibition of interplanetary flying machines is timely and useful for popularizing the idea of interplanetary communications."
4. Perelygin and Protopopov:
   "We greet those who were so bold as to open up the unknown."
5. Gorev:
   "Our mind is not accustomed to all the 'wonderful and unknown' which literally was seen and heard, as if in a dream, yet we understand that this is not a fantasy but a completely feasible idea supported by the achievements of science and engineering."
6. The reporter of the "Rabochaya Moskva," Salomeya G. Vortkin, to the inventor Fedorov:
   "I am going to accompany you on the first flight. I am quite serious

about this. As soon as I heard what you had done, I tried in every way to make certain that you would take me with you. Please do not refuse my request."

7. Setr, an artist at the 3rd Government Cinematographic Studio: "The exhibition is clearly set up. It would be desirable that our inventors achieve the first landing on the moon. . . ."

212 CONCLUSION

Flight in the upper layers of the atmosphere, outside it, and in space, introduces many new problems which until now have only begun to be solved and require further research.

We feel that a working plan is needed for studying the following problems mentioned:

1. **Propellant.** Selection or development of a new propellant of maximum efficiency. Studies of existing types of propellant. Methods of storing, igniting, and handling them.

2. **Engine**. Development of various types. Shape of nozzles. Temperature effects. Operation at low temperatures. Efficiency.

3. **Materials.** Properties at low and high temperatures. Minimum weight and maximum strength.

4. **Design.** Analysis of external forces. Optimum shape. Possibility of variable-geometric layout for flight in- and outside of atmosphere. Minimum weight and [maximum] strength.

5. **Controls**. In- and outside atmosphere. Control by reaction rudders, gyroscopes, radiation, automatic controls.

6. **Stability**. Measures to maintain stability: reaction, gyroscopes, movable masses, etc.

7. **Drag** at high velocities.

8. **Effect of large accelerations** on human beings and their living conditions in a rocket.

9. **Launching conditions:** Launching of rockets from airships, airplanes, or mountains. Launching from the ground. Launching angle. Use of catapults. Launching of unmanned rockets to various heights.

10. **Landing**. Gliding at large velocities. Drag. Use of parachutes. Selection of time and place of landing. Experimental flights of manned rockets.

11. **Celestial navigation**. Development of accelerometers, periscopes, chronometers, speedometers, solar-radiation meters, high- and low-temperature thermometers, etc.

12. **Computation of flight conditions** in connection with the laws of gravity.

There are still many problems which may be encountered and whose solution is not within the capacity of a single person.

Just as the modern airplane is the result of the work of many persons who developed optimum wings, airscrews, engines, controls, and who studied flight conditions, takeoff and landing conditions, etc., so the problem of rocket flight in interplanetary space will be solved mainly by the combined efforts of many people.

A stimulus for future interplanetary flights is supplied by various scientific aims: study of the upper layers of the atmosphere, of the properties of the medium above the atmosphere, and of cosmic radiation, astronomical observations, and lastly, flight to other planets.

The problem of interplanetary communication is of great scientific interest. Its solution is beyond the power of a single person, so that it will be advantageous to establish a national or international institute for
213 interplanetary communication.

This institute should comprise the following departments:

1. Propellant
2. Engines
3. Materials
4. Design
5. Controls and stability
6. Aerodynamics
7. Accelerometrics
8. Astronomy and celestial navigation
9. Operations (takeoff, landing, flight)
10. Physiology (effects of acceleration, temperature, radiation, etc. on human beings).

Establishment of such an institute should be our present task. Realization of interplanetary communication will, however, be the task of our children.

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