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Volume I

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PREFACE

Rocketry and astronautics encompass the physical engineering sciences, including fluid mechanics, thermodynamics, vibration theory, structural mechanics, and celestial mechanics, among other disciplines. Workers in this vineyard have ranged from the empirical experimenter using time-honored "cut and try" methods, to the scientist wielding theoretical principles. In the twentieth century the coupling of the physical and engineering sciences, industrial advances, and state support produced awesome progress in rocketry and astronautics—for the most part within living memory. Although these events have profoundly affected many aspects of everyday life, they have received limited historical scholarly attention.

Seeking to encourage study in this field, the International Academy of Astronautics of the International Astronautical Federation sponsored a symposium on the history of astronautics at Belgrade in 1967. Since that time a history symposium has been held annually at the International Astronautical Federation Congresses, and the proceedings have been published in English and Russian. The English language edition of the first two symposia (Belgrade 1967 and New York 1968) appeared in 1974.*

These two volumes comprise the Proceedings of the Third Through the Sixth History Symposia of the International Academy of Astronautics (Mar del Plata 1969, Constance 1970, Brussels 1971, and Vienna 1972). The thirty-nine papers have been organized in four parts: (1) Early Solid-Propellant Rocketry; (2) Rocketry and Astronautics: Concepts, Theories, and Analyses after 1880; (3) The Development of Liquid- and Solid-Propellant Rockets, 1880-1945; and (4) Rocketry and Astronautics after 1945. The History Committee of the International Academy of Astronautics selected the theme for these symposia: "new contributions to the historical literature on rocketry and astronautical developments initiated before [19--]," with the date set twenty years before each symposium. The "twenty-year rule" was established to permit authors a measure of perspective and to avoid some of the complications with state security regulations. Although unevenness in the quality of the contri-

* Frederick C. Durant III and George S. James, eds., "First Steps Toward Space: Proceedings of the First and Second History Symposia of the International Academy of Astronautics at Belgrade, Yugoslavia, 26 September 1967, and New York, U.S.A., 16 October 1968," Smithsonian Annals of Flight, No. 10, 1974. The Russian edition: Iz istorii astronavtiki i raketnoi tekhniki: Materialy XVIII mezhdunarodnogo astronavticheskogo kongressa, Belgrad, 25-29 Sentyavrya 1967, Moscow, 1970. (Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, Stock No. 4705-00011, \$4.00.)

butions is to be expected wherever session chairmen create international programs from submitted abstracts alone, I think the reader will find that these symposia have met their thematic objective.

I am grateful to the members of the History Committee of the International Academy of Astronautics and the NASA Historical Advisory Committee for their encouragement and support in the preparation of these proceedings. A special debt is owed the National Aeronautics and Space Administration, especially Monte Wright and Frank Anderson of the NASA History Office, who arranged for the printing, and the Jet Propulsion Laboratory, California Institute of Technology, for the resources necessary to see the editing and typing completed. I am also indebted to Peter Rouklove and Vladimir Petrov, who greatly improved the English language translations of the Soviet papers. Finally, heartfelt thanks are due Shannon Facer and Bobbie Rosen, who typed the manuscript. Any editorial errors or inconsistencies that remain are mine.

R. Cargill Hall

Pasadena, California
December 1976

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PART I

EARLY SOLID-PROPELLANT ROCKETRY

ROMANIAN ROCKETRY IN THE 16th CENTURY⁺Elie Carafoli and Mihai Nita (Romania)⁺⁺

A mediaeval manuscript, recently discovered in Sibiu, a town in central Romania, was found to contain important new information on the development and construction of powder rockets. Handwritten in old German, the Sibiu manuscript is in the form of a "coligatum" with texts by three authors.¹ The last of these authors, Conrad Haas, served as the Chief of the Artillery Arsenal in Sibiu from 1529 to 1569; his portion of the manuscript, devoted to rocketry, is the subject of this paper.²

In comparing Conrad Haas' document with about thirty works on pyrotechnics of the time, either published or in manuscript form, D. Todericiu of the University of Bucharest judged the technical creation in the town of Sibiu, in the ensemble of European pyrotechnics, a valuable analysis of the mediaeval concerns in ballistics, pyrotechnics, and the construction of rockets. Written by Haas sometime between 1529 and 1569, his chapter "On rockets" in this manuscript describes the activity carried out in the construction of rockets in Sibiu by the author together with local pyrotechnists.

The value of the Sibiu manuscript resides in the information that it furnishes concerning a number of most interesting technical achievements, quite a lot of which have a character of priority in the history of the progress in rocket technique. Thus, the investigations undertaken in the past few years have confirmed the fact that the Sibiu manuscript is the oldest document known up to the present that contains references and definite data concerning the construction of multistaged rockets.

⁺Presented at the Third History Symposium of the International Academy of Astronautics, Mar del Plata, Argentina, October 1969.

⁺⁺Carafoli is President of the Commission on Astronautics of the Academy of the Socialist Republic of Romania; Professor, Institute of Fluid Mechanics, Bucharest. Biographical information on Nita is unavailable.

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In Figure 1 Haas gives the sketch of a double rocket--which would be called nowadays a "two-staged rocket." The operating principle of this rocket is fairly similar to the manner in which a two-staged rocket is conceived to work nowadays. At first the charge of powder in the first engine is ignited and provides the propulsion for the rocket (the ensemble of the two engines, together with the payload). Once the first stage stops working, the flame is conveyed to the propellant in the second engine which provides additional propulsion of the rocket. It is of interest to note that in this sketch the separation of the first stage is not necessary. Haas provided for the integral consumption of the first engine while the propellant burned. To this end, he made the rocket cover out of paper impregnated with various substances which burned as the propellant was consumed in such a way that, when the first stage was exhausted, the second engine remained on the trajectory as an independent entity.

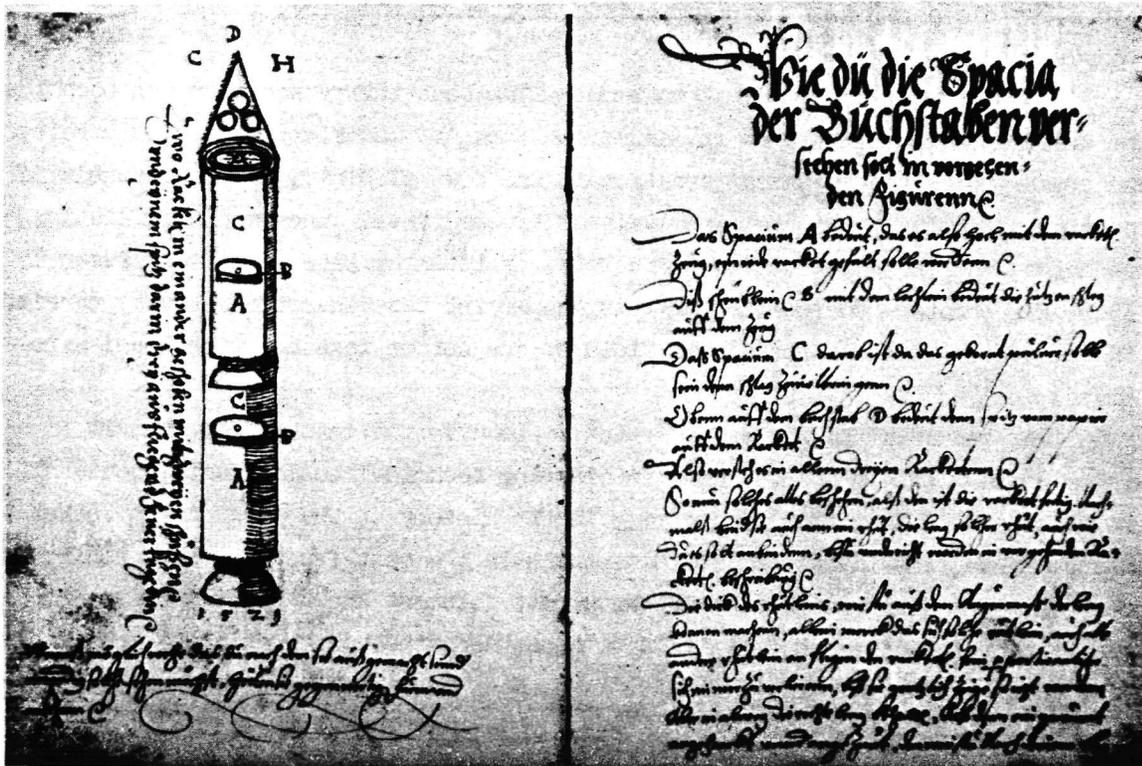


Fig. 1

The successful experiments performed with such rockets led Haas to the construction of a three-stage rocket (Figure 2). The operation of this rocket was similar to that of the two-staged rocket. Another result of the technical thought in Sibiu at the beginning of the 16th century was the testing of the possibilities of transporting to a certain distance, with the aid of rockets, a powder barrel which would explode on returning to earth (Figure 3).

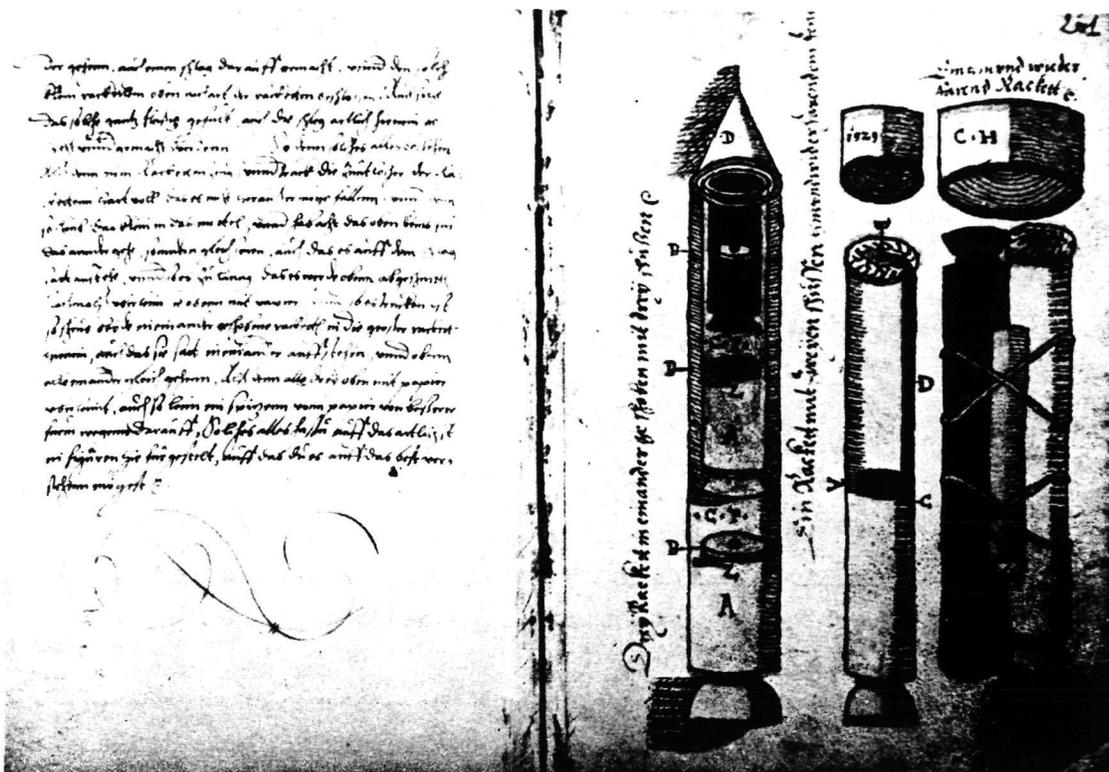


Fig. 2

Apart from extending the range by using a rocket system with successive ignition, interesting solutions for obtaining guidance and flight stability are to be noticed. One can readily see that the solutions Haas adopted were somewhat more advanced than the old Chinese "fire arrow." We can see in the photo that, according to the conception of the Sibian pyrotechnists, the rocket possessed the same main elements as any modern rocket: the body of the rocket, the payload, the propulsion system, and the stabilization system in the shape of a swept-back tail.

As a matter of fact, it is with surprising clearness that the idea of using the rocket as a means of conveyance appears in the manuscript. Figure 1 shows the front end of the rocket beneath the cover of which lies the payload, represented by

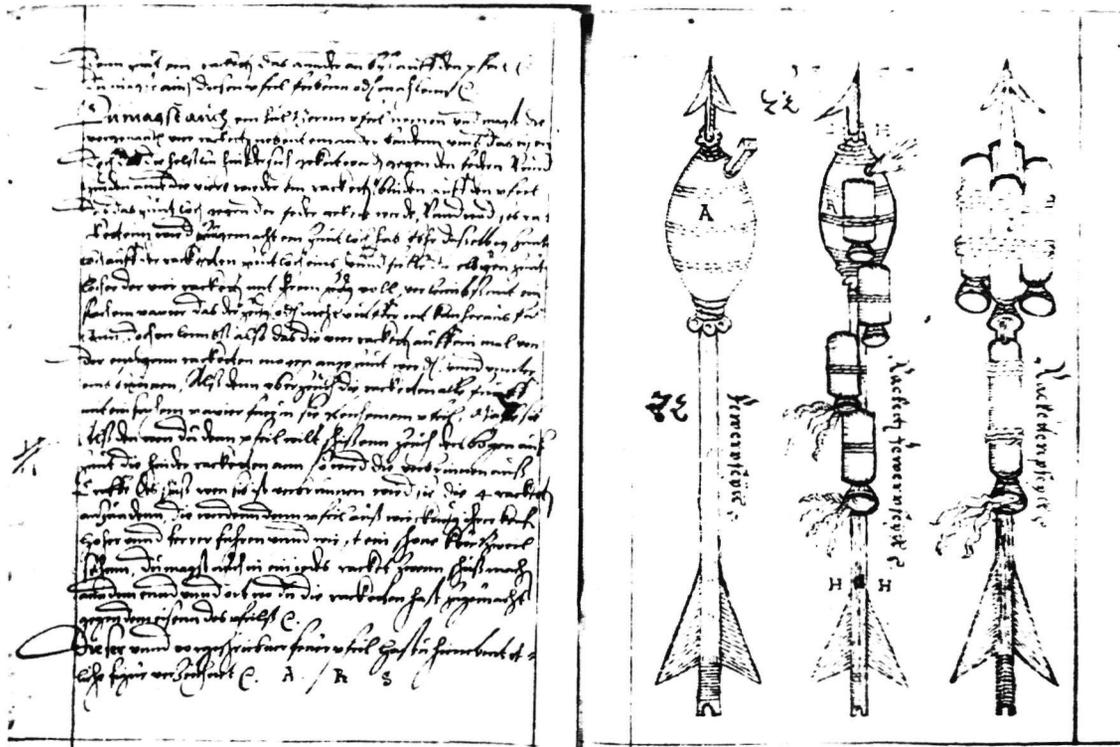


Fig. 3

three balls. One may perceive the similarity between the solution adopted four centuries ago in Sibiu and the mode used nowadays for carrying any load by means of rockets.

The pages of the manuscript also reflect the existence of valuable experience in the field of pyrotechnics taken over from local handicraftsmen, both in the domain of the manufacture of powder and its ingredients. Thus, Haas described the methods used by the Romanian natives in Transylvania for obtaining saltpeter and for manufacturing a coal that could provide a controllable combustion of the powder. Here Haas mentioned the recipes worked out by the well known pyrotechnist Hanes Walach, of Romanian descent, a specialist whose name is to be met with in the historical documents belonging to the end of the 16th century and mentioned in older studies of highly-reputed Romanian historians (such as Nicolae Iorga and C. C. Giurescu). Hanes Walach (in translation, John the Romanian) had perfected five powder recipes, called at that time "hard powder," out of which one was said "to burn just as water runs," that is, very steadily.

Along the same line of ideas, we should mention the stellar form of the powder grain adopted for many of the rockets described in the manuscript which is very much like the combustion surface of solid propellants used at present. The use of the

experience of the local handicraftsmen for obtaining the ingredients of powder, and particularly of the reputed experience of John the Romanian, accounts for the fact that Conrad Haas developed his ideas in Sibiu, in Transylvania, carrying out his activity there for over 40 years, from 1529 to 1569. The Sibian manuscript represents an actual vade-mecum of the rocket technology. Apart from the data pointed out above, it also includes numerous details concerning the construction of each constituent element of the body, tests and various experiments of jet-propelled technique, the judicious distribution of the propellant in the rocket stages, etc. Haas' activity and the influence he exerted found a powerful echo in other authors, both contemporaries and successors.

In chronological order, Haas' work appeared before the creations of several famous authors, such as Biringuccio (Venice, 1540), J. Schmidlap (Nürnberg, 1561), L. Fronsperger (Frankfurt, 1557 and 1566) and Kazimir Siemienowicz (Poland, 1650). The analysis of their works and of those written by other authors, compared to Haas' text and drawings, emphasizes similarities and ideas that were taken up again, thus reflecting the flux of ideas between contemporaries and their successors. In view of this, Sibiu of 1529 represents a starting point in the history of the modern rocket. Numerous specialists in the history of rocket technology, as for example Professor Dr. Subotowicz, Professor René Taton, and Professor Dr. Friedrich Klemm, agree to this position which has restored Haas in the history of multi-staged rockets.

Unlike all the other military engineers of his time, Haas and his collaborators were constantly preoccupied with rocket technique, and particularly with the peaceful application of rockets. The drawing in Figure 4 is significant in this respect, it is the image of a little flying house atop a rocket, and can be interpreted as Haas' naive prefiguration of the idea of future manned space flight.

Haas concluded his manuscript with the sentence: "But, my advice is for more peace, not war." That sentiment conveyed over centuries will perhaps find its fulfillment in contemporary society, and thus meet the hopes of all mankind.



Fig. 4

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1. Registered in the National Archives at Sibiu under the title Pars Arhivi Civtas Cibiensis - Varia II 374.
2. A further elaboration of the Haas work can be found in D. Todericiu, Preistoria rachetei moderne (Prehistory of the Modern Rocket). Bucharest: Publishing House of the Romanian Academy, 1969.

THE SWEDISH ROCKET CORPS, 1833-1845⁺Å. Ingemar Skoog (Sweden)⁺⁺

Rockets for pyrotechnic displays are known to have been used in Sweden as early as the 17th century. However, it took the English bombardment of Copenhagen in 1807 to bring the possibilities of using rockets in war to the attention of Swedish military authorities. In 1810, the Swedish chemist J. J. Berzelius visited Copenhagen and, through friends, contacted some Danish military officers. The discussions naturally turned to the British bombardment of 1807 and the destructive effects of the Congreve rockets. Some unexploded rockets were found in Copenhagen (Figure 1), and samples of both the propellant and the incendiary were given to Berzelius. On his return to Stockholm¹ he managed to analyze the two compositions, whereupon he began preparations to improve on them. Subsequently, in the following year on April 4th, the Swedish King ordered the Royal Academy of Military Sciences to appoint members of a formal commission Brandraketcommitten, "to investigate the proper composition of war-rockets and to make experiments."²

The first tests with Congreve-type rockets manufactured in Sweden were performed in June 1811.³ The rockets, possessing a diameter of 118 mm (4.6 inches), attained a range of about 1.5 km (1 mile). The propellant as well as the manufacturing technique were improved during the following years, mostly because of the intensive work of the Brandraketcommitten. In 1812 and the beginning of 1813 the rockets tested were very similar to the Congreve rockets, with a length of 945 mm (36.8 inches), a diameter of 109 mm (4.25 inches), and a weight of 20 kg (45 pounds) (Figure 2). The total weight including a 5.95 m (19.5 feet) guiding stick was 23-24 kg (52-54 pounds), and the average range was 2.5-3 km (1.5-2 miles).⁴

⁺Presented at the Third History Symposium of the International Academy of Astronautics, Mar del Plata, Argentina, October 1969.

⁺⁺Presently at Dornier System GmbH, Friedrichshafen, German Federal Republic; PhD in Mechanical Engineering and member of the International Academy of Astronautics History Committee, and the Swedish Society of Aeronautics and Astronautics.

Congreve'ske raketter fra Københavns bombardement, 1807.
Fot. Orlogsmuseet.

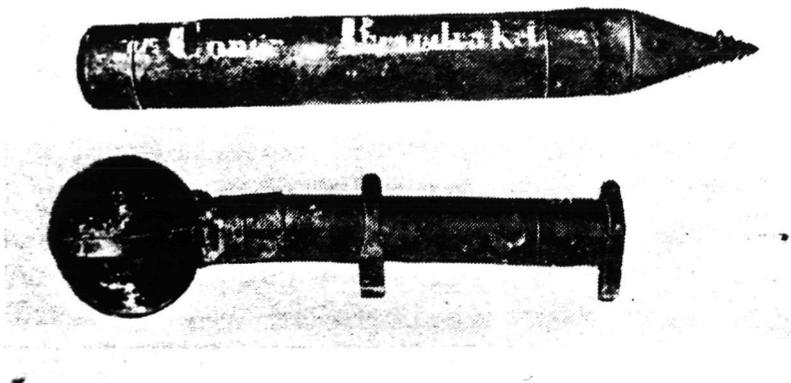


Fig. 1

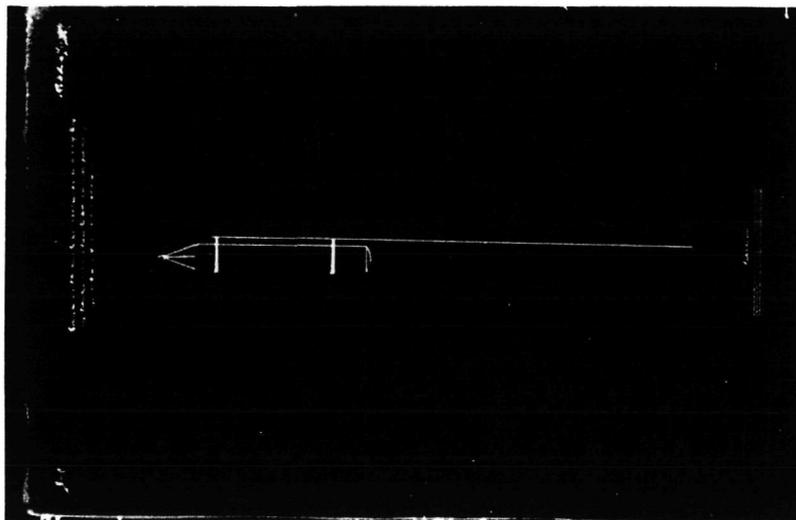


Fig. 2

In May 1813 the work of the Brandraketcommitten was terminated when most of the officers in the commission were assigned to the Swedish Crown Prince Carl Johan, and to this Army was also attached the British Rocket Brigade, later known as The 2nd Rocket Troop. On October 2, 1813 the Rocket Brigade was attached to the bodyguard of the Crown Prince. The British Rocket Brigade took part with Swedish forces in several attacks during the Battle of Leipzig, on October 16-18, 1813. For their gallantry, several officers and privates were awarded the Swedish decoration "For Brave Conduct in the Field." The Rocket Brigade continued to march with the Crown Prince until January 18, 1814, participating in two more sieges for which they again received the thanks of the Crown Prince.⁶

During the Napoleon campaign, Swedish officers saw firsthand the results of these rockets in war. In the late 1810s rocket tests were taken up again by the Swedish military. Together with the tests conducted in Sweden, rocket manufacturing techniques were collected from other European countries, e.g., England and Denmark, by traveling Swedish officers. An excellent report on the manufacturing of the Congreve rockets in Woolwich, England, was written in 1829 by Captain D. W. Silfverstolpe.⁷ Recommendations to set up a Swedish rocket brigade, however, received no support from the Government, which showed very little interest.

But on April 14, 1831, a German engineer, Martin Westermajjer, submitted a most valuable proposition to the Swedish Government through the Swedish Ambassador in Berlin. For several years Westermajjer had worked as a pyrotechnist in the Austrian rocket factory at Neustadt, and later on in the same profession in Warsaw. Under contract to the Prussian General von Braun, he had also instructed the Royal Prussian Artillery how to manufacture rockets. He offered to visit Stockholm on his way from Berlin to St. Petersburg in Russia, and give full instructions on rocket manufacturing, as well as to make some test-firings during a three-month stay. More important, he offered to pass on all information as to the manufacturing-techniques of different rocket-types and their use in Central Europe.⁸

The Swedish Government accepted the offer, and during the summer of 1831 Westermajjer made some 20 rockets. On August 18, 1831, he conducted a test-program with 16 of them, of which only three failed.⁹ Westermajjer's manufacturing costs for these rockets amounted to only a quarter of the costs for the previous Swedish ones, with the same firing range of about 800 meters (0.5 miles). Westermajjer also wrote a very thorough and excellent report on the Austrian rocket-system that was illustrated by a group of Swedish military officers, instructed by Westermajjer before he left Sweden.¹⁰ Based upon Westermajjer's visit, the Swedish military again recommended organizing a rocket brigade. The final decision, made by the Government on behalf of the King on December 28, 1832, created the Royal Rocket Corps by decree.¹¹

Lieutenant J. W. Westerling, who had worked closely with Martin Westermajer in 1831, was appointed Commander of the Royal Rocket Corps. In peacetime the Royal Rocket Corps consisted of 3 officers, 4 warrant officer, 1 bugler, 4 non-commissioned officers, 60 fireworkers, and 2 other technicians. The group of fireworkers was divided into smaller units to handle 8 launchers brought along on rocket-wagons. With this organization, the military believed the number of launchers could be easily doubled to 16, which was thought to be the number needed in war. The Royal Rocket Corps was stationed at Marieberg outside Stockholm, where the artillery had a workshop for pyrotechnical equipment, and where the Artillery College (Högre Artilleriläroverket å Marieberg) was also located.

Because of the Westermajer instructions in 1831, the manufacturing technique of rockets for the Royal Rocket Corps was similar to the Austrian one.¹² The propellant consisted of 65.4% saltpeter, 21.4% sulphur, 11.2% aldercarbon, and 2.0% alcohol. The saltpeter, sulphur and carbon were ground in separate wooden rotating cylinders (Figure 3), passed through a sieve, and then mixed in a fourth cylinder. Later the composition

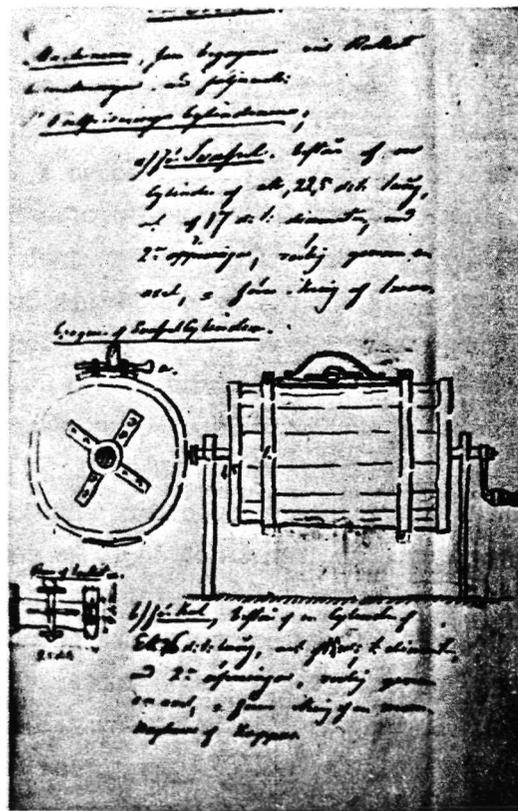


Fig. 3

was moistened with the alcohol in order to make it more elastic for pressing into the metal-cases. Each case was made of sheet-iron and joined longitudinally by rivets. The bottom of the case was formed by cutting slots in the cylindrical case, and bending the flaps over an inserted metal ring. The composition was pressed into the case by a screw-press (Figure 4), in small portions, generally about 50 for each rocket.

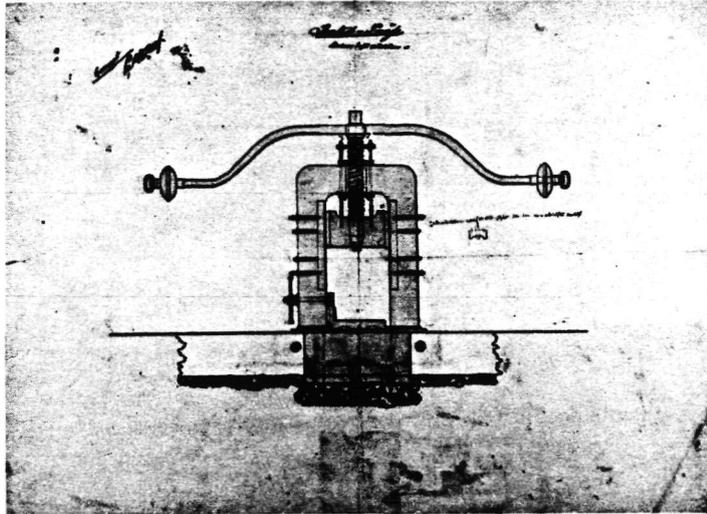


Fig. 4

The homogeneous rocket-body was placed in a drilling machine (Figure 5) in order to shape the burning surface. On top of the rocket-case was attached a spherical, hollow shell containing the explosive fire-composition. The top of the propellant was covered with a layer of pressed clay, through which a small hole was drilled. This hole, filled with meal powder, permitted the propellant to ignite the explosive-shell when the propellant was consumed (Figure 6). The exhaust outlet was carefully covered with a piece of canvas glued to the rocket-case. The propellant-igniter ran through the canvas. A small guiding-stick was attached to the case; then the complete rocket was balanced with small pieces of lead placed at the end of the stick in order to bring the center of gravity into a plane through the end-surface of the rocket body. Finally, the whole rocket was painted black.

Though various types of rockets were tested, only two types were manufactured in great numbers: the "2-inch" and the signal-rockets. The "2-inch" rocket still preserved (Figure 7) is 390 mm (15.5 inches) long, 56 mm (2.20 inches) in diameter and weighs 3.4 kg (7.5 lbs) without a guiding stick. The stick is 2.3 m (7.5 feet)

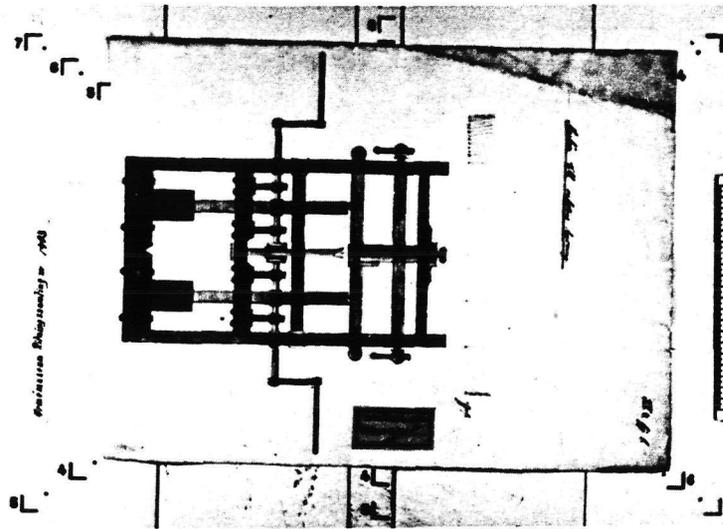


Fig. 5

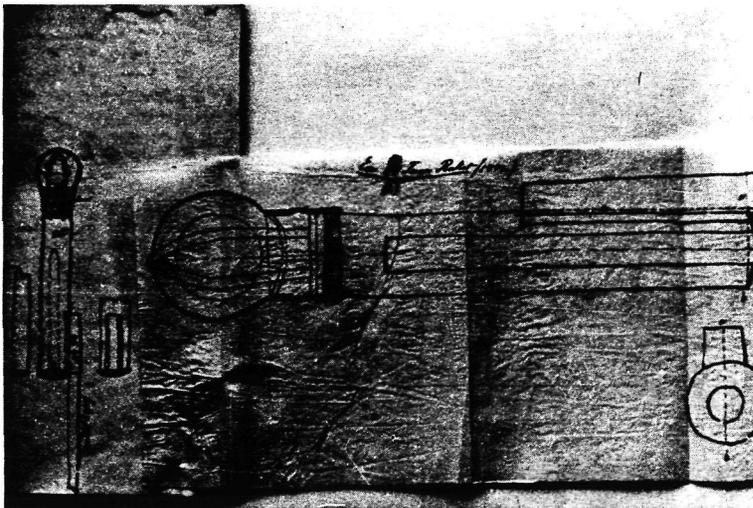


Fig. 6

long. The range for this type of rocket was, when launched elevated, 600-1,000 m (2000-3000 feet). In the facilities of the day, records show that 240 of these rockets could be manufactured every eight weeks. The signal-rockets still preserved (Figure 8) are 220 mm (8.65 inches) long, and 28 mm (1.1 inches) in diameter. The sticks are 900 mm (3 feet) long; the weight without a stick is about 0.2 kg (0.4 lb.) each. The signal rocket case was made of paper. A larger "2.5 inch" rocket with a 12 pound shell was also manufactured in the same way as the "2-inch" rocket, but in smaller quantity.



Fig. 7



Fig. 8

The Royal Rocket Corps also tested several interesting experimental rockets. One, fitted with delta-wings and a fin instead of the guiding stick (Figure 9), was manufactured according to a design made in 1821 by M. Vaillant from Boulogne. The length of this preserved rocket is 385 mm (15.2 inches); the diameter of the body 56 mm (2.20 inches; the expanse 440 mm (17.3 inches); the height 250 mm (10 inches). The rocket is fitted with a ring of 15 mm (0.6 inches)-high metal plates (Figure 10) at the rear; the exhaust-orifice is 22 mm (0.82 inches) in diameter. The weight of the shell is 1.5 kg (3 lbs). Unfortunately, no test-results on this rocket type are to be found. The idea for a luminous parachute bomb came from the Danish Rocket Corps, and

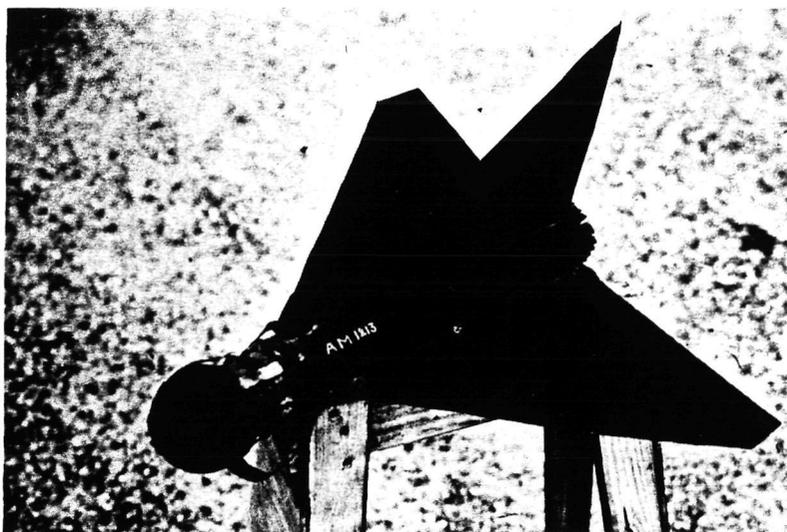


Fig. 9

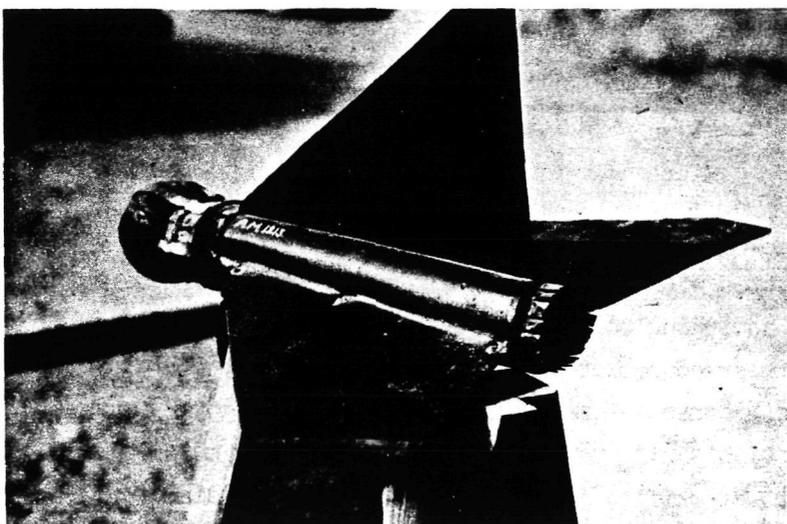


Fig. 10

one of a Swedish design was made in the 1830s (Figure 11). The total length of this preserved rocket is 710 mm (28 inches) and the diameter of the case is 70 mm (2.75 inches) at the rear end.¹³



Fig. 11

One of the largest early 19th century Swedish rockets, the "3-inch," was made according to plans of the Congreve rockets (Figure 12). An extant rocket of this type is 670 mm (26.4 inches) long and 90 mm (3.5 inches) in diameter; the weight without the 4.2 m (14 ft) long guiding stick is 8.16 kg (18 lbs). The Royal Rocket Corps also conducted tests in the late 1830s with rockets launched out of a tube without a guiding-stick that indicated the attempt to stabilize the rocket by rotation.^{14,15}

Considering the relatively poor aiming precision, the use of rockets on open fields proved limited, especially because it took about three minutes to fire 6 rockets from one launch stand. In the same time 6 cartouch-shots could be fired with greater effect. The rockets proved very useful, however, in defending positions against cavalry attacks and in mountain war. In the mountains, transporting heavy artillery was

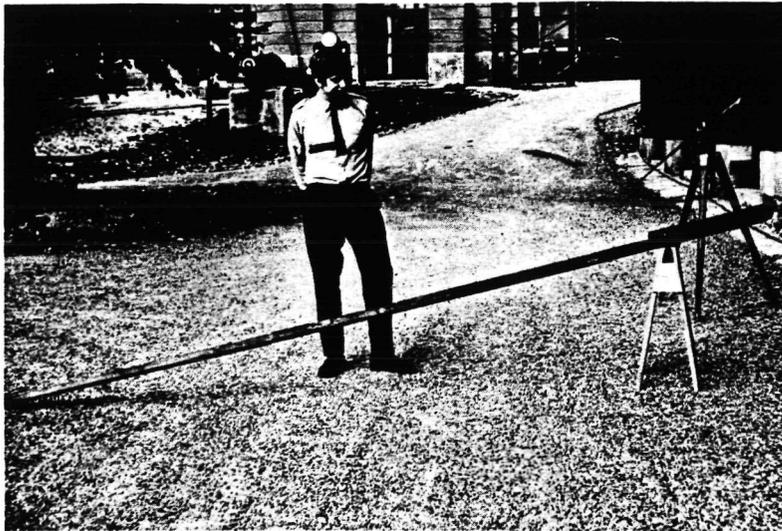


Fig. 12

impossible and rockets could be carried by the fireworkers. Therefore, this became one of the rocket's most advantageous applications. A third important application was in siege war. Inside a fortress, rockets could be used from positions where a heavy gun could not be placed. Moreover, the rockets could quickly be moved, when the situation changed. An attacking army could also use them before heavy guns had been brought into position, or for covering a reorganization of gun positions.

Despite testing, the technical development of the Swedish rockets was limited, and in the mid 1840s the ordnance was almost of the same type used when the Royal Rocket Corps was formed. Rocket corps in other European countries, e.g. Denmark meantime, were reorganized to pyrotechnical working units. After a visit to Denmark and Prussia in 1845, Commander Westerling of the Royal Rocket Corps determined that the use of the corps should be reconsidered. The order for reorganization was contained in a decree dated October 24, 1845: "The Government has upon the proposal from the General of the Field Ordnance and Commander of the Artillery, decided to change the Rocket Corps to a manufacturing unit called the Firework Corps . . ." Thereafter, from 1845-1876, the Firework Corps manufactured all kinds of pyrotechnical devices for the artillery service.¹⁶

However, this reorganization did not mark the end of the use of rockets in Sweden. A Government decree of March 13, 1846, authorized each artillery regiment to be equipped with two rocket launchers. The rockets already manufactured were to be used in firings by artillery officers. The launchers and rockets were kept by the regiments

until the mid-1860s, when they were finally retired from service in Sweden.¹⁶

To compare the performance of these rockets with modern ones, a rough calculation can be made from the specifications given in Reference 12. The "2-inch" rocket had a black powder propellant weight of an estimated 1.18 kg (2.6 lbs), and a total weight including the stick of 4.15 kg (9.15 lbs). Based upon the maximum range found in Reference 12, and without any corrections for the air drag on the rocket, the specific impulse amounted to $I_{sp} = 440 \text{ Ns/kg}$ (44 seconds). The theoretical maximum specific impulse for black powder is 2400 Ns/kg (240 seconds). It should be noted, however, that this rocket was not designed with a nozzle, but a simple exhaust orifice in an almost flat end-surface. There is insufficient information in Reference 12 to permit an estimation of the thrust.

An examination of the rockets preserved at the Royal Army Museum in Stockholm indicates that all 14 extant rockets are still fitted with their original propellant (Figure 13). This would permit tests by propellant experts to determine the properties of a 140-year-old solid propellant, as well as the static thrust and the specific impulse of a rocket from the 1830s.⁺

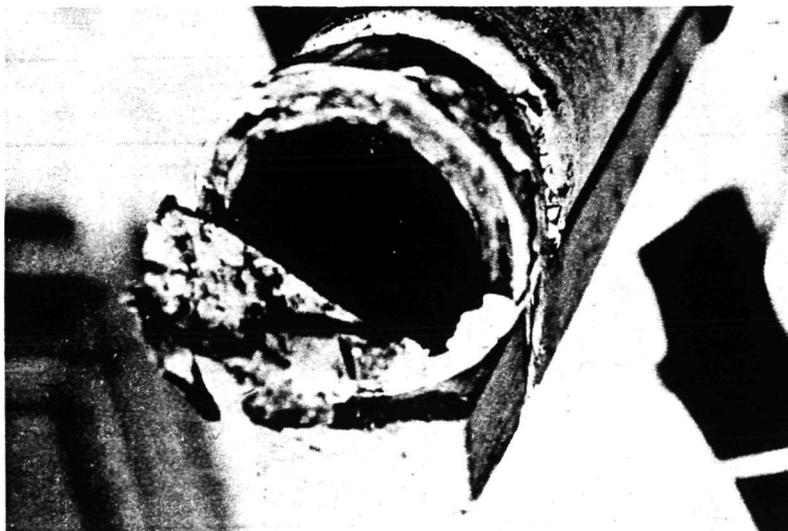


Fig. 13

⁺See Jan Hansson and Å. Ingemar Skoog, "Analysis of Early 19th Century Solid Propellant," Ninth History Symposium of the International Academy of Astronautics, Lisbon, Portugal, 1975—Ed.

No direct evidence of a continuous relationship between early 19th century war rockets and the later development of astronomical devices exists. But the ideas and techniques of rocketry in the 1810-1845 period did form a basis for W.T. Unge's early rocket inventions and innovations in the 1880s which, among other things, led to the successful application of the de Laval nozzle on rockets.

APPENDIX

VARIOUS TYPES OF ROCKETS TESTED IN SWEDEN, 1810-1845

Model	Weight with stick, kg	Length mm	Diameter, mm	Stick length m	Range, m	Notes
Congreve, Copenhagen, 1807		420	55			Exhaust orifice diameter 26 mm (Fig. 1, upper)
		350	40			Shell diameter 100 mm (Fig. 1, lower)
Swedish 1811		710	118		1500	Elev. ~ 50°
Swedish 1812	23-24	945	109	5.95	2500-3000	Fig. 2
"2-inch," 1842	4.15	390	56	2.3	600-1000	Manufactured in larger quantities. $I_{sp} = 440 \text{ Ns/kg.}$ Figs. 6&7
Signal-rocket	0.42	220	28	0.9		Paper-case. Two fins at the end of the stick. Fig. 8
Delta-winged rocket, After Vaillant 1821, in 1830s	~3.3	385	56	-		Expanse 440 mm, Height 250 mm, Exhaust orifice diameter 2.2 mm Figs. 9&10
Luminous parachute bomb, 1830s		710	70 (at rear) 110 (at front)			Fig. 11
"3-inch" 1830s	8.16 (without stick)	670	90	4.2		Fig. 12

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BARON VINCENZ VON AUGUSTIN AND HIS RAKETENBATTERIEN:
A HISTORY OF AUSTRIAN ROCKETRY IN THE 19th CENTURY⁺

Frank H. Winter (USA)⁺⁺

INTRODUCTION

Of all the war rocket batteries and rocket establishments in the last century, none was so large or sophisticated as those of Austria. The Austrian "Kriegs-Raketen Anstalt" ("War Rocket Establishment"), and later the numerous "Raketenbatterien" ("rocket batteries), represented the quintessence of the art of rocketry in the 19th century. This is evident since many other nations copied the Austrian pattern of rocket equipment and rocket troop organization. A closer study of the state of the art in later Hapsburg Austria therefore provides an ideal example of overall developments in Europe during this period.

Initially, the solid-propellant war rocket was designed and introduced by the Englishman Sir William Congreve in 1804-1805 and was widely used in the Napoleonic wars. Congreve's projectile was little more than an advanced firework sky-rocket with a metallic cartridge and a warhead. Its novelty and adverse effect on the morale of the enemy--rather than its actual destructiveness--made it a somewhat "romantic" mode of warfare. The British eventually institutionalized the Congreve rocket and raised a special rocket-armed unit called a "Rocket Corps."

Under Captain Richard Bogue, the Corps became the sole representative of Great Britain in the famous "Battle of Nations" at Leipzig in 1813. Bogue's Corps frightened two French brigades into surrender with a few volleys. The "Battle of Nations" more than any other engagement established the reputation of the Congreve rocket. The excitement it generated on the continent led to a virtual pre-twentieth century arms race in which almost every European nation sought to emulate Congreve and his works and to raise their own elite Rocket Corps. Austria was one of these nations and in time it emerged preeminent.

⁺Presented at the Fifth History Symposium of the International Academy of Astronautics, Brussels, Belgium, September 1971.

⁺⁺Historian, Astronautics, National Air and Space Museum, Smithsonian Institution, Washington, D.C.

THE PIONEER WORK OF AUGUSTIN

As early as 1808, under the orders of the Director General of the Artillery, Chief Fireworks Master Anton Mager produced 24 sheet-iron cased war rockets that were successfully test fired. Nothing further was done with military rockets in Austria, however, until the pioneering work of Baron Vincenz (Vincent) von Augustin (Figure 1). "The name of Augustin," wrote an early authority, "is inseparable from the development of Austrian rocketry."



Fig. 1. The Austrian rocket pioneer Vincenz von Augustin (1780-1859). Portrait from the Heeresgeschichtliches Museum, Vienna.

Augustin was born in the town of Pest (later, part of Budapest), Hungary, then under the rule of the Austrian Hapsburgs (1780). He began his life's work perfecting the rocket after witnessing Bogue's Corps at Leipzig in 1813. Augustin was then a Major of Artillery on the staff of the senior Austrian officer at Leipzig, Field-Marshal Phillip Schwartzenburg. Major Augustin was much taken with this new weapon and recommended strongly that an investigation be conducted to duplicate the weapon and form an Austrian Rocket Corps. Augustin, already distinguished for developing his own high-accuracy (to 0.00001 Viennese Fathoms) geodetic or surveying apparatus, as well as authoring a standard surveying textbook, was granted permission to undertake these studies.¹

Following the Allied victory at the Battle of Leipzig and the Peace of Paris in May, 1814, Augustin was sent to the Netherlands, Paris, and London on a diplomatic mission. While in the latter city he visited the Royal Arsenal at Woolwich. Here, he again witnessed the firing of Congreve rockets though at a demonstration on the Arsenal practice grounds rather than upon the battlefield. Congreve and his British associates, of course, hardly revealed the details of the projectiles or their manufacture. Subsequently, Augustin's superiors sent him to Denmark to see the only other rocket establishment then existing in Europe. Only after considerable diplomatic pressure did the Danes finally permit Augustin a limited inspection of their rocket facility.

Like Austria, Denmark had been directly influenced by Congreve's example. Captain Andreas Schumacher of the Danish Engineer Corps took the initiative and, working in the strictest secrecy, had erected a secluded rocket laboratory on the island of Hjelm, in the Kattegat Sea. The mania for secrecy regarding Congreve rockets had become a pattern which was to be just as rigorously followed by the Austrians. It was so pronounced that the Danes stipulated that Augustin's trip be conducted only in the strictest confidence. The visit was arranged through special negotiations at the highest levels between leading members of the Danish government and the famous Austrian statesman, Prince Metternich.

Augustin made the trip in late 1814 or early 1815, travelling incognito as a businessman under the alias "von Augustry." He learned of the date and meeting place only after he arrived in Hamburg. The Danes gave Augustin nothing in writing and only the barest details verbally. By March 1815 he was back in Vienna. Augustin was soon after given a royal grant to pursue his aims. He immediately established a "Krieges-Raketen-Anstalt," or "War Rocket Establishment" at the military works of Weiner-Neustadt, slightly more than 32 kilometers south of Vienna, and recruited some military pyrotechnists to help him.²

Augustin's rockets differed significantly enough from the designs of Congreve and Schumacher, so that they eventually became known as the "Augustin System."

In addition to making military rockets, Augustin also worked out coordinated battlefield maneuvers and exercises. Progress was extremely rapid and by May 31, 1815, he reported that his crew of 46 non-commissioned officers and men were ready to be sent into the battlefield immediately as a "Raketenbatterie"—armed with some 2400 rockets of different calibers 5.8, 8, and 10 millimeters. The unit was mustered into the Austrian Army on a test basis, the first of an ever multiplying family of batteries.

While constituted along the lines of an ordinary Austrian artillery battery, the new unit wore a distinctive uniform and was supported by special companies of artificers, or military pyrotechnists. Augustin, although not its field commander, remained in charge of the *Kriegs-Raketen-Anstalt* at *Weiner-Neustadt*. He saw the battery perform for the first time in battle in 1815. This action, the siege of *Huningue*, on the left bank of the Rhine in Alsace, France, was one of the last actions of the Napoleonic wars. "The premature fall of the fortress of *Huningue*," wrote a later historian, "and the quick end of the campaigns of 1815 prevented the further employment of the Austrian rocket battery." Austrian authorities, particularly *Archduke Johann* who was near *Huningue*, at *Neudorf*, were already convinced of the usefulness of rockets, and sent favorable reports to the Kaiser.³

The following year the Kaiser expressed his confidence in the weapons and personally encouraged their development. Augustin's rocketeers were put on a permanent—rather than an experimental—standing in 1817, and were renamed the *Feuerwerks-Corps*.⁺ Staff headquarters for the corps continued at *Weiner-Neustadt*, remaining there throughout the history of the Austrian rocket establishment.

Augustin was promoted to lieutenant-colonel in 1817, retaining his position as the commandant. He held this post until 1838, and, throughout the remainder of his long career, was always closely associated with the establishment. The *Fireworks Corps* brought in new men and later expanded into two sections. The first was a field or service company, and the second a higher paid "maintenance company" of artificers who actually made the rockets. In 1819 Augustin ordered a further expansion. A second field battery was added, soon followed by even more. Additional buildings were also constructed at the rocket factory in *Weiner-Neustadt* at a cost of 42,000 Florins (more than \$20,000 by today's values)—a very sizable expenditure. These works included a mealing house to mix the gunpowder composition, a bag or packaging room for preparing the incendiary mixtures, and two more mixing houses operated by a water-driven mill for the final preparation of the propellant. The *Kriegs-Raketen-Anstalt* grew to such

⁺This interesting designation was probably an outgrowth of the office of the "*Feuerwerkmeister*," or "Firework Master" of the Old Austrian Army from the late 18th century who was responsible for maintaining a laboratory for the production of all pyrotechnics, including light balls, torches, signal rockets and skyrockets for victory celebrations.

proportions and reputation that as early as 1825 Weiner-Neustadt became known as "Raketendorf," or "Rocket Town." In this sense, it was the precursor of Peenemunde of the Third Reich.⁴

By 1820 Austrian artillery authorities believed they had reached a point of near perfection in rocketry. Like the Danes, they considered their rockets far superior in design to those of Congreve. Also, like the Danes, the Austrians were convinced that their foremost rocket pioneer had brought them the highest state of the art of rocketry. Various Austrian and German journals of 1820 announced that Augustin had successfully fired his "perfected war rockets" before the royal court assembled at Weiner-Neustadt. The following year it was similarly reported Augustin had introduced some signal types capable of being seen at "enormous distances." In 1821 Augustin's rocketeers, or "Raketeurs," first fully proved themselves in battle, quelling insurrectionists in Naples.⁵

AUSTRIAN WAR ROCKETS AND THE FIRST COLONIAL UPRISINGS

Though thrice defeated in the Napoleonic wars, Austria emerged from the Congress of Vienna in 1815 as one of the most far-flung and powerful empires on the European continent. Austro-Hungary consisted of German-speaking Austria, Bohemia, Moravia, south Poland, Lombardy, Genetia, Dalmatia, Carniola, Istria, and the separate kingdom of Hungary, with Croatia and Slavonia. Some of these territories were amongst the most mountainous and difficult to secure in Europe. It is thus small wonder that both the Austrian monarchs and the military heirarchy quickly realized the value of rockets for offensive fighting in such terrain. Classed as artillery and approaching the firepower of certain guns, war rockets could easily be transported to regions inaccessible to ordinary field pieces. Though the Austrians later built numerous rocket carriages called wursts (because they were oblong and resembled wursts or sausages), rockets could just as easily be carried by horse or human.

Besides Vincenz Augustin's great pioneering efforts, the rugged Austrian-Italian alps, the mountainous Dalmation coast, and the steep hills of Naples must have also served collectively as strong factors for the adoption and emphasis of war rockets in Austria. As insurrections grew within the empire, the Austrians fielded more and more rocket troops. In turn, the success of these troops grew in proportion to the superiority they gave Austria in mountain combat, and added to their longevity. The Italian wars for unification—the Risorgimento—and the fight for independence by Austro-Hungary's other provinces also made the Austrian war rocket establishment one of the most active. The rising at Naples in 1821 was a small foretaste of what was to follow.⁶

The fifteen rocket stands and a small compliment of rocketeers in the Naples expedition fought with notable success, particularly in the battles of Antrodocco, San Germano, and in the taking of the Abruzzi Pass. Austrian rockets caused the Italians to fall back to disarray, according to de Montgéry, "but it isn't certain whether the rockets had created fear [solely] out of their numbers." The Austrians were convinced enough of the rocket's effects upon morale, besides their firepower and strategic advantages, to begin introducing them into other branches of the military.

An Austrian frigate was reportedly armed with them at the Trieste station in 1823. This was probably the Royal Imperial frigate Medea, upon which Augustin's son, Ferdinand, served in 1826. This vessel bombarded the Moroccan city of Mequine, or Meknes, with incendiary rockets, in a punitive expedition against Riff pirates. Rockets were also tried in the cavalry, with special rocket cavalry munitions carriages adopted by that branch. By far their greatest employment was in the Artillery. With further uprisings in Italy, more Raketenbatterien were raised and permanently stationed in that country. By 1835 the batteries were posted primarily in Lombardy-Venetia (Figure 2).

In 1838 Austrian rocket teams successfully helped put down a minor Serbian revolt in Montenegro. In 1840 a detachment—"picturesque-looking warriors" one historian called them—accompanied a small Austrian fleet assisting the British in bombarding the city of Beirut, Syria (now the capitol of Lebanon). On September 8th, according to Weygand, ". . . a violent fire was opened upon the town. The houses burned under the action of Congreve [type] rockets and in a short time were reduced to cinders." Meanwhile, the Anstalt underwent some organizational changes and Augustin rapidly advanced in his career.⁷

EXPANSION OF THE ROCKET ESTABLISHMENT AND THE LATER COLONIAL WARS

Baron Augustin had already risen from a lieutenant-colonel in 1817 to full colonel in 1821. In 1831 he was commissioned a major-general, and a field-marshal-lieutenant in 1838; eventually, in 1849, he was appointed the General Director of Artillery of the Royal Imperial Army. With each advance in rank and honor, Augustin was able to build up his Kriegs-Raketen-Anstalt to such an extent that, by 1850, it had become the largest and most sophisticated in the western world.

By direct negotiation or by example, several other European nations adopted the "Augustin System." In 1831 for example, the Swedes signed a contract with a former pyrotechnist who had worked under Augustin.⁺ This same pyrotechnist

⁺See A. Ingemar Skoog, "The Swedish Rocket Corps, 1833-1845," in this volume— Ed.



Fig. 2. Austrian rocket practice in Mantua, Italy, 1846. From the Heeresgeschichtliches Museum, Vienna.

similarly helped the Poles and the Prussians. In 1852 the Swiss turned down the efforts of one of their own countrymen and adopted the Austrian system outright. Contractual arrangements were also made with the Kingdom of Bavaria, Wurttemberg, and one or two other German states.⁸

While the details of rocket manufacture were thus well circulated, often by unscrupulous and renegade pyrotechnists, Austria and other powers still zealously guarded their "secrets." De Montgery in 1825 said that the public was "severely interdicted to the entry of Weiner-Neustadt." Later, the Kaiser himself made periodic inspections of the laboratory and decreed that no other outsider should be admitted without his personal consent. Not even permission from an Archduke would do. The men at the laboratory also had to swear to reveal nothing. Nevertheless, in 1835 an English officer familiar with Congreve rockets managed to elude the Austrian guard and enter the gates when they were opened for the Emperor. He subsequently witnessed firing trials and expressed considerable amazement at the accuracy and performance of the rockets, and the scope of the works.⁹

In 1831 the original Fireworks Corps received its first large augmentation.

It was increased in size by additional companies, a depot, and one ordnance or maintenance company. Other companies were added or subtracted according to the military-political situation within the Empire. Ultimately, in 1850-1851, the entire organization was converted into the "K. K. Raketeur Corps" (Royal Imperial Rocket Corps) of 15 Raketenbatterien (one for each Army Corps), besides an Ordnance Company, a Staff Company, three reserve companies, and a Staff School. An even larger "Raketeur Regiment" was formed in 1854. It consisted of 18 rocket batteries which, in time of war, could be further expanded to 20, though the relative size of each battery was somewhat decreased. Augustin's establishment had thus swollen from approximately 100 men in 1815, to approximately 4000 in 1854. As early as 1829 the total in officers and men of the rocket establishment already amounted to 475 troops. Establishments in other nations varied considerably in size, but on the average usually consisted of only one special Rocket Battery or Corps of 160 men.¹⁰

These sweeping organizational changes in the Austrian rocket establishment undoubtedly occurred largely in response to the bloody Italian revolution of 1848-1849. It was a time of the greatest need for and strain upon Austrian arms, particularly war rockets. At the outbreak of hostilities there were two Raketenbatterien stationed in Italy, both in Venice-Lombardy, and each armed with six "Raketengeschutz" or "Rocket Guns" (actually rocket stands). As events unfolded, nine Raketenbatterien were eventually dispatched to Italy, besides a temporary or provisional battery. The customary "wursts" and other munitions carriages accompanied these troops.

"Raketeurs" served well in almost every major Italian action and in many minor skirmishes. They particularly distinguished themselves at Curtatone, Custoza, Monte Castello, Pastrengo, Aquilla, and at the bombardment of Venice (Figure 3). Battery No. 1 was said to have been exceptionally useful in street-fighting at the outbreak of the Revolution in Milan, and in the affair of Pastrengo. Battery No. 2 also performed excellently, firing explosive rockets from 600 to 1200 paces, and, with one grenade rocket, knocked out a gun emplacement manned by four men. At the bombardment of Udine, batteries 3, 4, 5, and the provisional one, were reported to have made "very good effect" with their rockets. Some of these batteries similarly performed well at the attack of Vencenza, where it was said there were fires in many places, "most of them caused by rockets." According to the account of the Rocket Armament Commandant during the Italian campaign, Major H. Reisner, the overall effect of the rockets was outstanding, particularly in mountain engagements. They were reliable, highly accurate at short range, and could be brought to mountain spots inaccessible to other weapons where only foot soldiers could go.¹¹

The Italian Revolution, in turn, precipitated a popular insurrection in Hungary in 1849. Austrian authorities responded by deploying their Raketenbatterien. Seven batteries participated in crushing the "marauders on the frontier of Bosnia,"



Fig. 3. Some men of the Swiss Jager Regiment reconnoitering the Austrian bombardment of Venice, Italy, 1849, near the fort of San Secondo. They appear to be watching some of the Austrian war rockets used at this engagement. One thousand rockets were taken in the bombardment by the Austrians. From *Neue-Illustrirte Zeitschrift* (Stuttgart), Sechster Band, 1850, Nr. 20, p. 156.

as the Russian Konstantinoff phrased it. These troops likewise fought well, especially at Petervasar and Szegedin (Szeged) in the South of Hungary, and also at Temesvar (or Timisoara), now in west Rumania.¹²

By 1854 the huge Raketeur-Regiment establishment, with Augustin at its head, appeared well justified. In 1859 another war between Italy and Austria flared up, although Augustin did not live to see his troops in action again. He died on March 6, 1859, a few months before his requested retirement would have taken effect. In 1860 his position was assumed by Major-General Friedrich August Ritter von Schmidt, a former captain-lieutenant in the old Fireworks Corps, long involved with its logistics.

While Augustin founded the Austrian rocket establishment and watched its rise, he was spared its decline and eventual abolishment. Already in the revolt of 1859, or the Austro-Sardinian War, both the Austrian Army and the Raketeur-Regiment

suffered reverses. At the Battle of Magenta on June 4th, they faced a Franco-Italian coalition and were overrun. Some raketeurs, nevertheless, were able to ambush some encampments and wound many French soldiers on their march towards the city. A similar outcome followed at the Battle of Solferino on June 24th. The rockets behaved well on the mountains at Solferino, but failed to dislodge the enemy. The Frenchman, Susane, perhaps in a less than impartial tone, said that the Austrian rockets were insignificant and of no real help to the Austrians.¹³ With these events, some officials lost faith in the military rocket, and in 1860 the regiment was reduced in size. But there were still 12 Batterien, and there was also the timely introduction of a new and promising rocket which helped bolster the Austrian Army's confidence in the weapon.

The English civil engineer William Hale approached the Austrians in 1858 with his supposedly more accurate, all metal, stickless or spin-stabilized rockets. After several trials were held (presided over by Schmidt), the Austrians purchased the secret of these projectiles and also his hydraulic presses for the sum of two thousand pounds. The Austrians thoroughly altered the configuration of these rockets and according to an Austrian writer, "retained only Hale's principle." Consecutively, new light, 1.4 kilogram mountain guns were also introduced into the Army and given to the Raketeur-Regiment in 1863 to augment its firepower for mountain warfare. With this change came a new designation for the Regiment and a further reduction in actual number of Raketenbatterien. The Regiment now became the "Raketeur-und Gebirgs-Artillerie-Regiment," or the Rocketeer and Mountain Artillery Regiment." It had 8 Raketenbatterien, 6 mountain gun batteries and 2 field companies.¹⁴

Considerably diluted in strength from its former days, the Austrian rocket establishment could only withstand one more defeat before being abolished altogether. That reversal came in 1866 in the Austro-Prussian War. Nine Raketenbatterien (two at the start) took to the field but were useless against the powerful Prussian artillery, especially their new "Zundnadelgewehr" or breech-loading "Needle guns." Moreover, the mountain-trained Raketeurs were out of their medium in the relatively flat lands of Bohemia, particularly at the strategic battle at Koniggratz. Only in the Italian uprising of 1866, at the Italian naval bombardment of the island of Lissa in the Dalmatian archipelago, did Austrian Raketeurs enjoy any noticeable success. Even so, while the ten 2.7 kilogram rocket guns (stands) ashore withstood the attack and were ably used for defense, their actual effect upon the enemy appears trifling. Austrian rockets served more successfully against the Italians (Garibaldian insurgents) at the Fort of Peschiera, in 1866. (Figure 4)

The demise of the Raketeur-und Gebirgs-Artillerie-Regiment had already commenced in 1864, when its troops began to be transferred to other units. Several



Fig. 4. Austrian rockets at the siege of Peschiera, Italy, 1866, against Garibaldian insurgents. From *Ueber Land und Meer* (Stuttgart), Vol. XVI, Sept. 1868, p. 814

batteries were raised again especially for the wars of 1866, as we have mentioned. This also occurred in 1869 when two Raketenbatterien were virtually resurrected from the ashes, and sent to put down some rebels in Krivosije, Dalmatia (Hungary). After this action, the once numerous and proud Rakettenbatterien were disbanded.¹⁶

AUSTRIAN ROCKET TECHNOLOGY

The state of Austrian rocketry acquired a considerable reputation for its superiority, although the rockets themselves were relatively small. The Russian Konstantinoff--who greatly admired Austrian rocketry and was one of the few persons permitted in the works of Weiner-Neustadt (he went there twice)--observed that though small, the rockets were very accurate. This was achieved by careful fabrication, and by firing at very close ranges, usually at about 731 meters as compared to up to 3199 meters for French and English Congreve models. (The French and English Congreve rockets would deviate greatly in azimuth.) Konstantinoff also remarked that they were

"completely different from the Austrian ones in both their appearance and performance."

Standard calibers throughout the years were 5 and 6 millimeters.

They were designated according to exterior warhead diameter and also classified into applications of field (or light) rockets, and siege (or heavy) rockets. The former were 2.7 and 5.4 kilogram (5 and 6 millimeters) grenade-, shot-, and throwing ("wurf") rockets, incendiary heads, flare balls, and shrapnel rocket; the latter were 7.3 kilogram and 12.7 kilogram bomb, grenade, shell flare ball, and blasthead rockets (Figure 5)

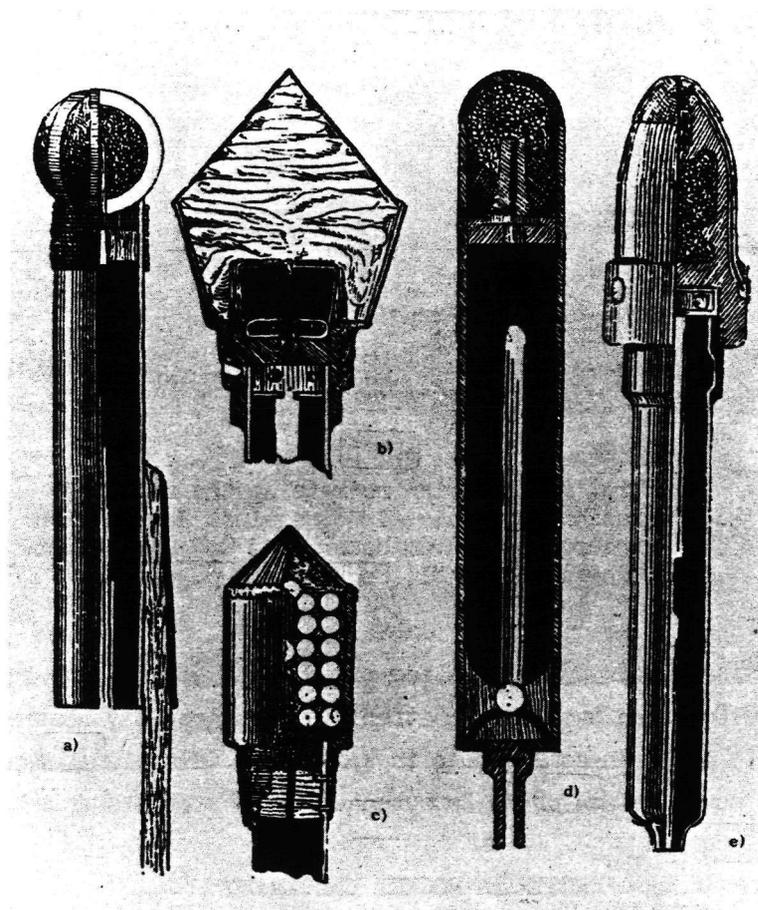


Fig. 5. Austrian rockets. a) stick rocket with grenades, Augustin system; b) light ball rocket head with parachute, for rotation rocket; c) cartridge or shrapnel ball head, for stick rocket; d) first model of Hale rotation rocket [presented to the Austrians]; e) Austrian rotation rocket, with 2.7 kilogram (6-pounder) shell. From Anton Dolleczeck, Geschichte der Oesterreichischen Artillerie (Vienna, 1887, p. 351.

Throwing rockets carried 4.1 kilogram grenades, while shrapnel rockets carried twenty-eight 0.03 kilogram balls, which scattered upon the enemy by a suitable explosive charge and burst at 112.5 to 150 meters. Like the grenade rockets, those with shell balls and blast heads were intended for mine effect. Incendiary heads were long and filled with an incendiary mixture. Flare balls, such as those tested by Augustin in 1821, were for illuminating the terrain and were usually ejected and suspended by parachute when the rocket reached its highest altitude. They attained ceilings of up to 728 meters, and illuminated a circular area of about 243 meters in circumference. On the average the light lasted 2½ minutes and normally could be seen at a distance of about 160 kilometers.¹⁷

Austrian Hale rockets, called "Halle Raketen" or "Rotations-raketen," generally retained these calibers although larger, experimental rockets are known (Figure 6). The usual sizes were the 1.8 or 2.7 kilogram hollow, shell (the shells could be filled with a variety of warheads), incendiary, and lightball rotation rocket. Ranges of stick and rotation rockets were also comparable, with mean ranges of 750 meters, effective ranges of 600 meters, and maximum ranges (with correspondingly very wide dispersions) of 900 to 1425 meters.

While most artilerists considered the rockets of this era very accurate there were perhaps the more discriminating critics who believed on the contrary, that their precision left much to be desired. The truth was that innaccuracy was inherent in all rockets of the 19th century. Standards in all nations were relatively low because of the crude state of the art, especially in propellant technology. Not even the introduction of the Hale stickless rocket saw a noticeable increase in the level of performance for these essentially low-impulse, unguided projectiles. Later rotation rockets did gain somewhat from a higher impulse and hydraulic-pressure rammed propellant. Nonetheless, Austrian stick rockets were impressive in comparative trials with other field pieces of the day. In the late 1850s such a trial was held on a 375 meter course at Linz in Upper Austria. The 5.5 kilogram throwing rocket was tried against 13.6 and 27.3 kilogram mortars and a 4.5 kilogram howitzer. The trial results were:

Of 120 bombs discharged,	34 hit the target:	30% hit
Of 120 grenades discharged,	12 hit the target:	10% hit
Of 158 rockets discharged,	105 hit the target:	75% hit

It is assumed that Austrian rotation rockets would have equalled or excelled these figures in equivalent tests, though the accuracy of other artillery increased markedly in later years, particularly after the Austro-Prussian campaign of 1866. Rockets by comparison, had barely improved, and were soon eclipsed altogether.

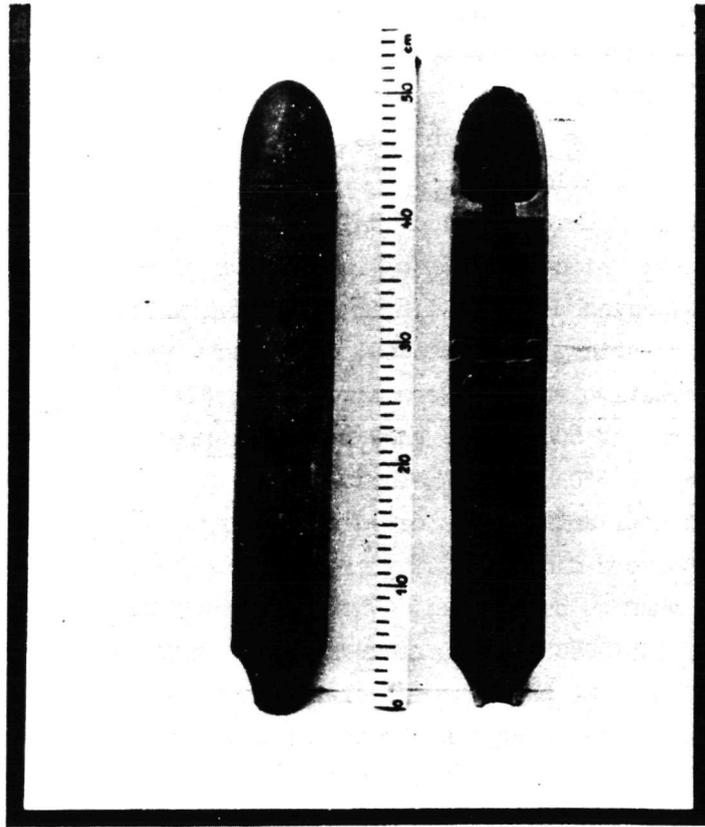


Fig. 6. Austrian Hale "Halle" rocket, 1860, of 5.4 kilogram (12-pound) caliber, shell. From the Heeresgeschichtliches Museum, Vienna.

This relatively static level of technology in the last century is, most significantly of all, the underlying factor in the rise and eventual fall of the 19th century rocket.¹⁸

The introduction of the Hale all-metal stickless rocket and the hydraulic press represented major improvements, but they were not enough for the 19th century rocket to vie with other ordnance. The essential ingredient lacking, as will shortly be evident, was a new higher specific impulse propellant base. Hale's improvements were further ameliorated by the Austrians and were nonetheless necessary steps.

In Austrian manufacture the old stick rocket had a stick usually with square cross section, 280 centimeters long by 2 centimeters thick. For ease in transportation and to prevent warping, it came in two separate pieces of equal length which were clamped and hammered to the rocket casing when ready to use. The Hale rocket dispensed with it altogether and made for easier transportation and handling and the carriage of more rounds. Stick rockets were also less sturdy and were made from a 2 centimeter sheet formed into a cylinder and soldered together. Rotation models, on the other hand, were of iron plate tested at 400 atmospheres and of .2 centimeters gauge.

The cast iron warheads of the rotation rockets were cylindro-ogival, like British Hale rockets, and were either part of the rocket casing itself (as in the first Austrian rotation rockets) or were separate pieces screwed to the casing by a matching thread. Warheads of stick rockets were usually affixed to the casing with canvas cloth, sheet metal strips and string.

Ignition methods improved through the years, and varied from copper percussion fuses to rifle-type percussion locks mounted on the launchers. Ignition of the warheads in stick rockets was accomplished by combustion of the propellant communicating directly to the base of the warhead by a fuse or a wood cylinder with a powder hole drilled through it. In rotation rockets there were either hollowed out channels, "iron-fire tubes," or impact fuses set in the noses of rockets.

The propellant was always the same, *viz.*, gunpowder of low specific impulse, and generally came in the formula of 80 parts saltpeter, 12 parts sulphur, and 14 parts charcoal. In the stick rockets the propellant was manually or mechanically pressed into the case on a spindle cavity at an undetermined and probably uneven pressure ("under utmost compression"). The propellant for rotation rockets was hydraulically charged at 67,200 kilograms pressure on the total surface with the cavity then bored out.¹⁹

Guncotton, developed by the German chemist, Christian F. Schobin in 1845, remained too potent for use as a rocket propellant which required a more stable, slower, and propulsive character. Modified guncotton was, however, later applied to other ordnance pieces which had also benefitted from progress in metallurgy as well as from rifling and breech-loading in the 1860s.

The technological gap between the rocket and other ordnance thus grew ever wider. The Swedish chemist and engineer Alfred Nobel invented a more stable improvement over guncotton called double-base powder, or ballistite, in 1888, but it arrived too late to be applied by the diligent Austrians in the weapons of their Raketenbatterien. Significantly, improved double-base powder later powered nearly all the solid fuel rockets used during World War II.

The 19th century Austrian rocket launchers or "rocket guns," as they were called, were not true guns but tripod mounted launching racks or tubes (Figure 7).

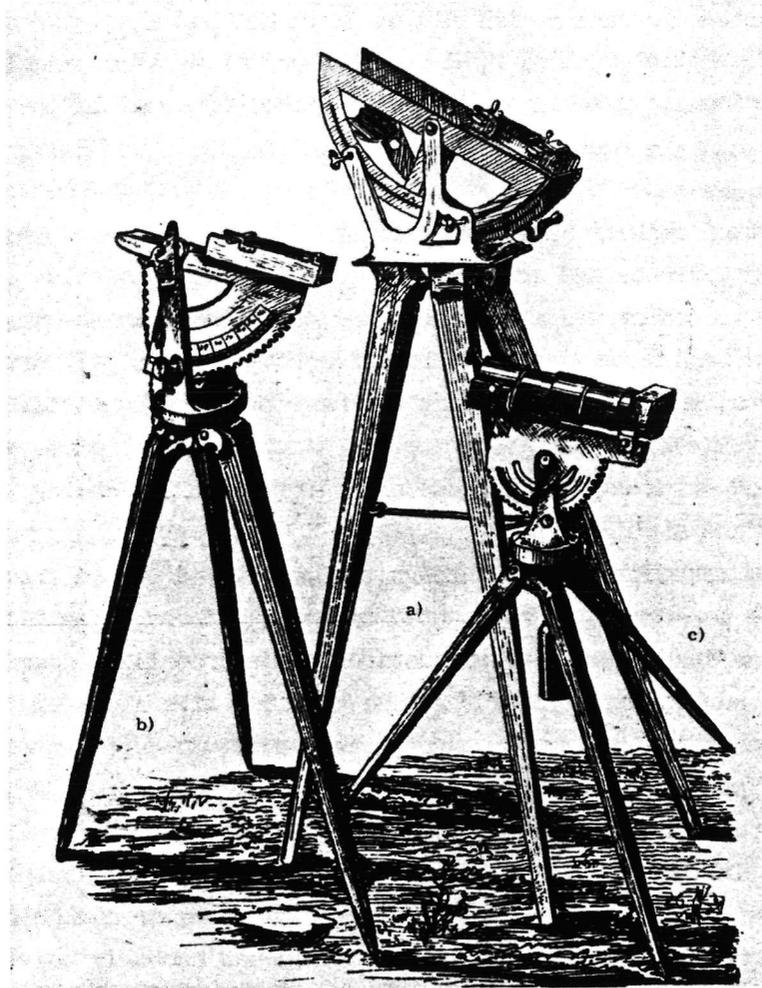


Fig. 7, Austrian rocket stands. a) 10.2 centimeter (4-inch) "anchor" stand; b) 5.4 kilogram (12-pounder) stand for stick rockets; c) stand with counterbalance weight, for rotation rockets. From Anton Dolleczek, Geschichte Der Osterreichischen Artillerie (Vienna, 1887), p. 351.

There were many designs, probably the most advanced being an all-metal open ribbed tube for holding and launching rotation rockets. The usual tripod launcher had wooden tripod legs, squared or tapered at the ends, sometimes with points to steady them on the ground. Most of them also came with quadrants for adjusting the appropriate firing elevation by means of tightening screws. The Austrians favored low firing elevations, usually set at 25 degrees. Some also had sighting devices and also percussion locks attached.

In one model of a rotation rocket, a 4.5 kilogram metal bob was suspended under the stand to help steady the stand during firing. This particular stand had an

overall weight of 11.8 kilograms and could easily have been carried by one man, or dismantled and carried by several. Most had a weight of about 9 kilograms or less. "Wursts" also varied over the years, as did launcher carts. A Raketenbatterie usually consisted of 6 "wursts" and 3 carts, with additional carts in reserve. In the 1840s the typical munition supply of a battery was about 700 rounds, depending upon caliber and rocket class. Wursts also carried sticks and fuses, and transported the troops of the batteries who in the 1840s consisted of one gunner, three corporals, and 36 men. In turn, they were serviced by the maintenance companies. In short, Raketenbatterien were self-contained units.²⁰

The Austrian rocket establishment in its equipment and foundations, its growth and decline, was not unique. It differed in being the largest, best organized, and most sophisticated of many rocket establishments in Europe, and thus was a perfect example of rocket technology of the age.

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HUNGARIAN ROCKETRY IN THE 19th CENTURY⁺István György Nagy (Hungary)⁺⁺

HISTORICAL BACKGROUND

Hungarian rockery in the last century developed in close connection with the memorable historical events that took place during 1848-1849. The Hungarian Revolution and the War of Independence shook the Hapsburg Empire to its very foundations and, though at the end the heroic Honvéd army had to yield to superior numbers, the Revolution rendered possible the development of modern Hungary. These important events also saw rockets adopted and used in the Hungarian Revolution and the War of Independence.

The Paris Revolution in February 1848 was followed by revolutionary risings in a number of European countries, chiefly in the countries of the Hapsburg Empire. Under the pressure of the March Revolution in Hungary, the Imperial government conceded to some of the Hungarian national demands. Though still part of the Empire, Hungary was invested with some independence, and the Austrian Emperor—as King of Hungary—appointed the first independent Hungarian ministry, the Batthyány government in which Lajos Kossuth, the Minister of Finance, played a leading role.

After making the involuntary concessions to Hungary, the Imperial Court made every effort to repeal them. This effort became increasingly pronounced with the decline of the European revolutions. During the summer of 1848 an armed conflict was expected, and the Batthyány government initiated the organization of an independent Hungarian army. The Imperial forces launched an invasion in September, but the new Honvéd army repulsed the attack. In this critical situation the Batthyány government abdicated, and the Hungarian Parliament invested ruling power in the National Defence Committee under the presidency of Kossuth. The new revolutionary government was confronted with the enormous task of organizing the armed defense of the country.¹

One of the most important aims of the October 1848 Revolution in Vienna was to thwart plans for another invasion of Hungary. But the revolution was suppressed, and Hungary was again invaded. The Hungarian army retreated step by step before the enemy, and in January 1849 the Imperial troops took possession of Budapest.

⁺Presented at the Sixth History of the International Academy of Astronautics, Vienna, Austria, October 1972.

⁺⁺Hungarian Astronautical Society, Budapest, Hungary.

The Kossuth government transferred its seat to Debrecen, and from his town energetically organized the national defense.²

Side by side with the Hungarian honvéds fought foreign volunteers, mainly Poles, Italians, Austrians, and Germans. Besides the illustrious Hungarian military leaders, several commanders of foreign origin played a significant role, including the Polish generals Józef Bem and Henryk Dembiński, and the English general Richard Guyon.

In the spring campaign of March 1849, the Hungarian army started a successful counter-attack and liberated the greater part of the country. The Parliament declared the independence of Hungary and dethroned the Hapsburg dynasty. But after these victories the fortune of war took an unfavorable turn. Upon concluding a military expedition in Italy, a considerable number of Austrian forces were transferred to the Hungarian front. In addition, the new Austrian Emperor, Franz Joseph, asked the Czar of Russia for assistance, and in June the troops of the Czar crossed the Hungarian frontier. The numerical superiority suppressed the War of Independence, and general Arthur Gorgery, the commander-in-chief of the Hungarian revolutionary army capitulated at Világos³ in August 1849.

THE AUSTRIAN ROCKETRY IN THE FORTIES

The Hungarian revolutionary army withstood the experience and numerical superiority of the Imperial forces for almost an entire year. The resoluteness of the Hungarian army, the activities of a number of revolutionary organizers and military leaders, and the efforts of the newly established national arms factory⁴ which supplied the army for a while with various up-to-date weapons, among them war rockets, made this possible.

At this time the armies of the great European powers had introduced Congreve's war rockets and formed rocket corps, either as an independent branch of service or attached to their artillery. In the Austrian army a modified type of war rocket was employed. These rockets were designed in 1815 according to the conceptions of Vincenz Augustin,⁵ an Austrian major born in Hungary.⁶ For services rendered, Augustin later was made a baron and promoted to general.⁺ In 1844, four years before the Hungarian War of Independence, William Hale in Great Britain patented his invention, the spin-stabilized stickless rocket.⁷

⁺See Frank H. Winter, "Baron Vincenz Jon Augustin and His Raketenbatterien: A History of Austrian Rocketry in the 19th Century," in this volume--Ed.

The Hungarian rocket technicians were mainly former non-commissioned officers who had completed their military service in the Austrian rocket corps (called the "Firework Corps"). They were acquainted only with Augustin-type rockets, and the organization of the Hungarian rocket units was similar to the Austrians. For this reason it is important to briefly survey the state of Austrian rocketry.

Rocket troops in the Austrian army were organized in the same way as the field-artillery. The rocket batteries consisted of six so-called rocket guns. The rocket gun was not a true gun; this name was used to designate a complex of one or two launchers, the ammunition supply (about 200 rounds) and means of transport (one or two carriages).⁸ The all-metal launching rack or tube was mounted on wooden tripod legs. To direct the appropriate firing elevation its upper part bore a quadrant with adjusting screws. The launcher was provided with a sighting device and lock to actuate the percussion-cap of the rocket. Taken down from the transport carriage, the launcher could be carried by one man.⁹ It had an overall weight of 19 Viennese pounds (10.5 kilograms).¹⁰ Five men tended a rocket gun.

The rocket ammunition consisted of three parts: the rocket itself, the warhead, and the guiding stick. The cylindrical rocket case was made of sheet-iron, with the propulsive charge (gunpowder) mechanically pressed into the case. Contrary to Congreve's rocket where the charge was ignited by a firing-tape, the Augustin-type was ignited by the percussion-cap mentioned above.¹¹

As is well known, the guns in the Austrian artillery about this time were not characterized by their calibres, but in a traditional way, regardless of the type of the projectile, by the weight of an iron cannon ball which fitted into the gun barrel. This designation was extended to rockets, and the Austrian rockets were classified according to the nominal weight of their warheads. For example, the rocket of 6 (Viennese) pounds (3.4 kilograms) carried the same warhead as the projectile of a gun of 6 pounds. Thus, the true weight of the rocket or of the warhead considerably differed from the nominal one.¹²

According to this nominal weight and the tactical use, the Austrians made a distinction between field or light rockets, and siege or heavy rockets. The former were of 6 and 12 pounds (3.4 and 6.8 kilograms), the latter of 16 and 28 pounds (9 and 15.7 kilograms). At the time of the Hungarian War of Independence, the Austrian field batteries were equipped with rockets of 6 pounds. There were shotrockets ("Schussraketen") with a grenade, canister (Shrapnel), and incendiary warheads, or with flare balls. Another type was the throwing rocket ("Wurfraketen"). These carried howitzer-grenade warheads and, contrary to the shotrockets which moved on flat trajectories, flew steeply.¹³

ROCKETRY IN THE WAR OF INDEPENDENCE

The problem of securing adequate armaments proved every bit as difficult as organizing the independent Hungarian army. Military preparations were greatly hampered because the available supply of war materials could not satisfy demands. To solve this problem, the government set about both buying arms from abroad and starting the production of arms at home.¹⁴ However, after September 1848, it was not possible to buy a considerable amount of arms abroad because after the start of the armed conflict the country was practically blockaded. Nevertheless, plans for importing war materials were not abandoned until the end of the War of Independence.¹⁵

Many difficulties plagued the quick development of the home manufacture of arms too. In the middle of the 19th century Hungary had an underdeveloped industry, and there were only a few engineers, technicians, and other specialists skilled in arms production. Moreover, the available machine stock was quite incomplete, and efforts to get machines from abroad also failed. Part of the machinery for the new national arms factory, established in Budapest, was designed and made by Josef Szkopál,¹⁶ a man later to become a designer of rockets. We know of only one foreign expert employed in the arms factory: French chemist Chateau who directed the production of fuses.¹⁷

Another possibility was to invite foreign pyrotechnists into Hungary and, with their assistance, produce war rockets. Ferenc Pulszky, the Hungarian under-secretary of state, entered into negotiations with the Viennese pyrotechnist Anton Stuger, but these talks were broken off with the collapse of the October Revolution in Vienna.¹⁸ The government made attempts through diplomatic channels to obtain other foreign specialists. The Hungarian Prime Minister, Lajos Batthyány, turned to the Foreign Secretary of Great Britain, Viscount Palmerston, in August 1848 and asked him to detail a British officer to Hungary--one who had knowledge of rockets.¹⁹ There is no evidence of further developments of this action; presumably the Foreign Office left the request unanswered.

About this time negotiations with William Hale were initiated. By the way, Hale's connection with the Hungarians continued even after the suppression of the War of Independence. According to contemporary records, the Batthyány government sent a special delegate to Great Britain, Fedor Karacsay, to talk with Hale.²⁰ Repeated negotiations were carried on with him. We learn from a letter, written in May 1849 to Ferenc Pulszky, then the head of the Hungarian diplomatic mission in London, that these talks proved unfruitful.²¹

Nonetheless, the Hungarian armaments program included the production of rockets. Sándor Mózer, a one-time non-commissioned officer of the Austrian rocket corps, appeared in October 1848 with his own rocket design. He obtained good results from experiments which lasted about six weeks. Though working with simple tools, he

succeeded in making good launchers and rockets, which a military commission assigned to firing tests in December 1848.

These rockets were of 3 and 6 pounds, fitted out with a simpler device to ignite the charge. Instead of Augustin's percussion-caps, the charges of the new Hungarian rockets were ignited by Congreve-type firing-tapes. Since there were no pressing machines available to fill the charge into the rocket case, Mózer had to do this operation manually.

The December firing tests also brought favorable results; the range of these rockets was as high as 2200 paces (about 1650 meters). In keeping with the recommendations of the above mentioned military commission, the Minister of War promoted Mózer to lieutenant of a newly established Hungarian rocket corps. Mózer's two comrades, Károly Unger and József Vilfling--also one-time non-commissioned officers of the Austrian rocket corps--received the same commission.²²

But the production of the new rockets had just begun when Budapest was occupied by the Imperial troops, and the arms factory was speedily relocated to Nagyvárad²³ in the last days of December 1848. Owing to excellent organizing work, after an interruption of only two weeks, arms production started again. A rocket department was set up in the factory under the direction of Szkopál. Mózer continued his work in this branch of arms production. Szkopál designed rockets of 7 pounds, and, with this heavier type, he achieved a range of 1400 paces (about 1050 meters). It may be presumed that later Szkopál improved his results by making a thorough examination of captured Austrian rockets.²⁴

Soon after the production recommenced in Nagyvárad, three rocket-guns--namely a half-battery--were sent under the command of Vilfling to Bem's forces in Transylvania.²⁵ Eventually, the factory assembled one such half-battery of rockets weekly, and placed them at the army's disposal. Besides the above mentioned types of 3, 6, and 7 pounds, a few rocket guns of 12 pounds, and some of 4 pounds, were produced.²⁶ Exact figures of production regrettably have not survived. According to conservative estimates, the Hungarian arms factory produced about 50 rocket guns during the War of Independence.²⁷

The activity of one of the heroes of 1848-1849, Áron Gábor, is also connected with Hungarian rocketry. Áron Gábor appears in Hungarian military history mainly as an outstanding gun-founder. This eminent technician and organizer established a gun-foundry in the Transylvanian town of Kezdivásárhely.²⁸ Later, in May 1849, he visited the arms factory in Nagyvárad and made a study of the production of rockets. Returning home he began to make use of his new knowledge; we learn from one of his letters that the rockets he made were put to test in June 1849. Some weeks later, however, he was killed in action.²⁹

The rockets were put into action in the first phase of the war, mostly in engagements in mountainous terrain.³⁰ In December 1848 and January 1849 the Imperial forces employed rockets at Szikszó, Kassa,³¹ Tokaj, and in February at Igló.³² The latter engagement was a remarkable one. In a surprise night attack, a great part of the town of Igló was destroyed by incendiary rockets. In repulsing this attack the Hungarian troops under Colonel (later General) Guyon's command overran and captured one rocket launcher and some hundred rockets.³³

In the spring campaign the Imperial troops engaged rockets in warding off the Hungarian attack at Petervasara as well as in the battles of Kápolna and Isaszeg.³⁴ The Hungarian army put rockets into action in the siege of the fortress of Buda (on the western part of Budapest).³⁵ The rockets played a part in the Transylvanian military operations too. Besides the minor engagements, at the siege of Gyulafehérvár³⁶ some rocket guns were employed by Bem's forces.³⁷

According to the battle order of June 1849, the Imperial forces had on the Hungarian theatre of war altogether 68 rocket guns. At the same time, under the Hungarian battle order, there were 28 rocket guns at the Honvéd army's disposal. In the battle order of the interventionist Russian troops, rockets were not to be found. Austrian rocket batteries were detailed to these troops.³⁸ In the last phase of the war³⁹ the Imperial troops put rockets into action in the battles of Szeged, Szóreg and Temesvár.⁴⁰ The Hungarian forces, on the occasion of laying down arms at Világos, handed over 12 rocket launchers and 158 rockets to the Russian army.⁴¹

HUNGARIAN CONNECTIONS WITH THE ROCKETRY OF THE FIFTIES

After the suppression of the War of Independence, Hungarians in exile made plans for an armed uprising in their country. Kossuth, then the leader of the Hungarian refugees, entrusted the former General János Csetz in 1851 to take care of the production of war rockets.⁴² Kossuth renewed relations with William Hale who, on Kossuth's initiative, employed in his rocket factory some Hungarian refugees. Taking part in this action was August Usener, a one-time officer of the Prussian and later of the Hungarian army.⁴³ Based upon a denunciation by Usener, an inquiry was instituted against Hale in 1853, and so this plan of Kossuth was frustrated.⁴⁴ It is worth mentioning Karl Marx reported about this so-called Rocket Affair in a New York newspaper.⁴⁵

A few years later, another Hungarian scientist began activity in the field of rocketry. Lajos Martin, then an officer of the Austrian engineer corps, made a design for a spin-stabilized rocket in 1856, and investigated some problems concerning the theory of rockets. Leaving the army he published some details of his studies in the journal of the Hungarian Academy of Sciences in 1860.⁴⁶ The priority of William Hale as inventor of the spin-stabilized rocket is beyond dispute. Nevertheless, everything

points to Martin as being the first who worked out a mathematical method of dimensioning for stress this type of rocket. In this manner Martin was one of the pioneers in the field of theory of rocket technology.

Martin later got the professorship of higher mathematics in the newly founded University of Kolozsvár⁴⁷ and was elected a member of the Hungarian Academy of Sciences. His later scientific activity concerned the theory of aviation.⁴⁸

Thus, rocket development in Hungary during the last quarter of the 19th century, as in other countries, came to a standstill.

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NONMILITARY APPLICATIONS OF THE ROCKET
BETWEEN THE 17th AND 20th CENTURIES⁺

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Besides pyrotechnic display, nonmilitary uses of the rocket began as early as the 17th century when the need for visual communications at sea was recognized. Thus, one can say that this use is one of the earliest in "applied" rocketry. But the first commercial application involved fishing.

THE WHALING ROCKET

The 17th century saw the invention of the whaling rocket, or rocket driven harpoon. The earliest accounts of such a device are fragmentary. Apparently the first such rockets were developed by Abraham Speeck, a painter, firework manufacturer, and all-round inventor of Amsterdam. In 1637, Speeck commissioned Captain Cornelis Pietersz Ys, a Dutch whaling master, to try out the whaling rocket harpoon. Ys completed the trials on April 24, 1638, in the Arctic Sea off the coast of Spitzbergen. Witnesses observed that the rockets were as ineffective against whales as musket balls. Specifically, the rocket was too heavy and unwieldy to be used in an open whaling boat bouncing about in the sea.¹

Development of the gun, the growing technological competitor to the rocket, outpaced further research into the whaling rocket for almost two centuries. The first whaling gun probably made its appearance in 1731. However, William Congreve, the rocket entrepreneur of the early 19th century, revived the idea of a rocket harpoon. In 1821, Congreve and Lieutenant James Nisbet Colquhoun, A Royal Artillery officer, received Patent No. 4563 for "Application of Rockets to the Destruction and Capture of Whales." The broad-brush patent covered various means of launching such harpoons, including the musket, the rocket tube, and the cannon, from open decks and under the sea. It even

⁺Presented at the Fourth History Symposium of the International Academy of Astronautics, Constance, German Federal Republic, October 1970.

⁺⁺Alabama Space and Rocket Center, Huntsville, Alabama.

included the use of rockets to kill whales after they had been struck by conventional harpoons.

However, the two men did produce at least one type of whaling rocket. It is currently on view at the Rotunda Museum of the Royal Arsenal, at Woolwich. The rocket was manufactured at Congreve's private rocket factory at Bow, in Essex, beginning in 1817. At least the whaling rockets were known to have been manufactured there as late as two years after Congreve's death in 1828.² In 1821, Sir William Scorsby, Sr. took a supply of them aboard Fame, along with its coinventer Lieutenant Colquhoun and two gunners from the Royal Arsenal to instruct the ship's harpooners in how to use them.³ There can be no doubt as to the efficacy of the rocket in this particular occasion. Late in the year Scorsby wrote to Congreve that his rockets succeeded beyond expectation in killing whales.⁴⁻⁵

Following Congreve, Captain Thomas Welcome Roys, the first American whaler to penetrate the Bering Straits in 1847, took an interest in the technology. A decade later he received a patent for a whaling rocket in England, apparently having conceived the idea while in Portugal. The design attached to Patent No. 3201, issued on September 2, 1857, in England, also shows a striking resemblance to the Congreve whaling rocket. It is said that he tested his rocket at Woolwich Arsenal between 1856 and 1865. His first American patent on the rocket did not appear until January 22, 1861. He later patented his rocket in several European countries, in conjunction with a partner: Gustavus Adolphus Lilliendahl, a New York city firework maker and owner of a whale-bone cutting house, who seemed an ideal partner to engage in the whaling rocket venture.

The Roys and Lilliendahl whaling rocket received its first sea trials during the whaling season of 1865-1866, at the end of which Roys withdrew from the venture. The two had established a whaling station in Iceland, and attracted the attention of several prominent Europeans, in particular, Captain-lieutenant O. C. Hammer, a Dane and veteran of the First (1848-1850) and Second (1864) Schleswig Wars with Prussia. Hammer apparently gave several of the rockets to the skilled firework manufacturer Gaetano Amici, whose displays were world famous in Copenhagen's Tivoli Gardens. For several years Amici worked on improving the Roys and Lilliendahl rocket with little success. However, he did develop and later patent a whaling bomb (fired from a cannon) that may have influenced the famous Sven Foyn, the Norwegian whaling master who invented a gun that effectively did away with the rocket, as well as the hand-thrown harpoon, for killing whales.

Nonetheless, Lilliendahl entered into patent arrangements for the whaling rocket with the firm of Fletcher and Suits, Inc., of San Francisco, sometime in 1878. Fletcher and Suits modified the basic Roys and Lilliendahl rocket in several ways, after having test-fired a number of them to assure themselves that the idea itself was practical. They increased its overall weight and substituted a more energetic gun-

powder for both its motor and warhead. With the modifications made by Fletcher and Suits, the whaling rocket became 2.1 meters long, 7.62 centimeters in diameter at the motor case, and weighed about 14 kilograms. It reached a range between 50 and 60 meters.

The California rocket proved to be very successful. It was particularly effective in the Arctic Ocean where its 50-meter range permitted the whalers to get at the "shy" bowhead whales, a very difficult task for an open boat with hand-thrown harpoons. There seems to be little reason to doubt the contemporary newspaper accounts of how good the rockets were and the catches attributed to them. Captain Bernard Cogan of the bark Rainbow was so impressed with a demonstration of the California whaling rocket that he ordered a number of them for his vessel, and he was the inventor of the Cogan breech-loading bomb gun, a competitor for the rocket.⁶

The only other whaling rocket commercially produced during the latter part of the 19th century was the Cunningham whaling rocket, invented in 1880 by Patrick Cunningham, a former crewman on Captain Cogan's Rainbow. It was a modification of his lifesaving rocket discussed below. The rocket had a gun barrel loaded with a bomb-lance attached to it. The rocket propelled the harpoon into the whale and the gun fired the bomb-lance into it. The rocket is said to have been used chiefly in near-shore fisheries, but no contemporary descriptions of its use and effectiveness have been found.⁷

While the whaling rocket certainly proved itself practical, and in at least one case superior to any other type of harpoon for use in the open boat, it fell into disuse before the end of the 19th century. For one thing, the whaling gun had been vastly improved by Sven Foyn. Largely, however, it seems to have been a question of economics and logistics. The California whaling rocket cost \$50 each, with no known discount for large lots. The whaling rocket was also subject to damage in a rolling, tossing, and pitching ship, and the damp environment affected its powder charge. Rockets exposed for long periods to the environment of the whaling ship often did not fire, or burst prematurely upon ignition.

THE LIFESAVING ROCKET⁸

Considering the relative inaccuracy of the rocket weapons in the 18th, 19th, and first half of the 20th centuries, it is quite possible that more lives were saved by rockets than were taken by them. Between 1871 and 1962, in Britain alone, 15,000 lives were saved from shipwreck by the lifesaving rocket. A Frenchman, A.M. Ducarne-Blangy, "a gentleman of Picardy," claimed in 1791 to have fired a lifesaving rocket at Féré; however, there is no documentary evidence to the fact. On the other hand, he definitely fired such a rocket "in the month of Thermidor of the 7th year"

of the new French republic. The test, in July or August of 1799, was witnessed by an official committee of the new government, including two Admirals, Rosily and de Missiessy. The rocket Ducarne-Blangy used was undoubtedly a commercially available one. The motor case was 32 millimeters in diameter, and it carried a 3.4 millimeter wire attached to its stabilizer stick to a range of 165 meters. He also fired rockets with diameters of 42 millimeters and 48 millimeters, which reached ranges of 192 meters and 177 meters—the former with a silk cord 6.77 millimeters in diameter. Nevertheless, the committee seemed unimpressed. Again, in 1805, he tried unsuccessfully to interest the French government in this humanitarian device.

Ducarne-Blangy fired his rockets from ship-to-shore rather than vice versa. His reasoning was logical in view of the state of the technology of rocketry at the time. Generally speaking, the winds in the situation would be toward the shore. The tail-wing materially improved the range of the rocket, and the shore presented a much larger target for the unpredictable rocket. While opinion as to the more efficient mode—ship-to-shore or shore-to-ship—varied over the following 150 years, both modes were developed in parallel.

The first British entrepreneur in the lifesaving rocket was Henry Trengrouse, a cabinet-maker of Helston, in Cornwall. Born on March 18, 1772, Trengrouse was reared on a part of the English coast where wrecks were commonplace. On December 29, 1807, he watched in horror as the frigate Anson battered itself to pieces on the rocks beneath the cliffs of Mount Bay, near Land's End. It seemed to him incredible that there were no means of saving the lives of the 100 crewmen and passengers that were lost only 100 meters or so from the shore. That catastrophe caused Trengrouse to devote the rest of his life to perfecting some means of saving the lives of the shipwrecked. The geography and rough seas off the Cornish coast quickly convinced him that the lifeboat (invented only 17 years earlier) was not the answer to the local problem. The mortar, heavy as it was, could not be readily handled among the rugged cliffs.

Trengrouse spent a decade and £3,500 of his own money in developing the first lifesaving rocket. We know nothing of the details since he worked in secrecy. On April 28, 1818, he demonstrated it at Woolwich Arsenal, and at least two types of modified commercial skyrockets were used: a 227-gram model with a mackerel line, which reached 188 meters; while a 0.5-kilogram model with a similar fishing line carried to 233 meters. But William Congreve, the comptroller of the Royal Arsenal, was the man commissioned by the Lords of the Admiralty to undertake the design of a lifesaving rocket.

William Congreve prepared six sets of his lifesaving rocket by October 9, 1825, and they were ready for sea trials in the following year. The rocket he proposed was his 14.4 kilogram war rocket modified with an anchor or grapnel instead of the usual explosive or incendiary head. So modified, the rocket weighed 27 kilograms. Attached to the end of the stabilizer stick was a pulley through which was run a double

line. In theory, the rocket impacted on the beach and dug in. The double line was attached to the mast or super structure of the ship.

Fastened to the double line was a spherical life-buoy that sounded good in practice. It had an off-set center of gravity that would keep the occupant upright in the buffeting wind and sea. The occupant pulled himself to shore with the double line. Once he was safely ashore, the buoy was hauled back to the ship. Since the buoy was open, it readily filled with water and the occupant found himself trying to pull against the drag of water rather than air. Several trials were made with Royal Navy ships detailed for the purpose at Portsmouth, Plymouth, and Chatham. The results were uniformly discouraging. Some rockets reached the beach as planned; others gyrated through the air because of the altered ballistics induced by the pulley and trailing line. The sets not used were quietly returned to stores, and Sir William just as quietly withdrew from further exploits in life-saving rocketry as he had done earlier in the whaling industry.

Next to appear on the lifesaving rocket scene was John Dennett, born at Carisbrooke, Isle of Wight, on September 25, 1780. He also felt that the ship-to-shore mode was optimum.⁹ Dennett at first adapted the 5.4 kilogram Congreve rocket launched from a tripod-mounted tube for use in the shore-to-ship mode and a railing clamp in the ship-to-shore mode. The rocket, with a lifeline attached, attained a range of 300 meters in a test before officers of the Royal Navy on January 18, 1826. Impressed by the performance, the Navy established rocket lifesaving stations at three locations on the southern coast of the Isle of Wight.

Over the next dozen years, Dennett continued to improve his system. With the help of his son, he began manufacturing his own 4-kilogram rockets with a 3.6-meter stick. He tested it several times against the Manby mortar. Its performance in each case was impressive, especially when his system weighed 70 kilograms against which the Manby mortar weighed 260 kilograms. In 1828 Dennett sought to increase the range of his rocket by clamping two of them together. While his parallel-step model did reach 400 meters, it proved very difficult to achieve simultaneous ignition. This technical flaw notwithstanding, the 8-kilogram double rocket remained the official English rocket until 1865. Many of them stayed in stores for much longer--in 1890, the crew of the Ibex was taken off by one of them after the ship had wrecked in Scrachell's Bay, Isle of Wight.

Following Dennett as a pioneer in lifesaving rocket development was Alexander G. Carte, a native of Hull, Yorkshire. By 1825, he had been appointed Ordnance Storekeeper and Barrack Master at the Citadel in Hull. He began experimenting with various commercial rockets and different sizes of lines. By 1836, he offered his first set for sale, and by 1851 they were in use in 29 lifesaving stations in seven English counties and at a few stations in Denmark as well. Carte furnished launchers

for both the ship-to-shore mode and the shore-to-ship mode and his system was used in both. The rockets were carried in a chest with the necessary cordage and ancillary equipment. A 54-kilogram set cost only £18.8s.

By mid-19th century, Edward M. Boxer, Superintendent of the Royal Arsenal, solved the problem of greater range for the life-saving rocket. He developed a tandem step rocket, a design which had been known as early as the mid-16th century. It consisted of one motor case forward of another. At burnout of the first, the second ignited, boosting the velocity. However, it is important to realize that Boxer's rocket was not a two-stage rocket. The first motor did not drop off after burnout. On March 15, 1865, the Boxer rocket officially replaced the Dennett double lifesaving rocket. The rockets were manufactured at Woolwich Arsenal and were licensed for export by the Board of Trade. While the Boxer 5.4 kilogram was widely adopted in England, its costs tended to militate against its use in other countries. The Boxer rocket remained in service for more than 80 years, and between 1840 and 1912 it was responsible for saving 9,407 lives.

As the 19th century drew to a close, William Schermuly, a former British seaman himself, undertook to improve upon the life-saving rocket. As early as 1887, he decided that the ship-to-shore mode was the more effective and began development of such a system which he exhibited at Queen Victoria's Diamond Jubilee Exposition a decade later, where it won a gold medal. Schermuly's rocket, despite its paper case, had a range of 285 meters. The unit was very compact, with the trough launcher being clamped to the lid of the box containing the lifeline. The entire unit was hung over a line to minimize the rolling of the ship. The lifesaving line was faked into the box in a special pattern that insured it would pay out after the rocket without fouling or kinking.

It was not until 1912 that Schermuly began to realize a commercial success with his compact lifesaving unit. He later replaced the paper case with a more substantial metal case and used a modified pistol for the launcher. His models found a ready market in several European and Asian countries. In 1948, when the Boxer rocket was officially superseded, the Schermuly became an accepted substitute. In 1965, Schermuly's company switched to a cordite or double-based propellant instead of gunpowder in all rockets except the 12-pound heavy-duty Coast Guard model.

Germany also produced a lifesaving rocket—two, in fact. Both were the products of the Royal Firework Laboratory at Spandau. The rockets were manufactured at the request of the Deutsch Gesellschaft zur Rettung Schiffbruechiger (DGzRS). The rockets produced were modifications of the German 8-centimeter war rocket. The resulting rocket had an overall length of 1.8 meters and a weight of 19 kilograms and could carry a line to 390 meters. A 5-centimeter rocket with a range of 295 meters was also developed. The 8-centimeter rocket also could be fitted with an anchor head to convert

it into a kedging rocket. Fired from shore toward the sea, it anchored in the bottom, permitting the crew of a lifeboat to haul themselves to a wreck in a heavy surf where oars would little avail. The 5-centimeter rocket was used by the DGzRS primarily for training purposes, although other countries used it for lifesaving purposes.

Sweden's venture in the lifesaving rocket was a modified war rocket developed by Wilhelm Theodore Unge in the late 1890s. It was a spin-stabilized rocket similar to the Hale design with a range of 270 meters. The unit weighed 75 kilograms complete and was housed in a wheeled container. The rocket was ignited electrically, and a few seem to have been sold in England, Australia, and India. But the venture as a whole was a commercial failure.

The only successful American lifesaving rocket was that of Patrick Cunningham, a former whaler and one-time President of the American Carrier Rocket Company of New Bedford, Massachusetts. He patented his first model in 1882. The Cunningham rocket had a novel feature in that the lifeline was coiled into a steel cylinder that formed the stabilizer stick of the rocket. Overall it measured 2.2 meters in length and 8.75 centimeters in diameter. It weighed 20 kilograms and had a range between 300 meters and 765 meters depending on the weight of the lifeline used. At least 20 stations were provided with them in 1888. Only one specimen is known still to exist--in the Twin Lights Historical Association Museum, Long Branch, New Jersey. This rocket also has a trough-type launcher made of open tubes and attached to a tripod fixed at a 45-degree angle to give maximum range. In 1891 Cunningham patented a novel wooden shipping crate for the rocket that converted into a launcher for use in the ship-to-shore mode of operation. Cunningham died in 1921, but his interest in rockets had waned several decades earlier.

COMMERCIAL SIGNALLING AT SEA

As early as 1889, F. Cundall sought to get an international agreement for a standard set of pyrotechnic signals at sea. He was not successful; but toward the end of the century the rocket, in conjunction with other pyrotechnics, found an important application in pre-radio communications.

Near the end of the 19th century and in the early years of the 20th century elaborate codes were worked out by shipping companies to identify ships as well as the nature of their cargoes and destinations. For example, a vessel of the Cunard Line passing a shore station in Ireland would fire a blue light followed by gold star rockets to identify its company. In October 1903, Elders & Fyffe, a leading British fruit company, registered its own special code of signals with Lloyds of London. A green light forward and a red light aft, from an Elders & Fyffe ship, meant "3,000 to 5,000 stems ripe and turning;" a red light forward and a green light aft meant "5,000

to 10,000 stems ripe and turning. Proceeding to Liverpool."

With such information as this in hand, company agents could begin making sales before the ship even docked. However, Marconi rapidly developed wireless telegraphy and commercially exploited it, forming his own company in 1900. The shipping companies were among its first customers, and the rocket was relegated to a stand-by or emergency means of communication.

THE SOUNDING ROCKET BEFORE GODDARD¹⁰

The concept of the rocket as a high-altitude platform for scientific instrumentation had its immediate forerunners in the work of a Frenchman and two Germans at the end of the 19th century. Armédée Denisse, a French pyrotechnist, in 1895 sent a camera aloft on a rocket in what was probably the first such use for the rocket. Ludewig Rohrmann, of Drauschwitz, and Alfred Maul, an engineer of Dresden, also conceived of the rocket as a means of taking pictures from high altitude.

Rohrmann received a German patent on his apparatus (No. 64,209) on July 14, 1891. In view of the complexity of his photographic apparatus it is unlikely that his device was ever successfully developed. The camera was to have been powered by a clock-work which would operate the shutter as well as position and remove the film holders. It also was to have been suspended from a parachute on a universal joint. Both the parachute and camera were to have been recovered by a cable attached to them and paid out from a winch during the flight of the rocket. How such a mechanism would have withstood the forces of launch and parachute opening is hard to imagine.

There is no doubt, however, that Alfred Maul's photo-sounding rocket was a reality. Maul designed, built, and launched a rocket that did take pictures at altitudes of 800 meters. His first flight was made in 1904 and he continued experiments until 1914. His initial efforts met with little success. The black-powder propelled rocket boosted a camera to an altitude of 300 meters. The camera carried a film plate 40 millimeters by 40 millimeters, but the shutter did not always work and the parachute recovery system frequently failed. The rocket motor and nose cone (with camera and parachute) was one meter long and 10 centimeters in diameter and the stabilizer stick some 4 meters long.

Maul concluded from his first experiments in 1901 that he would have to build larger rockets if he were to achieve the degree of ruggedness and reliability he wanted. Over the next few years he built and tested rockets of succeeding larger size. For his propulsion units he used clusters of the 8-centimeter rocket produced by the Royal Fireworks Laboratory at Spandau. The overall length increased to 4.6 meters and the weight to 25 kilograms, an improvement that resulted in an altitude of 500 meters. By 1912, he had a rocket 6 meters long and a weight of 42 kilograms. It

carried a 138-millimeter focal length camera with a photographic plate of 200 millimeters by 250 millimeters that produced extremely good detail from a height of 800 meters.

The system Maul produced was highly sophisticated from a technical viewpoint, and by 1914 it had achieved a respectable degree of reliability. A conical nose cone containing a camera mounted on a gyroscopically stabilized platform was attached to a cylindrical housing that enclosed the parachute recovery device. The camera shutter was tripped by an electro-pneumatic device powered by a small battery and an inertial switch that functioned when the rocket reached its maximum ordinate. It also released the parachute. This payload compartment was mounted on the rocket motor which was ignited by electrically fired squibs. It featured a long stick to assist in stabilization during flight, and the stick had four fins at the aft end to prevent axial rotation of the rocket. The parachute was attached to the payload compartment and the rocket motor and stick by a 10-meter line. The payload compartment was attached at a point considerably above the rocket. Thus, the heavier rocket struck the ground first and the camera descended more gently.

Equally as well-engineered was the launcher and ground support equipment. The 400-kilogram launcher, rockets, chest containing two spare payload compartments, and ancillary material was compactly fitted onto a two-wheeled cart that was pulled by two rocketeers. The launcher consisted of two open-truss sections that bolted together so that it stood 7.5 meters tall. Upon electrical ignition, the rocket also received a boost from an iron weight that dropped by a pulley arrangement from the top of the launcher.

Like the signal rocket, however, Maul's photo-sounding rocket reached perfection only to become technologically unemployed by advances in another field of engineering. By 1914, the airplane had advanced to the point where a man with a camera could take pictures at altitudes up to 3,600 meters, and from vantage points widely separated in space and time.

ROCKETS IN THE EARLY 20th CENTURY

With the abandonment of the war rocket from the arsenals of Europe in the last quarter of the 19th century, between World War I and World War II, groups interested in a manned rocket for interplanetary travel began to form, though the costs and technology involved in such projects was grossly underestimated.¹¹

The first attempt to launch man by a rocket was done in Jersey City, New Jersey, as part of a motion picture. F. Rodman Law, a parachutist who had leaped from the top of the Banker's Trust Building and the Williamsburg Bridge in New York, as well as from an airplane at a height of one mile, was to be launched while the

cameras filmed his ascent. The rocket measured 0.3 meters in diameter and 3 meters in length. Its stabilizing stick was a heavy timber 6 meters long. The motor compartment was made of sheet steel and loaded with 22.5 kilograms of gunpowder by the Detwiler and Street Fireworks Co., of Jersey City, from whose property the launching was to take place.

Law sat in a special seat covered by a conical nosecone of cardboard. The plan called for the rocket to lift him to a height of 1,050 meters, at which point he would descend by parachute to the ground. But instead of rising into the air the rocket detonated on the launcher. Law fell some 6 meters to the ground, badly burned but alive.¹²

More serious proposals for manned rockets were made several years later. In Germany in 1933, Rudolf Nebel announced that the Bank of Magdeburg had assured him a loan of \$4,000 to construct a liquid propellant rocket (using liquid oxygen and gasoline) that would carry a man to a height of 1,000 meters by a thrust of 800 kilograms, where he would descend by parachute à la Law. The engine would have adjustable nozzles so that the acceleration produced would amount to only 3 g. And the optimistic launch date was scheduled for the following spring. Like so many projects of the times, this one never materialized.¹³

ROCKET PROPELLED VEHICLES ON EARTH

More serious attention and serious engineering effort was given to propelling man by rocket on Earth than to the stunts and dreams such as those of Law and Nebel. In Germany, one of the founders of the Verein fuer Raumschiffahrt (VfR), formed in 1927, began such experiments as early as March 12, 1928. On that day at Fritz von Opel's race track at Ruesselsheim, near Mainz, a test was made using gunpowder rockets purchased from the commercial fireworks firm of Friedrich Sander attached to an Opel automobile from which the engine had been removed. The project had been engineered (and sold to Opel) by Max Valier, a science writer and founding member of VfR. The rockets attached to the rear moved the car 150 meters in 35 seconds.¹⁴

Opel eventually provided a special racing car, without a motor, to which clusters of solid propellant rockets provided by Sander were attached.¹⁵ Tests made with them in April of the same year finally accelerated the car to 112 kilometers per hour, and Opel capitalized on the feat with full-page advertisements in several German magazines. Opel next manufactured a special racing car with a battery of 24 Sander rockets, which he drove on May 23. It reached a speed of almost 200 kilometers per hour. Opel went on to make several more rocket-propelled cars, one of which, mounted on railroad tracks near Hanover, reached a speed of 180 kilometers per hour on June 23, 1928.

Opel and Valier later disagreed, and Valier turned to a liquid propellant engine for automobiles. In these he collaborated with Dr. Paul Heylandt, head of a company that prepared industrial gases including liquid oxygen. Their first attempt, using liquid oxygen and gasolene was made on April 19, 1930. Though not entirely successful, Valier was confident that he could improve performance in order to make an appearance at the Aviation Week scheduled in Berlin from May 25-31. He worked feverishly in Heylandt's factory, late at night, the engine exploded and a piece of steel severed Valier's aorta. He died almost immediately.¹⁶

Valier's death brought adverse publicity to rocket research in general. However, Valier's death probably did cause the VFR, which had never fully approved of his rocket car experiments, to concentrate on the serious engineering development of small liquid propellant rocket engines to verify theoretical concepts and to improve such technology. The story of the VFR, as well as the British Interplanetary Society, the American Rocket Society, the two Russian rocket groups, and the French organization that became the Societe d'Astronautique Francaise, can be found in Ley's Rockets, Missiles and Men in Space, von Braun and Ordway's History of Rocketry and Space Travel, and the journal literature of the organizations themselves.

In the history of the development of the rocket plane, it is interesting to note the early role of the solid propellant rocket in the propulsion of aircraft. The first experiments in this field were made in Germany prior to World War II. Indeed, the first such manned flight took place on June 11, 1928 near Wasserkuppe in the Rhoen Mountains after several cautious unmanned tests. Two Sander solid propellant rockets were attached to a glider piloted by Friedrich Stamer, a member of the Rhoen-Rossitten Gliding Society. The rockets had a thrust of 20 kilograms and were ignited electrically by Stamer after the glider had been launched by a catapult. The plane travelled some 1,300 meters in 60 to 80 seconds.¹⁷

Following his split with Valier, Fritz von Opel seems to have become infatuated with the possibilities of rocket propulsion beyond his area of immediate commercial interest: automobiles. He financed and, indeed, piloted a rocket-propelled glider on September 30, 1929, at Frankfort-am-Main. Again the propulsion system was supplied by Sander; it consisted of 16 gunpowder rockets, each producing 22.5 kilograms of thrust. In this case, however, the glider took off under rocket thrust. It did not depend upon the boost provided by a catapult as in the case of Stamer's flight a year earlier. The glider reached an altitude of some 15 meters at a top speed of 120 kilometers per hour and travelled some 1,500 meters.¹⁸

THE POSTAL ROCKET

One of the more utilitarian aspects of rocketry foreseen in the early 1930s was the rapid delivery of the mail. The simplicity of the rocket and its

high velocity seemed to the enthusiasts of the various rocket societies in Europe-- and elsewhere--the answer to the problem of shortening the time it takes for a letter to traverse rugged terrain and large bodies of water. In large part, this enthusiasm seems to have been justified by the early and rather poor showing made by the airplane as a fast delivery means.

Airmail, if the United States can be taken as a typical case, was erratic at best. The aircraft of the day were limited in range and were especially vulnerable to the weather, particularly rain, snow, and fog. Night flights were heroic feats, if they were attempted at all. But the rocket seemed able to overcome these technical shortcomings, particularly because it was unmanned. More importantly, it seemed to the rocketeers of the 1930s that the pattern of development of commercial aviation would be along lines that limited the rapid delivery of mail on a wide-scale geographical basis. Airplanes required airports, and these expensive facilities could be provided only by the largest cities. What was needed, then, was a supplemental means of delivering mail between villages in inaccessible or rural areas where airplanes could not and would not fly.

Willy Ley states that the earliest uses were in the South Pacific Ocean among the Tonga Islands in the early 1900s. He specifically notes that the island of Niuafo'ou had mail delivered to it from ships that could not dock because of the treacherous waters off-shore. The rocket so employed was a modified Boxer lifesaving rocket. Apparently the rockets fell into the ocean short of the island as often as not and sunk or impacted on shore, scattering the letters upon the land. By 1902, the practice seems to have been replaced by the more reliable method of sealing the mail in cans and tossing them over the side to be washed closer to shore where they were recovered by natives in boats.¹⁹

On February 9, 1928, Dr. Franz von Hoefft, president of the Gesellschaft fuer Hoehenforschung in Vienna, mentioned in a lecture that one of the rockets he intended to develop was a multistage vehicle which would "carry a mail pouch, and within an hour it would be able to reach any point on the surface of the Earth by flying a Keplerian trajectory." Thus, the idea if not the actual means reappears in that year. In June of the same year, Hermann Oberth, the German pioneer in astronautics, addressed a meeting of the Wissenschaftliche Gesellschaft fuer Luftschiffahrt in Zoppot, close to Danzig. In the course of his lecture, Oberth became expansive at the expense of the current state of the art of rocket technology. He said: "Therefore, I would suggest as a beginning, the construction of automatically guided rockets that can span ranges of 1,000 to 2,000 kilometers and carry payloads of 10 to 20 kilograms . . . Such rockets seem made for transporting priority mail over very long distances in extremely short times."²⁰

From these two ideas grew the only operational rocket mail system that was to appear in the 20th century. It was the realization of Friedrich Schmiedl, of Austria, who conceived of rocket mail as the answer to transporting letters across the rugged Alps of his country and between small villages that could not afford the expediency of airmail because of the perpendicular nature of the local terrain. Schmiedl experimented for several years, beginning in June 1923, with gunpowder rockets of his own design before he committed the Austrian mail to them. There is a certain irony today in the realization that he designated his peaceful rockets as V-1, V-2, etc. For Schmiedl, the V indicated versuchsrakete (experimental rocket) and not vergeltung (vengeance)—the more ominous designations in the rocketry of Germany.

After V-6, Schmiedl felt that his rockets were reliable enough to commit them to scheduled service. On February 2, 1931 rocket V-7 carried 102 pieces of mail between Schoeckel and Radegund. From then until March 16, 1933, with rocket V-14, Schmiedl delivered 1,768 pieces of mail between villages in the Austrian alps, chiefly between Schoeckel and Radegund and Kumberg. The last flight took place on March 16, 1933, between Garrach and Arzberg, whereupon the government ordered Schmiedl to cease all activities and destroy his launching facility at Schoeckel, with no explanation from the faceless authority of bureaucracy.

Schmiedl's rockets were fairly reliable despite the fact that they were propelled by gunpowder. Model R-1, for example, was 1.7 meters long, 24.5 centimeters in diameter, and weighed 30.7 kilograms. It would carry 330 letters and cards to a range of 3 or 4 kilometers. It also featured an interesting motor chamber, consisting of sheets of brass separated from each other by glue-soaked twine. The outer cover was aluminum and the inner liner was asbestos. The special gunpowder formula developed by Schmiedl produced an exhaust velocity of 800 meters per second. The parachute recovery system for the mail payload was also attached to the rocket to keep it from damaging property as it could in free fall after burnout.²¹ However, the rocket was not reusable.

Europe saw other experiments in rocket mail in the 1930s. A Czech electrical engineer named Ludvik Obcenasek, who had developed a war rocket for the French during World War I, began flight testing postal rockets in Prague in early 1930. His first models were propelled by gunpowder, but he fully intended to develop liquid propelled two-stage rockets that would leave the atmosphere and reenter, making intercontinental rocket mail possible. Rheinhold Tiling, a German engineer, in 1931 perfected a rocket with wings that was intended for postal delivery. The wings were folded into the body during launch and flight to burn-out, at which point they deployed and the rocket glided back to the ground. It reached an altitude of 800 meters and had a horizontal range of 8,000 meters. For several years he tested these rockets and

increased their performance. One is said to have attained an altitude of 8 kilometers when launched from Wangerooge, a small island of the Eastern Frisians. Like Valier, he was killed while working on a rocket in his laboratory in 1933.

Beyond all doubt the most colorful experiments in rocket mail were made in India. Dr. Stephen H. Smith, an Indian dentist was using the rocket for an astonishing number of nonmilitary purposes in addition to delivering letters in the state of Sikkim. During a flood of the Bengal River in 1937, he fired rockets with a small payload of food to a group of natives stranded on an island, saving them from starvation. In some of these flights, he used multistep winged models. And he certainly must hold the record for having been the first to send up mice in a multistep rocket with a life support system consisting of cheese and sugar. On July 27, 1937, he sent a rooster and a hen and 189 letters safely across the River Damodar.

His rocket mail experiments had the financial backing of Sir Tashi Namgyal, the maharajah, and the sanction of the British Post Office. Smith used rockets to send mail from ship-to-shore as well as shore-to-ship to a lighthouse on a small island. Smith kept meticulous records of the numbers and names of his rockets, and personally countersigned each envelope flown.²²

The only official rocket flight with a stamp issued by a government appears to have been made on October 15, 1939 in Cuba. The experiment was made by a Sr. Antonio Funes, who made several other flights as well. But the method of delivery was not adopted by the Cuban postal authorities. Such experiments received wide publicity, and similar rocket flights were made in the United States, Australia, Yugoslavia, Mexico, The Netherlands, France, Switzerland, and Luxembourg before World War II.

After World War II rocket mail faded from view as other technological advances in communications were made, in particular the communications satellite and high-speed data facsimile transmission via satellite. Still the idea did not die completely. It was kept alive largely by Captain Glauco Partel, an Italian engineer and space enthusiast. He formed a company that by 1967 had developed the Grillo 3, a cheap, reusable rocket propelled by superheated steam. Only 2.5 meters long it can carry a payload of 19.8 kilograms to a distance of 8 kilometers. Partel estimated (in 1967) that the cost per letter for such a rocket would be at most \$0.05, the Grillo 3 seemed a bargain. It is interesting to note that Partel specifically designed the Grillo 3 for the same purpose as Schmiedl had 37 years earlier: delivery of mail over mountains or to other isolated areas not easily accessible by air or surface transportation.²³

THE WEATHER ROCKET

The word weather is used here rather than meteorological to indicate that the rockets to be discussed were used in attempts to change weather conditions

rather than to study the physical, chemical, and dynamic properties of the atmosphere. Not until the end of the 19th century did scientists begin investigating the use of weapons to change the weather. Interest in this emerging technology was concentrated on projecting a source of noise, heat, or shockwave into clouds over arid regions.²⁴

The weather rocket apparently did not appear until early in the 20th century. Interest then had shifted to the destruction of hail clouds before they could loose their damaging missiles on crops below. The first such use seems to have been that of one R. Baur, of Stuttgart. He reasoned that the best method of producing an effect in a cloud was to have the explosion occur as near as possible to its center. Since the commercial firework rockets of the day could not reach the altitudes he desired, Baur worked with a manufacturer of pyrotechnics to develop a rocket that would meet his requirements. Basically, it needed a greater thrust to reach at least 1,000 meters; it must be safe to handle; and it must be easy to ignite. This collaboration later produced a rocket that reached a height of 1,200 meters with an explosive payload of about one kilogram. Baur tried his rockets in 1905 and developed a tactic of detonating one at the lower, center, and upper parts of a cloud more or less simultaneously. Results were inconclusive.²⁵

After Baur's experiments, little occurred in this area of research other than a few experiments in Switzerland. After World War I, a Swiss pyrotechnics manufacturer began the production of anti-hail rockets. Karl Mueller, of Emmishofen, produced two models: one 25 centimeters long and 3 centimeters in diameter, and the other 50 centimeters long and 4 centimeters in diameter. They had a vertical range of some 1,000 to 1,500 meters and were claimed to be effective over an area of one square kilometer.²⁶ During the same period, anti-hail rockets were manufactured by the Ecole de Pyrotechnique in Bourges. These rockets reached an altitude of 3,000 meters and had a remarkable exhaust velocity of 1,320 meters per second.

Tests with anti-hail rockets were carried out in Austria and Germany in 1931. Max Valier reported to Willy Ley the observations of such a test by an eyewitness. He stated that the first rocket to detonate in the cloud produced snow, while succeeding rockets changed the snow to rain. Valier also told Ley that Swiss insurance companies gave reduced rates for communities protected by anti-hail rockets.²⁷ Rockets to prevent hail appeared in Austria in 1933. Science editor Erich Dolezal, who witnessed firings, formed the theory that: "The explosion tears a hole into the hail cloud, and the horizontal wind below the cloud then enters this hole and tears the cloud apart."²⁸

Following World War II interest in the anti-hail rocket was renewed because advances in meteorology had shown that it was possible to make rain by seeding clouds with various chemical compounds, chiefly solid carbon dioxide and silver iodide. The Department of Agriculture of West Germany may have made extensive tests with them, but

no report of the findings has been released. The Russians, on the other hand, adopted the technique on a larger scale than any country in Europe. After initial experiments with rockets bought in Italy in the mid-1950s, the Russians founded a highly organized anti-hail service in 1961, which at that time covered 50,000 hectares. Only eight years later the service was protecting 500,000 hectares or practically the entire vineyard area of Kakhetia, in the Alazan valley of Georgia. The Russian system that is in use today resembles in organization and operation an anti-aircraft artillery defense. Radar units sited throughout the area keep on the alert for hail clouds throughout the dangerous periods of summer and fall. Once sighted and identified as a hail cloud, batteries of rockets go into action.²⁹

Among the rockets used is the 125-millimeter Oblako that carries a 4.5-kilogram payload of dry-ice (carbon dioxide) pellets to an altitude of 8 kilometers. Oblako is fired from a truck-mounted launcher and thus has a considerable degree of mobility. The Alazan rocket is also mentioned in the Soviet literature as carrying a payload of high explosive and silver iodide, minute particles of which form the nucleus for rain drops in the clouds before they can grow into hailstones. The use of such rockets reduced the damage to vineyards in the Alazan valley by 69 percent one year after adoption, according to Professor Alexander Buknikashvili, director of the Institute of Geophysics of the Academy of Sciences of the Georgian Soviet Republic.

Fruit-growers in Queensland, Australia, also started using rockets as an anti-hail measure after World War II. While not electronically as sophisticated as the Russian system, the method developed apparently works. Rockets of two types are fired simultaneously at visually detected clouds. One of the rockets contains a high explosive warhead, and the other has a payload of silver iodide particles. The rocket was also used for similar purposes in Switzerland and Italy.³⁰

MISCELLANEOUS USES AFTER WORLD WAR II

Undoubtedly the rash of imaginative uses of rockets for nonmilitary purposes derived largely from the publicity given them during the war. One of the earliest uses seen in a post-war world was the rocket as a means of individual transportation, long a favorite in science fiction. The idea seems to have evolved first among the rocket research personnel at Fort Bliss, Texas, in 1948. Thomas Moore, an American engineer working with the German rocket specialists at that U.S. Army base, suggested what he called a "jet vest" to members of the German group. Several captive flights were made with a subject suspended in a harness. At first compressed air was used, but later steam produced from hydrogen peroxide was substituted. Bedeufstig was in charge of the tests and provided a preliminary design of a control system for the jet vest. However, the priority of missiles development soon caused all research on it to be abandoned at

Redstone Arsenal.³¹

Interest in the jet vest continued elsewhere. Charles Zimmerman, an aeronautical engineer with the National Advisory Committee on Aeronautics at Langley Field, Virginia, in 1953, showed that a man could maintain a stable attitude while upright on a rocket motor. In the same year, Wendell F. Moore, a rocket engineer of the Bell Aircraft Company at Edwards Air Force Base, California, began studying a jet vest and making preliminary designs. In 1958, Moore and a fellow engineer James Powel built and flew in a tethered device similar to that demonstrated by Thomas Moore and Bedeurtig at Redstone Arsenal. However, the propellant in this case was nitrogen, and the device was controlled by the test conductor who throttled the flow of the gas to produce an up and down movement of the test subject.

In 1959, the U.S. Army Transportation Research and Engineering Command requested proposals for a Small Rocket Lift Device, as the jet vest was by then renamed. A feasibility study was made by the Aerojet General Corporation and submitted to the Command in February 1960. In August of the same year, the Command awarded a contract to Bell Aircraft Company, in Buffalo, New York, to build a device that would prove a feasibility design. Thomas Moore was made project manager, and such a device was constructed and first free-flight tested on April 20, 1961.³² For the following decade, the Bell device, including one and two-man models, was widely demonstrated in the United States and other countries. While both its military and nonmilitary (particularly lunar exploration) uses seemed obvious, the rocket belt never found a commercial market.

The first to exploit rocket-propelled subjects on sleds mounted on rails for studies in aerospace medicine was Doctor John Paul Stapp, then a major in the U.S. Air Force. He used it to determine the effects and tolerances of living organisms, including chimpanzees, bears, hogs, and men, to the forces of deceleration. Indeed, the first test subjects destined for use on the track were chimpanzees. When a shipment of them failed to arrive, Stapp rode the rocket sled instead.³³ Stapp's experiments with seating arrangements and body restraints on human subjects with the rocket sled track at Edwards Air Force Base convinced him as early as 1955 that a parachute-recovery system for manned spacecraft reentering the Earth's atmosphere was possible and would not exceed the deceleration limits of the astronaut.³⁴

The rocket sled track proved especially valuable for research into the problem of pilot bail-out from disabled aircraft travelling at very high speeds associated with jet planes. With this knowledge, aerospace doctors and engineers were able to design escape systems, in themselves rocket-propelled, that would insure that the pilots could leave the aircraft and not suffer the fatal consequences of wind-blast. The basic data for both deceleration and wind-blast were proved by the redoubtable Dr. Stapp. On December 10, 1954, he rode a rocket sled on the Holloman

Air Force Base (New Mexico) track with no wind protection at all. It reached a velocity of Mach 0.9 and produced a wind pressure on him of 540 grams per square centimeter. During the ride, he actually overtook a jet plane that was flying parallel to him, and decelerated at some 35 to 40 g at a rate of onset of 600 g per second. He suffered only minor physiological impairment.³⁵

In 1968, the United Technology Center (UTC) of United Aircraft Corporation, and American manufacturer of rocket motors, proposed a means of reducing fire hazards and facilitating reforestation in logged-over areas. Rather than having logging debris ignited in the usual manner by men with torches, fuses, and preplanted incendiary charges, UTC developed a rocket fired from a shoulder launcher from a range of 450 meters, assuring that personnel could not be trapped in the highly inflammable area.

Other Earth-oriented uses of the rocket to emerge after World War II included practical as well as academic uses. In Austria, during 1950 and 1951, rockets especially developed for the purpose, demonstrated their effectiveness in creating avalanches before they could occur naturally. In the ski resorts of that country, these rockets were used to create snow slides from distances up to 5 kilometers before such dangerous accumulations could threaten the lives of skiers or tourists in hotels by avalanches. While rockets worked well, they again lost out to their traditional competitor; the cannon and its projectile were cheaper and just as accurate at that range.

With a variety of relatively inexpensive rockets available by mid-1960s, scientists in the geophysical disciplines found a number of applications for them in the atmosphere and in the Earth, literally. The use of rockets for geodetic purposes dates back at least to a series of experiments made in and around London between 1749 and 1750 by several members of the Royal Society under the direction of Benjamin Robins.³⁶ In 1823, Sir William Congreve, demonstrating still more imagination when it came to the application of rockets, mentioned geodetic measurements in a patent (No. 9853) that he received in 1823. Only two years later, Sir Edward Sabine and Sir John Herschel conducted joint experiments with the French in which rockets were used to determine the longitudinal displacement between the observatories at Greenwich and Paris. Their results were so precise that they varied by only 0.5 angular seconds from those made after the development of the technique of radio ranging.³⁷

Other geophysical uses of the rocket in the 20th century found scientists studying lightning, in August 1966, employing them for a special purpose. Previous to their experiments, the inability to predict the point of strike of natural lightning led geophysicists to look for ways of triggering lightning artificially and making it strike where they could make measurements. They succeeded in doing so by using rockets to carry trailing wires toward likely-looking thunder clouds above the research vessel Thunderbolt cruising off the coast of Florida. They realized 17 successes out of 23

attempts.³⁸

The rocket has also made possible a new method of geophysical study termed terrodynamics. It was devised by the Sandia Corporation, of Albuquerque, New Mexico, and announced in March, 1968. It consisted of firing instrumented rockets at very high velocities into the Earth to transmit data on the decelerative effects of different types of soil structures, permitting a characteristic profile to be made. The technique should have a variety of practical and commercial applications in civil engineering, including, for example, the preliminary assessment of potential building sites in remote and inaccessible geographical locations. Rockets weighing as much as 2,700 kilograms and impacting at velocities as great as 2,992 kilometers per hour have been used in such studies. They have penetrated many meters of soil such as mud and weathered granite.³⁹

The first use of rockets in a similar function on other worlds was scheduled as a part of the scientific instrumentation of Apollo 14, the third planned manned lunar landing. Four rockets with high-explosive heads were launched on signal from Earth to various distances, exploding along a linear array of geophones deployed on the lunar surface by the astronauts. The resulting sound waves travelling through the lunar soil would thus provide valuable data on the mechanical properties of the soil in the region of Fra Mauro.

SUMMARY

Though the time has not yet come when man has beaten his swords into plowshares and his spears into pruning-hooks, he has turned one of his most awesome weapons toward peaceful uses. In addition to the applications described above, it should be noted that the largest rocket ever was not built for the purposes of destruction. It sent the first men from Earth to the Moon.

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THE USE OF CONGREVE-TYPE WAR ROCKETS BY THE SPANISH IN

THE 19th CENTURY: A CHRONOLOGY⁺Pedro Mateu Sancho (Spain)⁺⁺

EVENTS PRIOR TO THE 19th CENTURY

1238. The first reference to Spanish rocketry involved King James I and the use made of rockets against the Moors in Valencia. In the Memorial de Artilleria¹ the author observed: "In 1238 King James I of Aragon made use of a type of bomb against the Moors in Valencia, which the chronicler calls rockets [cohetes], composed of four sheets of parchment filled with a material that would burn instantly: these flaming projectiles were hurled by means of machines against the enemy on the beach where they burst upon dropping." Of course, there is some doubt concerning the correct use of the word rocket.

1537-1540. Luis Ortiz compiled Libro de Artilleria² that dealt with various types of artificial fireworks and other flammable devices for launching by hand or with machines.

1547-1617. Miguel de Cervantes, in the second part of the Quixote, wrote "por la cola de Clavileño le pegaron fuego con unas estopas, y al punto por estar el caballo lleno de cohetes tronadores boló por los aires con extraño ruido." ("By means of Clavileño's tail they lighted him afire with some tows, and at the precise moment, since the horse carried thundering rockets, he was blown through the air with a strange noise")

1573-1582. Santa Teresa de Jesús wrote in her Fundaciones "Como hubo tantos tiros de artillería v cohetes, después de acabada la procesión, que era casi de noche, anto jóseles de tirar más" ("There were many artillery and rocket shots after the procession was over, and as it was almost nighttime, they decided to shoot more")

⁺Presented at the Fourth History Symposium of the International Academy of Astronautics, Constance, German Federal Republic, October 1970.

⁺⁺President of the Agrupacion Astronautica Espanola, Barcelona.

These two examples provide an idea of how the rocket continued in use as artificial fireworks displays.

1590. Diego de Alaba and Viamont, in El perfecto capitán, instruido en la disciplina militar y nueva ciencia de la artillería,³ explained among other things, the ways to manufacture gunpowder for artificial fireworks and rockets.

1592. Luis Collado, a native of Lebrija (Seville), published his comprehensive work: "Plática Manual de Artillería."⁴ This document, first published in Italian in Milan, with the name of Platica Manuale della Artiglieria, described how rockets were used in wartime by the Spanish in the first half of the 16th century against enemy horsemen. He offered important advice for improving its effects, pointing out that launching through a large tube increased its range. He also advised adding petards to explode and to illuminate battlefields at night, resulting in disorder in the ranks of the enemy cavalry.

UTILIZATION OF ROCKETS IN SPAIN DURING THE FIRST HALF OF THE 19th CENTURY

1810. According to Winter,⁵ in 1805 Congreve suggested attacking the fortress city of Cadiz with rockets in an attempt to force the retreat of the French. This plan was carried out five years later. Although the results were not very spectacular, the event introduced Congreve rockets in Spain.

1810-1811. Napoleon created a commission to study rockets, and, under the leadership of the French, Congreve rockets began to be manufactured in Seville. With a range of 1,949 meters they gave poor results. Nonetheless, this was the first serious attempt at manufacturing rockets in Spain following Congreve's model.

1812. In the liberation of Badajoz, rockets were employed by the English and the Spanish under the command of Lord Wellington.

1814. Barrios Gutierrez⁶ noted that a French infantry and cavalry corp was disrupted by means of rockets during the blockade of Barcelona.

1820-1833. Tests were conducted in Havana with lightweight Congreve-type war rockets. The Marquis of Villuma declared in Sobre el Origen, Progreso y Estado Actual de los Cohetes de Guerra llamados a la Congreve:⁷ "France, and principally England, have spent considerable sums in experiments with rockets and other war arms, convinced that when it is known that an object may be useful, no sacrifices should be forgiven in obtaining it. The tests of Congreve-type rockets will be very long and costly before they can be perfected. . . . Although in relation to the effects produced by the rockets tested in Havana, it can be seen that we are very far from the perfection needed to use them advantageously; those tests should be considered among ourselves as the first step toward an acquaintance with this arm."

1833-1840. During the Seven Years War, the adherents of Queen Isabel II began to use war rockets, probably as a result of the interest created by the Marquis of Villum's report. They decided to send Lieutenant Colonel Nuñez Arenas (1835) to England for the acquisition of British rockets. Negotiations were to have resulted in the shipment to Navarra of almost 5,000 Congreve Rockets and expert personnel to train the Isabeline artillerymen. But only very limited quantities reached Navarra. As explained in "Cohetes a la Congreve," an editorial in Memorial de Artillería:⁸ "The Lieutenant Colonel Jose Nuñez Arenas went to London, carried out his commission, and transported to Navarre in 1835 a battery of rockets which in our opinion surpassed the ones which in that same epoch accompanied the English auxiliary legion in its operations. How the two types relate to our expectations, we cannot say, because we lack firm data However, we remember the good effects the rockets produced in Villamediana, Vendejo, and other places, where they were launched by both legionary rocketeers and the Spanish artillerymen."

THE USE OF ROCKETS IN THE AFRICAN WAR

1859-1860. Committed to the so-called African or Moroccan war, Spain purchased war rockets from a British firm and consigned them to the Artillery Corp under the command of Captain Miguel de Orus. These rockets were of much better quality than those used up to that time. Captain Orus "rocket batteries" were, in spite of the hurried and brief training, a complete success. Orus wrote in his memoirs: "having shot 66 rockets, and having two artillerymen injured and one bruised, the good direction of the rockets and the subsequent rebounding among the Moors was liked by all who witnessed them, thus meriting on this day the compliments of many leaders who had not believed rockets trustworthy, no doubt due to ideas they had of the rockets launched in the civil war without results, and some of which turned back on the troops that shot them."

In his memoirs, Orus continued to describe how the rockets were utilized as well as the incidents occurring in each battle.

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1859. Pedro Antonio de Alarcón in his well known Diario de un testigo de la Guerra de Africa,⁹ though not expert in artillery, wrote as a chronicler about the effect caused by the rockets on the Moroccans. He also described the utilization of rockets by the renowned General Prim in the famous battle of UadRas.

1863. Xavier Palomares Santiago in Memoria sobre la Guerra de Africa,¹⁰ explained how the "rocket batteries" were constituted, and observed that they were "very economical and manageable. Little instruction, personnel, or animals are required

to operate them. We think that the Spanish army should count on the war rocket. . . ."

FROM THE AFRICAN WAR TO THE END
OF THE 19th CENTURY

1869. Various Spanish officials studied rocketry in other countries, including Russia, where notable results had been achieved against the Turkish cavalry.

1872. The "Military Pyrotechnia" of Seville installed new machinery for the manufacture of even more powerful rockets. The Lieutenant Colonel of Artillery, Salvador Castro, interviewed General Konstantinoff, Director of the war rocket establishment in Czarist Russia. But the end of the rocket as a war arm was near.

1885. L.M.E. Audot Andor wrote El Arte de los fuegos artificiales,¹¹ a treatise on artificial fireworks which dealt with rockets that were recovered with parachutes.

1895. The Cuban War, that had quite an adverse effect on Spanish arms, momentarily rekindled interest in rockets. According to newspapers of the time¹² the rockets in question, invented by the French official Couspiere, were made of aluminum, powered with dynamite, and constituted part of the material of Cuban General Collazo's expedition. Evidently, the Cuban insurgents expected extraordinary results from these rockets. Vidal Rubi provided details of these rockets.¹³

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A SURVEY OF ROCKETRY AND ASTRONAUTICS
IN SPAIN⁺

Juan J. Maluquer (Spain)⁺⁺

This paper is based on reference 1, and complements the investigations of Professor Ramon Carreras.² The author believes it to be the first survey covering the entire field of rocketry and astronautics in Spain. The data used in this study can be found in a series of documents, pamphlets, books, and reviews in Spanish public and private libraries, and in public records. This paper should permit historians to pursue further, more detailed, research in these referenced sources.

The paper consists of four parts:

- Rockets
- Studies and Realizations
- Dissemination of an Idea
- Space Science Fiction

ROCKETS

Flying Fire and Rockets

In his Introduction to the History of Science,³ Sarton states that the Chinese made use of gunpowder for hand grenades or rockets in 1232. But Willy Ley⁴ mentions an Arab, Abu Mohammad Abdallah ben Ahmad Almaliqui (the last word meaning Malaga, A Spanish town in the Costa del Sol), also called Ibn Albaithar (son of the horse doctor), who in 1240 wrote a book describing saltpeter, one of the most important ingredients of gunpowder, as "the flower of the stone of Assos," adding that the Egyptians called it "snow from China."

Evidently gunpowder was introduced in Spain by the Arabs,⁵ and was used by the Arabs for the first time in the siege of Huescar (a town some 110 km northeast of Grenada) in the year 1324. A witness of this battle, Ben-Hudsail, wrote: "They

⁺Presented at the Fifth History of Astronautics Symposium of the International Academy of Astronautics, Brussels, Belgium, September 1971.

⁺⁺Professor of engineering, University of Barcelona.

(the Christians) thought that lightning and thunder were in the sky." However, it is also evident that the Armies of Ishmail, the King of Grenada, used a great engine that worked with naft (naft means gunpowder). This engine threw a red hot iron ball into the tower of the fortress, where, sparkling, it fell among the besieged, causing great damage as if from lightning from the sky.⁶ Was it a projectile thrown by a cannon, or a rocket according to the sparks mentioned? Nobody can be sure.

We must carefully consider the quotations of historians and chroniclers who often confused Greek fire in containers, thrown by hand or by engines of war, with self propelled rockets.^{7,8} For example, the Count of Clonard, a 19th century historian, equated Greek fire with rockets: "The invention of rockets is almost as old as Greek Fire; in the IX Century soldiers of Emperor Leon the Philosopher used it, but then it was only a small tube full of Greek fire thrown by hand onto the enemy. When this fire was introduced in Spain, probably through the Arabs, rockets attained more power and strength, and were more effective."⁹ The confusion between "flying fire" and "rockets" is seen repeatedly in our country as elsewhere during the 13th and 14th centuries, and continued for centuries thereafter.

Thus, in the conquest of Valencia (1238), it was said that James I used a kind of bomb of inflammable material against the Moors, which, thrown against a city, exploded on impact. The chronicler named them rockets,¹⁰ but as Artillery Major Juan Barrios observed,¹¹ "they were not rockets because they were thrown by machines." Again, in the siege of Niebla in 1262 by Alfonso X the Wise, his chronical asserted that "ingenios" (machines) threw rockets that exploded and caused the terror of the supernatural among the besieged. Some see rockets in this account, but Antonio Ballesteros Barreta in his well documented work about this Monarch conceded that some "believe that gunpowder was used for the first time in the siege of Niebla."¹²

Three centuries later the Purser Luis Ortiz, in the oldest Spanish manuscript on this subject, explained the manufacture of rocket fire-works, and also mentioned fire-balls and fire-sticks to be thrown with cannons, harquebuses, or by hand. In 1592 the famous "Platica Manual de Artilleria,"^{14,15} written by Military Engineer Luis Collado, was published. Collado described the use of rockets by the troops of Carlos V against besieged cities and enemy cavalry. Whatever the precise date of their appearance, rockets were well known and used in Spain by the early 19th century.¹⁶⁻²⁹

The Congreve War Rocket

In the early 19th century the Congreve war rocket (1804) became known in Spain as the "Cohete a la Congreve." The success of this rocket in military actions caused other nations to adopt them. Rocket batteries soon appeared in Denmark, France, Italy, the Low Countries, Austria, Poland, Prussia, Sardinia, and Spain.³⁰

During the Napoleonic wars in Spain, Napoleon sent an Artillery Captain to Sevilla to manufacture Congreve rockets. Their range was about 2,000 m.³¹ But in combat, as General Vigon observed,³² they did not fulfill expectations. Nevertheless, the French and English troops used them throughout the Spanish campaigns.³³⁻³⁸

In Spanish America in 1819, General Pezuela, Viceroy of Peru, confronted Lord Cochrane's fleet equipped with great quantities of rockets.³⁹ Cochrane advised the Viceroy to surrender: "The devastating fire that terrorizes the most formidable armies of Europe will burn down the ships anchored in this port and the City of Callao. The incendiary rockets have evidenced before the World that they are the most offensive part of an action."⁴⁰ But Cochrane's attack was repulsed.

The War Rocket In The African Campaign

Despite the uneven performance of the Congreve rockets in European and American military engagements, in 1859 a Spanish rocket battery was created and used very successfully in the African war, or Guerra Hispano-Marroqui in 1859-1860.⁴¹⁻⁴⁷ The rocket battery belonged to the Second Army Corps under the command of General Prim, and took part in a number of decisive battles. Pedro Antonio de Alarcon⁴⁸ observed that the Congreve rockets caused panic and great casualties among the enemy, an observation confirmed by others.⁴⁹⁻⁵³ Years later General Orus recalled: "During the African war the rockets did a very good service as their fire was very accurate and the material and moral effect that they had upon the enemy was great."⁵⁴

The War Rocket In The Cuba Campaign

The Cuba campaign at the end of the 19th century, briefly rekindled interest in the war rocket, beginning with a curious notice in the Madrid newspaper Imparcial on October 8, 1896. (The news referred to the expedition of Collazo, one of the chiefs of the Cuban insurrection). "It is supposed that this rebel chief has left Florida for Cuba with an expedition of men and arms. The material of the expedition is 2000 rifles, one million rounds of ammunition, 600 machetes, 400 pounds of dynamite with the necessary implements to manufacture gunpowder, 500 aluminium rockets of the Couspiere system, and 3000 shells."⁵⁵ Spanish Artillery Lt. Col. Gabriel Vidal y Rubi subsequently defended the convenience of rockets in the Cuba Campaign,⁵⁶ and introduced a horseback rocket battery in this campaign.

Vidal organized the battery of rocketeers on horseback as follows:

Material:	10 launchers with the corresponding tubes, and 200 rockets
Personnel:	3 Officers (1 Captain and 2 Lieutenants) 110 Rocketeers 5 Workers
Horses:	118

Every tripod launcher was served by:

- 1 launcher carrier Rocketeer
- 1 launcher Corporal
- 1 pointer Rocketeer
- 1 adjudant pointer Rocketeer
- 2 supplier Rocketeers
- 4 adjudant Rocketeers

Rockets and the Civil War 1936-39

"During the Spanish Civil War 1936-39," Wernher von Braun declared, "the rocket staged a brief, and somewhat unusual appearance. Converted sea-rescue rockets came into service for the purpose of transporting propaganda materials behind the enemy lines. The nosecone was especially constructed so that it would burst open at a predetermined time and release its payload of propaganda leaflets, which were printed on very thin paper."⁵⁸ Although unconfirmed, the Franco army, according to military officers in Zaragoza interviewed by the author, did employ rockets. By sporadic initiatives and with a purely local control, it seems that on the Aragon front the National Army used rockets similar to those used to disperse hail, equipped with guiding sticks and launched by fixed multiple launchers on tripods. They were applied as a crude anti-aircraft defence, at least at night, forcing aircraft to fly higher. Consequently, observation and bombing were made more difficult.

On the Republican side, rockets were used during the first year of the war. Mario Igual, a pyrotechnics manufacturer of Barcelona,⁵⁹ recalled an anti-aircraft rocket designed by the engineer Joaguin Grande with a seamless steel tube body. The charge was made by Pirotecnia Igual, and the rockets were launched in 1937 in Barcelona by the Italian volunteer "Batallon de la Muerte" (Death Battalion). The rocket was 9 cm in diameter and 30 cm long. Instead of fins, a boxlike appendage served to guide the missile. A square wooden tube was used for the launching. The ignition was by an electrical spark, and the rocket attained a height of some 3500-4000 meters.

Mr. Igual also manufactured propaganda rockets, the "Vulcan" message-throwers⁶⁰ for the Catalan Government, and war rockets. Metallic fins provided guidance. The charge consisted of 2 kg of gunpowder, and the warhead was a hand grenade ignited by the charge at the end of combustion. These rockets were used on the Aragon front by the Columna Durruti (anarchists). Patents to improve the guidance were sought,⁶¹⁻⁶² and, in all, some 10,000 rockets were manufactured for the "Subsecretaria de Armamento" by the 52nd war-factory in Barcelona.

Civil Uses of Rockets

Besides classic fireworks, the rocket has been and is used in Spain, as elsewhere, for life-saving and anti-hail purposes. The Spanish Lifesaving Society was founded

in Madrid in 1880, and Boxer rocket launching devices and Lyle-gun rocket launchers with ranges of 500 and 300 meters have been used since then.⁶³ In the mid-1930s Spanish ships were equipped with the Kongsberg M-52 rifle rocket line-thrower and the Schermuly pistol rocket line-thrower. Anti-hail rockets have been manufactured since 1880 by the Igual family in Barcelona, and also by the Firm Lecea in Vitoria. In the years after the civil war they have been used extensively with great success.

STUDIES AND REALIZATION

The "Play Ground"

Bishop Francis Godwin published The man in the moone or a discourse of a voyage thither, by Domingo Gonzales - The Speedy Messenger, in 1638, detailing the adventures of a Spaniard who traveled to the Moon. Gonzales managed the feat suspended from wild "gansas" (geese) trained by the hero. "All Andalusia knows my name and recognizes that I am Domingo Gonzalez, nobleman from the city of Seville, one of the most famous in Spain where I was born in 1552."⁶⁴

Abbot Hervás considered interplanetary space and the celestial bodies as a "play ground" for future astronauts and space ships. Hervás, "of the Royal Academy of Sciences and Antiquities of Dublin," published his Viaje estatico al mundo planetario⁶⁵ in four volumes, and described what he thought mankind would find on the celestial bodies.

Other, similar, works published in Spain include Conversaciones sobre la pluralidad de los mundos⁶⁶ and the Astronomer Flammarion's Los mundos imaginarios y los mundos reales.⁶⁷

"It may happen that fortune, one day, a second Columbus will endeavor to navigate to the Moon as the first sailed to the New World, and that a lynx Herschell on such a pillar will in the vast deep, new planets find, and some Fontenelle will live enough to thread the stars and tell the story."

The Herschel lunar exploration hoax of 1835, in the form of a communication of Dr. Grant to the Edinburgh Science Journal, also found its way into print in Spain.⁶⁸ Nonetheless, as late as 1868, Gomez Arias, Director of the Nautical School in Barcelona, believed that intelligent life likely existed on the Moon: "Some astronomers suppose that the Moon has no atmosphere Probably the Moon, as the other celestial bodies, are inhabited by beings whose nature, structure and capabilities, harmonize with the conditions of the celestial body on which they are parasites."⁶⁹

Cuban Archbishop Antonio María Claret must be mentioned as one of the first Spanish pioneers in rocket propulsion. In 1852 he witnessed in Holquin a manned balloon ascent, but the balloon failed and the aeronaut fell to the ground. Claret thought it over and, as his companion tells us in his diary, suggested using rocket propulsion to

give direction to the balloon, permitting them to fly against the wind.⁷⁰

In 1858, Maffiotte published an article describing a model rocket flying craft of his construction, consisting of a disc of bamboo and paper, 90 cm long and 70 cm wide, with a tail plane. He used a small iron cylinder with a 4 gram gunpowder charge as the rocket motor, disposed so that the axis of the motor passed through the center of gravity. The unit weighed 60 grams. The velocity obtained was 2.5 to 4.3 m/sec. The motor was inclined 30 degrees to give a vertical ascendent force. "Without any doubt," Mr. Maffiotte asserted, "there is a possibility of manufacturing a similar aircraft with the dimensions, resistance, and lightness desired, but it seems there will be difficulties in discovering a chemical compound better than gunpowder, both lighter and providing more gas production, and that does not explode as easily as the charges of the rockets now in use."⁷¹

Federico Gomez Arias was also interested in the propulsion of flying machines.[†] In 1872 he presented a paper on reactive propulsion.⁷² Even though Gomez did not mention space flight, his work is important for astronautics because he calculated the characteristics of a flying craft powered by a rocket engine many years before Kibaltchich, and suggested the possibility of propellants later proposed by Tsiolkovsky, and recommended a propellant feed system identical to the one described by Ganswindt. Arias' craft had a nacelle, where the pilot was situated, supported by a structure of three struts. A rocket engine was fixed above the struts, and the lower part had pneumatic dampers for landing. Gomez also foresaw the use of a stratospheric suit for balloon flights at high altitudes,⁷³ an idea brought into practice many years later in stratospheric flights.

The rocket engine consisted of a tube with a central combustion chamber, with both ends curved downwards to work as lifting nozzles, while two horizontal deviations at the forward end, controlled by valves, gave lateral propulsion power for the craft. Guidance was to be obtained by means of a rudder. The rocket engine, he said, "is based on the continuous production of gases, that, thrown into the atmosphere at a high calculated speed through a convenient section produces the necessary reactive effort for propulsion" As propellants he suggested gunpowder of a gross grain or in a paste, nitrocelulose, and nitroglycerine. He also suggested that "the detonation power of water, whose explosion, superior in power to the gunpowder, can be graduated as explained in the paper presented to the Scientific Society of Manchester, by Professor Piazzzi-Smith." This is perhaps the first proposal for using hydrogen-oxygen propellant for a rocket motor. Moreover, he proposed igniting the rocket engine by classical electrical methods, the flame of small alcohol burners, as well as the injection of

[†]See Ramon Carreras, "F. Gomez Arias' Rocket Vehicle Project," in this volume--Ed.

acids by a capillary tube producing automatic ignition. Finally, he proposed feeding the propellant cartridges into the combustion chamber by means of a revolver moved by a paddle wheel in the exhaust stream of one of the lift nozzles.

First Studies on Rocket Propulsion, Satellites and Space Flight

With the theoretical study of astronautics initiated by the pioneers Tsiolkovsky, Goddard, and Oberth, reviews began to appear in specialized journals in Spain. One of the most outstanding Spanish authors was the military and aeronautical engineer Manuel Bada, who in 1932-36 published a series of articles on astronautics in Revista Aeronautica, the official magazine of Air Authorities of the Spanish Republic. Based on the work of the pioneers, Bada examined jet motors,⁷⁴ jet propulsion,⁷⁵⁻⁷⁶ the yield of rocket engines,⁷⁷ propellants,⁷⁸ and the power obtained with these engines,⁷⁹ as well as stratospheric aircraft that would go in orbit, and the "orbital speeds" at different altitudes.⁸⁰

The Work of Lt. Colonel Herrera

Lt. Colonel Emilio Herrera, a Military and Aeronautical Engineer and one of the first military pilots in Spain, was Director of the Aeronautical Engineering School in Madrid (Escuela Superior de Aerotecnia). A great enthusiast of astronautics, he popularized the subject in lectures during the early 1930s.⁸¹ "Science and Aeronautics," a paper presented at the Academy of Sciences in Madrid in 1933, considered the requirements for attaining earth escape velocity. "It is astounding," he concluded, "to think of the fascinating marvels that will be offered to aeronautics, extrapolated until converted into astronautics."⁸² As a professor at the Escuela Superior de Aerotecnia he wrote a textbook on aerotechnics. In the second edition in 1936, he included a chapter on stratospheric flight, rocket propulsion and astronautics with the corresponding mathematical calculations.⁸³

Studies on Rockets and Space Travel After World War II

The use of rockets, and especially the V-2, during the Second World War, increased interest in rocket propulsion systems. Also, the announcements of satellite projects and future space activities gave way to discussions in articles and books, and its systematic study in engineering schools. Lt. Colonel J. Pazó, a Spanish aeronautical engineer, in 1945 wrote two articles on the history and theory of jet and rocket propulsion in Revista de Aeronautica,⁸⁴ though he did not reference space flight. At the same time another aeronautical engineer, Andres Lopez Rey, examined rocket propulsion and the efficiency of rockets and jets in Dyna, the review of the industrial engineers.⁸⁵⁻⁸⁶

In 1946, aeronautical engineer Captain S. Sanz aranguéz began to lecture on the theory of jet propulsion applied to liquid- and solid-propellant missiles, further promoting the development of rocketry and astronautics in Spain. A year later Julio Pastor included a chapter on the analytical study of rocket propulsion in his text book Termodinamica, published by the Instituto Nacional de Técnica Aeronautica (INTA).⁸⁷ Other individuals soon followed these examples.⁸⁸⁻⁹⁰

Bioastronautics

Various pioneers before the space age studied the behaviour of humans in the rarefied atmosphere at great altitudes, and under lower atmospheric pressure, using chambers and centrifugal devices.

Among the first to observe altitude sickness were the Spanish "Conquistadores" crossing the Andes.⁹¹⁻⁹⁵ Nieto Boqué has observed that the first experiment in Spanish aeromedicine occurred during the first Spanish balloon ascent in Lunardi in 1793.⁹⁶ The Duke de la Roca asked the aeronaut to take a bottle of water with him to be emptied at the maximum altitude, and filled with "superior atmosphere." This atmosphere taken from 3,400 feet was analyzed, and the results published in the Diario de Madrid on January 8, 1793.⁹⁷

The Monturiol Experiments

The death of a coral diver in the Rosas village on the Costa Brava, led Narcisco Monturiol to study the undersea world, and the creation of the submarine "Ictineo" (1859).⁹⁸ A contemporary, J. Estrany,⁹⁹ declared that "this inventor when building his ship made a complete device intentionally and expressively intended for physiological experiments."¹⁰⁰ Monturiol prepared for the survival of man inside a sealed chamber, and his work may also be considered as pioneering survival in sealed stratospheric nacelles or manned spacecraft (Figure 1) Speaking to fainthearted stockholders of his submarine company, he asserted: "Our country may not be worthy of possessing a chamber that would in the following centuries be applied to the great art of cruising in space where there is no possibility of life for mankind. But with the means provided by the mathematical, physical, and natural sciences, and the chamber of the "ictineo," the practice of this art has begun."¹⁰¹

He proceeded to conduct experiments in breathing, first with birds in a closed chamber (1858-1860), then with men in the "Ictineo." In this way, he determined the minimum volume of air necessary for human life without renovation up to two and a half hours. Monturiol studied the problems and solutions for the regeneration and purification of the atmosphere with oxygen, adsorption of carbon dioxide and condensation of water vapor,¹⁰² and the production of oxygen by various methods.¹⁰³ The studies included tests on the increase of temperature in closed spaces depending on the work done and the refrigeration required.¹⁰⁴ Furthermore, Monturiol examined the psychological implications arising from the confinement of crews in close quarters: "For this kind of investigation (in closed chambers) it is necessary to adopt all the precautions of prudence with the crew, consider the special character of each of them, and prevent excitement of the imagination that would lead to pain, anxiety, and discomfort."¹⁰⁵

Aeromedicine

In 1881, Luis Figuer, in his work on human physiology,¹⁰⁶ described the aeronaut altitude sickness in some detail, but aeromedicine as a basis of space medicine

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ICTINEO-MONTURIO

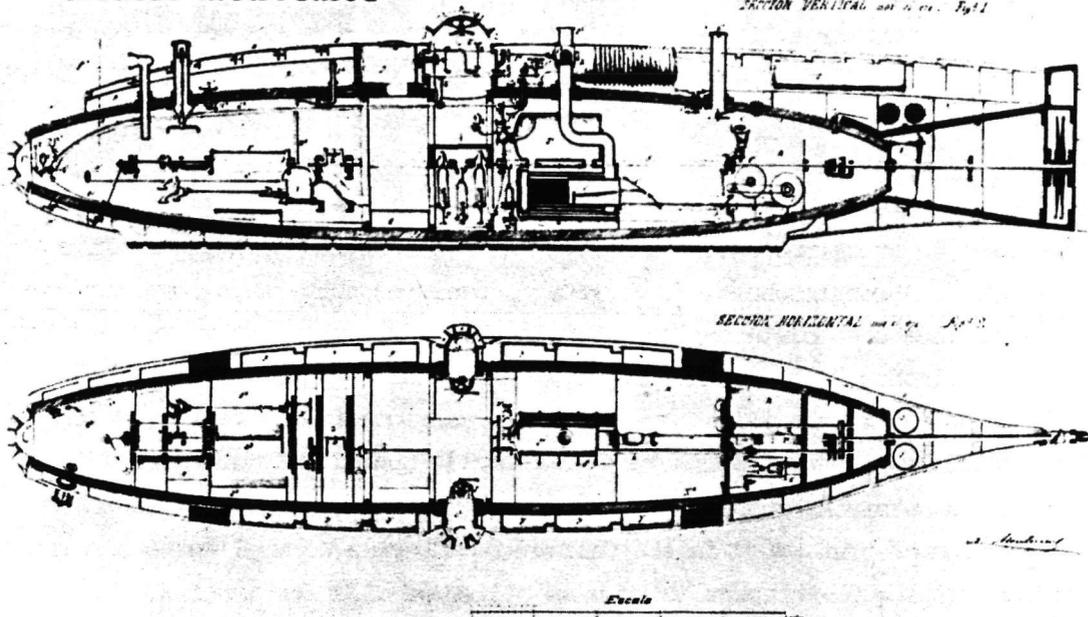


Fig. 1

began to develop in the 1930s with the flight of aircraft at great altitudes.¹⁰⁷ These studies and practical tests, constituted, as in the case of similar research in the U.S.A. and U.S.S.R., a point of departure for the growth of the bioastronautical sciences.

The Stratospheric Suit

In 1890 Gomez Arias published a pamphlet describing, among other things, six of his inventions, the ascension of the balloon "Zenith," and the death of two of the three aeronauts due to the lack of oxygen. He asserted that aeronauts should always be kept "at a pressure of one atmosphere, with sufficient oxygenated air for their breathing." He proposed a stratospheric suit for aeronauts, very much like the ones used by divers, connected to a collapsible air bag providing two cubic meters of air at one atmosphere per hour at great altitudes.¹⁰⁸

A much more elaborate stratospheric suit was developed by Lt. Colonel Herrera

for a stratospheric balloon ascent scheduled in 1936.¹⁰⁹ The final design had two layers, the first layer composed of a flexible and waterproof material, the second one reinforced with spires of copper around the arms, legs, and thorax to control the expansion of the first layer. At the elbows and knees there were articulations to facilitate movement. The head was protected by a diver's helmet.¹¹⁰

Herrera tested the suit at the "Escuela de Mecánicos de Aviación Militar," Cuatro Vientos (Madrid) in 1936 (Figure 2). Introduced in a vacuum chamber and



Fig. 2

covered with carbonic snow to obtain -70°C , at a pressure of 66 mm of Mercury corresponding to a simulated altitude of 18,000 meters, he remained during two and a half hours.¹¹¹ The test was a complete success, but some weeks afterwards the outbreak of the Civil War ended this interesting project.¹¹²⁻¹¹⁴

Aeromedicine After World War II

Flight at high altitudes for combat missions during World War II and the physiological problems involved, focused the attention of the aeromedical world on these conditions. In 1947 Dr. J. Ruiz-Gijon and Dr. F. Merayo published the results of their studies on the physiological problems of flights at high altitude in the "Centro de Investigacion de Medicina Aeronautica" in Madrid.¹¹⁵ Other studies followed.¹¹⁶ The requirements for building successful pressure suits were unusually severe, as Dr. H. Strughold, observed in 1945: "At the beginning of the stratosphere, the atmospheric pressure is approximately the same as on Mars."¹¹⁷

DISSEMINATION OF AN IDEA

The first Spanish book dedicated to astronautics, A la Conquista del Espacio (The Conquest of Space) appeared in 1946.¹¹⁸ This book based mainly on the work of the pioneers, considered propulsion by reaction, the space ship and the interplanetary voyage, an artificial satellite, possibilities of reaching celestial bodies, earthly uses of rockets, and the history of the rocket.¹¹⁹ (see also 147-148) Father Puig, S.J., Director of Iberica, that same year discussed the possibility of other inhabited worlds, and included a chapter on space flight and interplanetary communications.¹²⁰

Books

Some of the books on aeronautics and the history of flight include references to space flight. M. Morena Caracciolo (1922) referred to the promise of Sir Oliver Lodge that humanity would find a means to use atomic energy: "The day the prophecy of Sir Oliver Lodge is fulfilled, it will be possible to construct an artifact without wings and without a propeller, with only one exhaust tube through which the dis-integrated atoms will flow. It will ascend in the air, overcome the Earth's attraction, and pass the limits of the atmosphere to the sidereal spaces to visit the desolation of our satellite the Moon, Venus wrapped in clouds, and Mars with its mysterious channels. Aeronautics will then comply with the dictum: 'Sic itur ad Astra.'" ¹²¹

In 1940 Carlos Buigas explained the ways to interplanetary flight, the history of astronautics, and a journey to the Moon.¹⁵¹⁻¹⁵² Others soon joined with him to consider the prospects and problems of space flight.¹²²⁻¹²⁷

Articles in Reviews, Magazines, and Newspapers

The Jesuit review Iberica in 1928 described the tests of Von Opel's rocket-car,¹²⁸ and, three years later, the work of the space pioneer Robert Goddard.¹²⁹ But the first article (1932) to appear under the heading of "Astronautica" was written by

Carlos Buigas (the genial designer and builder of the luminous fountains in the International Fair of Barcelona in 1929). Published in the newspaper La Vanguardia, Buigas surveyed the problems of space travel, the work of Goddard, Oberth, and Hohmann, and proposed as a propellant of the future, atomic hydrogen.¹³⁰⁻¹³¹ In 1935 the Astronomer José Comas-Solá considered the future of mankind, and the necessity, as the density of population on Earth increased, of knowing whether other Worlds will be inhabitable.^{132, 133} But he did not think manned space flight possible in the near future, and favored automatic space probes. He believed that a vehicle would eventually circumnavigate the Moon and take photographs of its far side, and that, much to his distress, satellite bombing of the earth would soon become feasible.¹³⁴ Likewise, M. Jose Vazquez Garriga considered the subject of astronautics based on the book Raketenflug by Sänger¹³⁵ in Aeronautica in 1937, and in Aire, he asserted that, based on the stratospheric flights of Piccard, the possibility of interplanetary flight was not very far away.¹³⁶

With the release of data on the missiles and war rockets of World War II, interest in rocket propulsion was rekindled in Spain, and the Revista de Aeronautica, Iberica, Avion and other reviews periodically published articles dealing with rockets and space flight.¹³⁷⁻¹⁴⁵ In 1950, Father Antonio Due, S.J., in Iberica, stated that the launching of the "Wac-Corporal" placed man at the frontier of interplanetary travel.¹⁴⁶ Others speculated on military applications of space flight,¹⁴⁷ and also the possibility of lunar voyage along the lines suggested by Hsue Shen Tsien, then a professor at the California Institute of Technology.¹⁴⁸

Astronautical Societies

The first Spanish astronautical society, "Asociacion Española de Astronáutica," was founded in Madrid on February 11, 1949, by a group of Ingenieros de Caminos lead by Tomas Mur. Other members included: Mr. Ramón Daza, Francisco Gonzalez Quijano, and Vicente Roglá. Mur represented Spain at the first International Astronautical Federation Congress in Paris in 1950.^{149 150} In 1951 at the second Congress in London, Mur also represented Spain, one of the 10 nations that formed the I.A.F.¹⁵¹

In April 1949, Mr. Juan Z. Arboles established an Astronautic Section in Aster that published notes and articles on lunar rockets and satellites.¹⁵³⁻¹⁵⁵

SPACE SCIENCE IN FICTION

In 1855 Miguel Astorch, in Lunigrafia, described the Earth as it was seen from space in much the same way as the astronaut Frank Borman would describe it 113 years later. A study by Professor Carreras¹⁵⁶ gives us some interesting details of the work of this lawyer, poet, and writer of great talent. The Lunigrafia consisted of a series of nine volumes published between 1855 and 1858 in Barcelona

and Madrid.¹⁵⁷ In his first volumes, Estorch claimed to have translated a fantastic manuscript written by a German, M. Krotse. Krotse, of course, is Estorch spelled backwards.¹⁵⁸ Estorch¹⁵⁹ was a professor of mathematics; and possessed sufficient scientific knowledge to write a classic science fiction story. However, he abandoned science to describe a flight to the Moon onboard a projectile fired by a cannon, and a summary of the good habits found among the inhabitants of the Moon, the "lunicolas."

Estorch first describes a series of tests made with a special carbine. These tests took place "in one of the highest mountains of the Himalaya" to escape from the attraction of gravity and from the resistance of the air. The hero then ordered a cannon a la Paixhans to be made in England, that could shoot a projectile of two feet in diameter to the Moon. The hero of the story then "conceived the bold idea of placing a man inside."¹⁶⁰ The astronaut in this case was the hero's small servant, a native from Calcutta, named Leugim (the forename of Estorch spelled backwards). The launch took place as follows: "Our little Calcuttian was placed in a hollow iron ball disposed so that he could breath. In the upper part there were a number of special hooks that could be deployed for the descent and used as a parachute. I waited until the Moon reached its zenith, and fired the cannon."¹⁶¹ Estorch published this story ten years before Jules Verne's famous novel De la Terre a la Lune.

Estorch also referred to another Spanish author, Mr. Joaquin del Castillo y Mayone, who published a story in 1832 about a flight to the Moon in a balloon,¹⁶² that is three years before Edgar Allan Poe published The Unparalleled Adventure of One Hans Pfaal (1835). Estorch was followed by Enrique Gaspar in 1887, who described manned houselike spacecraft that orbited the Earth in a retrograde direction at so fantastic a speed that time went backward. The spacecraft was named "El Anacronopete" from "Ana" (backwards), "Cronos" (time) and "Petes" one who flies. Gaspar's machine was propelled by electricity, without supporting detail.¹⁶³

Lt. Colonel José de Elola y Gutierrez, a professor at the Academia General Militar and of the Escuela Superior de Guerra, honored several times for his scientific works, also wrote science fiction under the name of "Colonel Ignotus." During the first decade of the 20th century his stories were widely read and enjoyed by Spanish youth. In the eight novels of "Colonel Ignotus"¹⁶⁴⁻¹⁷¹ (1913-19), we find in "De los Andes al Cielo" that the hero employed a space vehicle, a great crystal sphere 600 meters in diameter, based on the decomposition of a radioactive material. The space flight novels of "Colonel Ignotus" may well be considered worthy of inclusion in all the anthologies of space science fiction.

Modern Space Science Fiction Stories

The dissemination of space travel ideas by the astronomical pioneers in the early 20th century led some Spanish firms to publish serials on space adventures. In

one of the first, in 1927, Onofre Pares described an advanced civilization in Australia that engaged in a series of interplanetary voyages and lunar expeditions.¹⁷²

Another novel, Coleccion Aventura, of the Editorial Juventud, was based on the studies and experiences of Oberth. The series also appeared under the title Marte invade la Tierra.¹⁷⁴ A similar series followed: La novela de aventuras published by Joaquin Gil,¹⁷⁵ El enigma del espacio,¹⁷⁶ and Jimenez de Letano, El final de una expedicion sideral, Viaje a Marte.¹⁷⁷ Other characteristic titles include: Los monstruos del rayo,¹⁷⁸ En el centro de la Luna,¹⁷⁹ and Mas alla de las nubes.¹⁸⁰ Likewise, a number of science fiction plays were written for the Spanish theater, and produced in motion pictures.

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HISTORY OF THE DEVELOPMENT OF ROCKET TECHNOLOGY
AND ASTRONAUTICS IN POLAND⁺Wladyslaw Geisler (Poland)⁺⁺

The development of rocket technology in Poland is several centuries old. It seems very likely that the first utilization of rocket weapons in Europe took place on Polish soil during the Tartar attack in the 13th century. The Polish historian John Dlugosz, who described the course of the decisive battle of Legnica (1241) in his chronicles, stated in the narrative that the Tartars carried a dragon head that spewed smoke and fire at the Polish knights, rendering them incapable of continuing the battle. In a monastery near the battlefield of Legnica, there is a painting which accurately depicts the Tartars' dragon head as described by Dlugosz.

Walenty Sebisch (1577-1657), an urban military architect living in Wroclaw in the 16th and 17th centuries, also left behind many drawings and notes pertaining to rocket fabrication and use. He wrote that the rocket launcher in the form of a dragon head, as employed by the Tartars at Legnica, was a traditional device for hurling military and decorative rockets, and that it was used later on in the Renaissance as well. Sebisch's rocket drawings show them equipped with small stabilizers attached to the body of the rocket. Sebisch also drew deep, conical recesses in the fuel which played the role of nozzles. Moreover, rocket clusters can be seen in Sebisch's drawings, corresponding to the current concept of rocket batteries. Other writers on rockets in Poland were Marcin Bielski in 1569, an anonymous writer in 1623, and del Aqua in 1637, a Venetian in Polish service. In 1643 a Polish translation of a book written on rocket construction by a Spaniard, Diego Uffano, appeared.

One of the principal contributions to the development of the art of rocket construction in Poland, indeed, of the whole of Europe at that time, was the work of Casimir Siemienowicz who led the Polish Royal Artillery under King Wladislaus IV. Written in Latin and published in Amsterdam in 1650, his book was titled Artis

⁺Presented at the Fifth History Symposium of the International Academy of Astronautics, Brussels, Belgium, September 1971.

⁺⁺Polish Astronautical Society, Katowice-Ligota.

magnae artilleries, Pars Prima (The Art of Great Artillery, Part One). A year later, in 1651, this work was published in French, then translated into German in 1676, and into Dutch and English in 1729. For over 100 years it proved an indispensable text-book for training artillery troops in all the countries of Europe. (Figure 1)

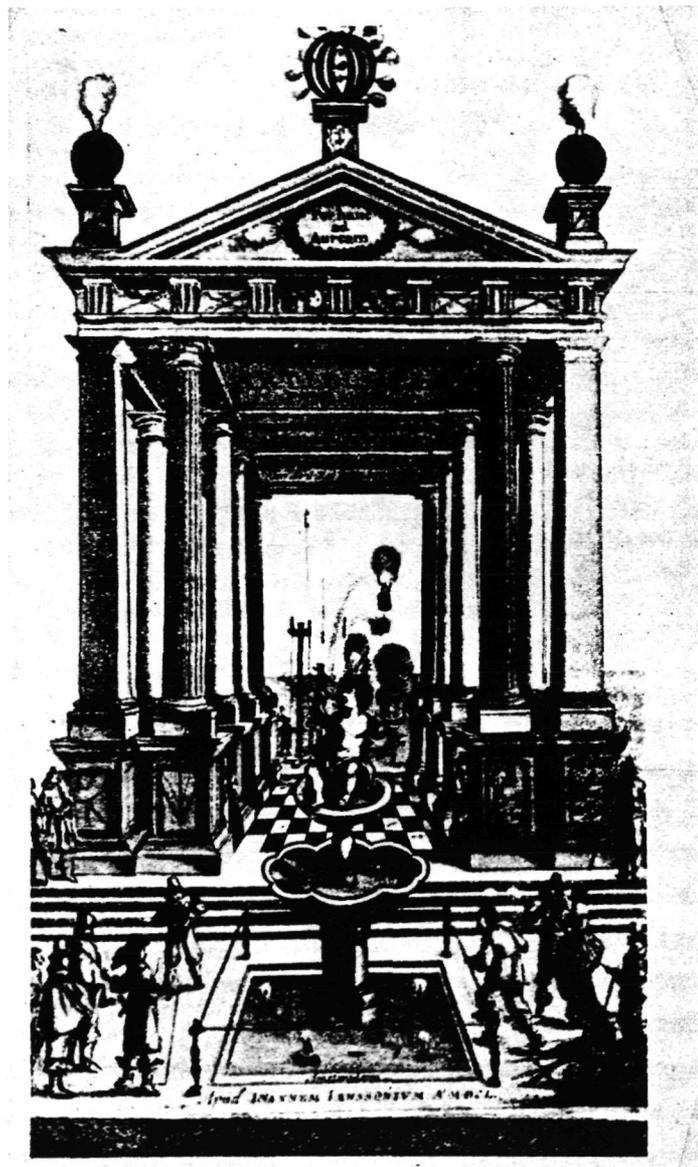


Fig. 1

In the third chapter (Figure 2) Siemienowcz provided a systematic and amply illustrated description of various rockets used at this time, as well as some

ARTIS
MAGNÆ ARTILLERIÆ
 PARTIS PRIMÆ
LIBER III.
 DE ROCHETIS.

 Mnum artificialium ignium, primum sibi vendicant locum Rochetz, vel *Pyroboli* ex Græco (tamen id improprie usurpatur ad nostras Rochetas: cum ~~magis~~ tela ignita denotet; de quibus infra) Italis *Rochette & Raggi*, Gallis *Fusces*, Germanis *Steigende Kassen*, vel *Ragetten*, & *Drachsen*, nobis vero Polonis *Roce* dicitur. Harum constructio perantiqua, & omnibus Pyroblastis nota factis: quæ licet facilis, laboriosa tamen, & accuratam præparantis requirit sedulitatem. Pyroboliæ verò operam daturi, ab his initium sumunt: nec incongruè sanè, cum omnes recreativi ignes artificiales, omnes Machinæ: ut sunt Tubi, Rotz ignitz, Gladii, Semispathæ, Globi, cæteraque his familia Pyrobolica inventa, absque Rochetis, vix esse possint. Igitur hoc tertio libro illarum præparandarum modum, varias formas, figuras, & usum sufficienter proponemus.

Fig. 2

of his own designs, including details of the construction, solid-propellant components, etc. (Figure 3). Siemienowicz was probably the first to propose a three-stage rocket, consisting of three nested casings, each ejected in sequence after the fuel had burned (Figure 4). The mass ratio of the first, second, and third stages was 6.4:2.4:1. Siemienowicz also described a two-stage rocket, with a rocket cluster (rocket battery) employed as the first stage, as well as various rocket launchers. For certain rockets, instead of the customary stabilization rods, Siemienowicz employed two, three, or four small stabilizer fins fixed to the casings.⁺

In the Warsaw Arsenal at the beginning of the 19th century, Josef Bem (Figure 5), a captain in the Royal Artillery, built rockets for use by the troops of the Polish Kingdom. His report on the construction, machinery, and solid propellants appeared in 1820 in French and German (Figures 6, 7, and 8). In his report, Bem also

⁺See Elie Carafoli, "Romanian Rocketry in the 16th Century," and Juan Maluquer, "A Survey of Rocketry and Astronautics in Spain," in this volume--Ed.

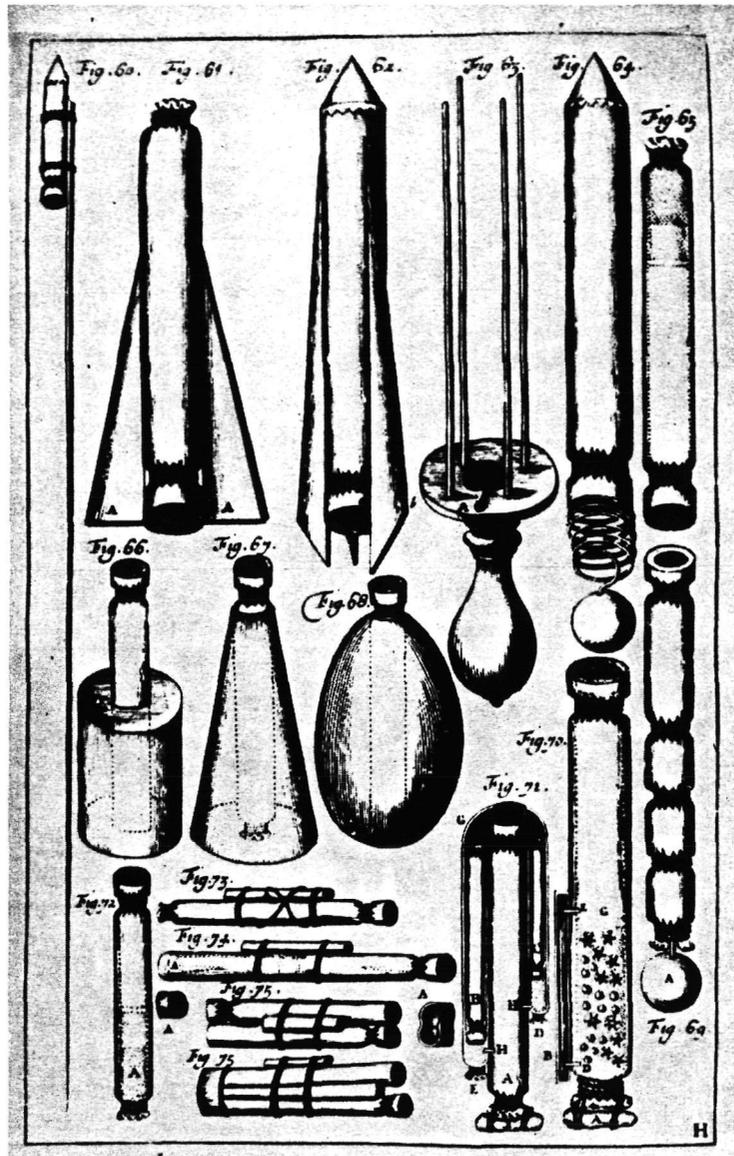


Fig. 3

described a rocket attack by the English fleet against the city of Gdansk in 1813. A few years later, in the battle of Grochow (February 25, 1831), rocket launchers were successfully employed by the Polish revolutionary Chief of Staff, General Pradzynski, against an advance of the Russian cavalry. He described it some years later in his Memoirs.

The complex development of science and technology at the end of the 19th century also contributed to the development of the theoretical foundations of space flight, indicating the possibility of using rockets for this purpose. Mieczyslaw

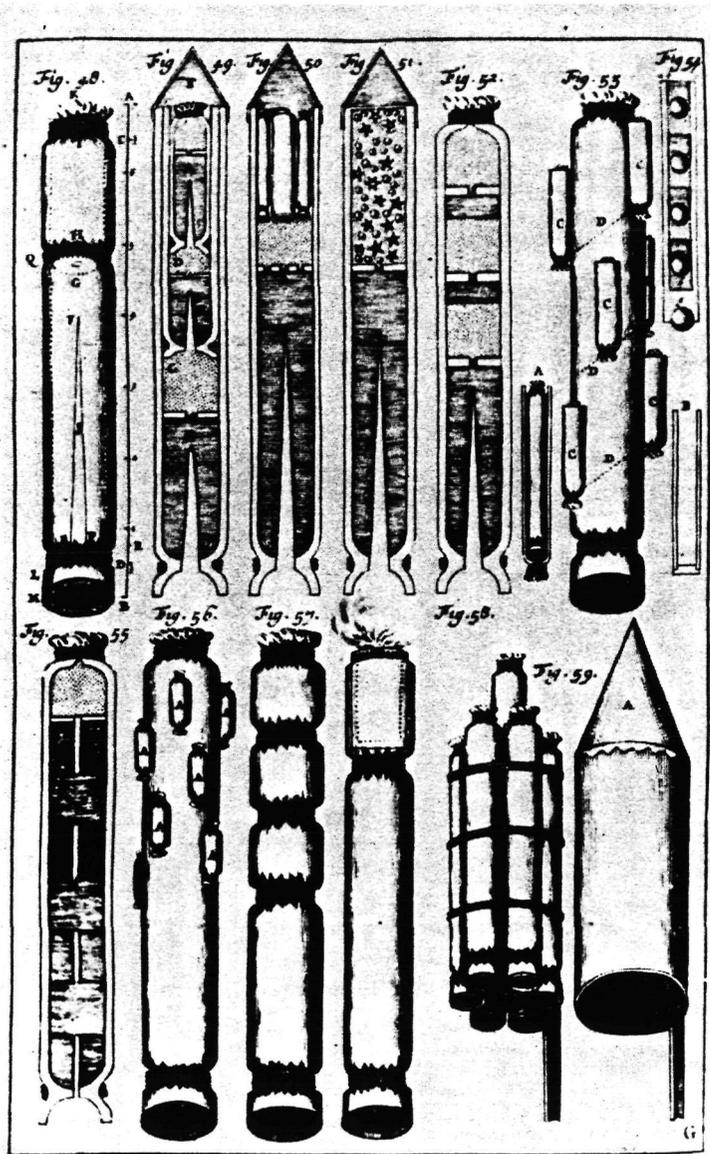


Fig. 4

Wolfke was one of the first to concern himself with this subject in Poland. Eventually he became a well-known physicist and professor at Warsaw University. As a young man in 1895, he wrote about using rockets outside the atmosphere of the Earth. Beginning in 1913, Franciszek Abdan Ulinski dealt with the topic of rocket flights, and his article on using electrically charged particles to propel the rockets appeared in the Viennese magazine Der Flug in 1920. The electrically charged particles serve as the ejected mass, thus propelling the rocket which Ulinski called a "cathode rocket." He



Fig. 5

envisioned solar radiation as the energy source, using thermoelectric batteries. Present-day ion thrusters are in a certain sense the implementation of Ulinski's ideas.

In 1932-1933 Ary Szternfeld, a young and as yet unknown researcher born in Sieradz near Lodz, in Poland, wrote his Introduction to Cosmonautics for which he was later honored by the French Astronomical Society. On December 6, 1933, Szternfeld gave a report in the Astronomical Observatory of Warsaw University on the results of his work. Two years later Szternfeld moved to the Soviet Union. There, in 1937, he

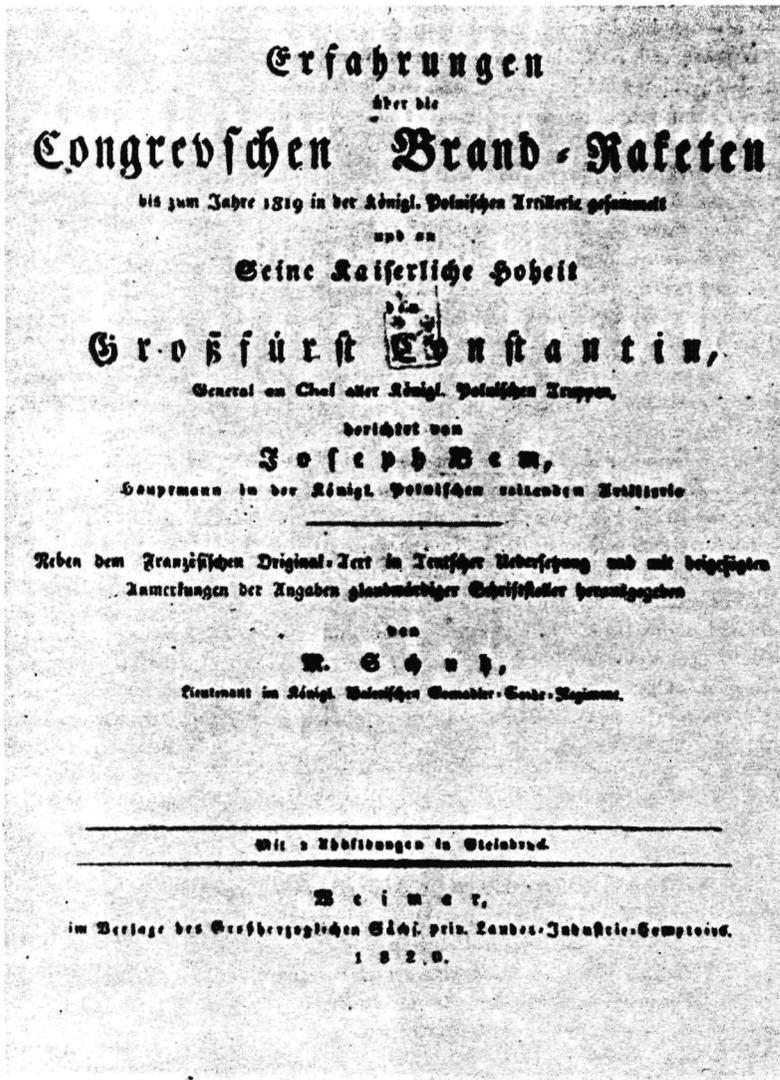


Fig. 6

published an abbreviated version of his work Introduction to Cosmonautics as a book.

Thanks to his arduous Benedictine work, Szternfeld was able to calculate the most favorable space flight trajectories for minimizing fuel consumption, trajectories which are astonishingly relevant even today. It is sufficient to observe that more than 150 artificial earth satellites have been launched by the Soviet Union and the United States—in the first 8 years of the space flight era—on the eleven orbital trajectories calculated by Szternfeld. The main parameters of the circular orbits of the Vostoks with Gagarin, Titov, Nikolayev, Popovich, Bykovski, and Tereshkova, as

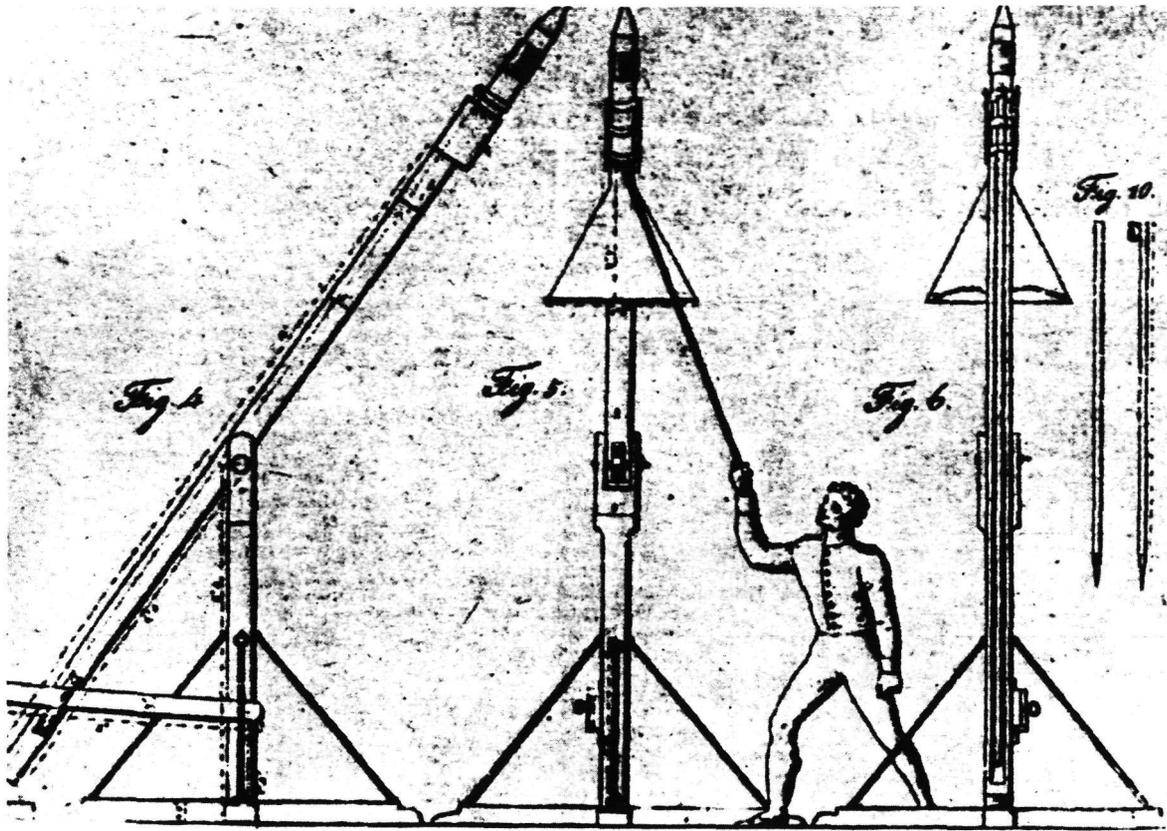


Fig. 7

as well as the Mercury capsules of Glenn, Carpenter, Shirra, Grissom, Young, and Cooper, differed by no more than 0.3 to 0.7% from the orbits calculated by Sztternfeld!⁺

In the 1930s Casimir Zarankiewicz, later a professor of mathematics and mechanics at the Polytechnic Institute in Warsaw and the first President of the Polish Astronautical Society, dealt with questions of rocket flights in the atmosphere of the Earth and in outer space. However, realization of rocket flights seemed a long way off at that time, and a claim that technological development would shortly permit such flights was usually received with skepticism, as I learned for myself during my reports given in the years 1934-1936. However, discussions of this problem remained very popular, and scientific magazines as well as popular weeklies revealed new information on this topic from time to time. As an example, in December 1928 the weekly magazine *Tecza* published an exhaustive article on the future and reality of space flights, based on the works of Esnault Pelterie and the experiments of Opel.

⁺See also Fritz Sykora, "Guido von Pirquet: Austrian Pioneer of Astronautics," in this volume—Ed.



Fig. 8

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PART II

ROCKETRY AND ASTRONAUTICS: CONCEPTS, THEORIES,

AND ANALYSES AFTER 1880

FIRST WORKS BY K.E. TSIOLKOVSKY AND I.V. MESHCHERSKY
ON ROCKET DYNAMICS⁺

Arkady A. Kosmodemiansky (USSR)⁺⁺

I.

Studies in the archives of the USSR Academy of Sciences make it possible to assert that K.E. Tsiolkovsky began a systematic study of the theory of rocket dynamics in 1896. Though he found it possible only to publish the first part of the work "Exploring Universal Space With Rocket Instruments" late in 1903,¹ he had obtained the basic formulae related to the rectilinear movement of rockets (in free space and in a homogeneous gravitational field) before May 10, 1897. A copy of the 1903 article with Tsiolkovsky's notes survived. He wrote: ". . . still, I am thankful to Phillipof (editor of the Nauchnoe Obozrenie magazine) for he ventured to publish my work; the date with formulae was found--May 10, 1897."

In the published work (1903) Tsiolkovsky studied the solution of the following problems in the rectilinear movement of rockets:

- . motion in free space under the action of thrust force alone;
- . motion in a homogeneous gravitational field of the Earth;
- . motion with constant acceleration caused by the action of the thrust force (in this case the mass of the rocket decreases exponentially);
- . smooth landing on the Earth's surface;
- . velocity efficiency.

We will show the solution of the first and the third problems, somewhat condensing Tsiolkovsky's original calculations and conclusions. His studies into the movement of rockets in free space is premised on the conservation of momentum. It can be written in the form of:

$$Mdv + V_1 dM = 0 \quad (1)$$

⁺Presented at the Third History Symposium of the International Academy of Astronautics, Mar del Plata, Argentina, October 1969.

⁺⁺Professor of Mechanics, Dr. of Physico-Mathematical Sciences.

In equation (1) M is the rocket mass, dv is the gain of rocket velocity due to the jettisoned mass dM , V_1 is the constant relative speed of combustion products at the nozzle opening of the engine. It follows from equation (1) that

$$v = -V_1 \int \frac{dM}{M} = -V_1 \ln M + C_1$$

where C_1 is the integration constant. If at the beginning of movement $M = M_0$, and $v = 0$, then $C_1 = V_1 \ln M_0$ and, consequently,

$$v = V_1 \ln \frac{M_0}{M} \quad (2)$$

Tsiolkovsky stated:² "The highest speed of the rocket will be . . . when all the stock M_2 (M_2 is the propellant mass) is consumed." If we are to designate the rocket mass, excluding propellant, as M_1 , then from equation (2) we receive the formula for the maximum speed of the rocket in the following form:

$$v_{max} = V_1 \ln \frac{M_0}{M_1} = V_1 \ln \frac{M_1 + M_2}{M_1} = V_1 \ln \left(1 + \frac{M_2}{M_1} \right) \quad (3)$$

Formula (3) is perhaps the most famous Tsiolkovsky formula. In the Soviet scientific literature the ratio of the propellant mass (M_2) to the rocket mass, excluding propellant (M_1), is called the Tsiolkovsky number and is designated by the letter Z . Then

$$v_{max} = V_1 \ln (1 + Z) \quad (4)$$

Tsiolkovsky's work of 1903 gives values of v_{max} for Z ranging from 0.1 to 193 (and $Z = \infty$), assuming that the propellant components are liquid hydrogen and liquid oxygen, and $V_1 = 5,700$ m/sec.⁺

⁺Tsiolkovsky stipulates that such a high value was obtained under the supposition of a complete transformation of chemical energy into the kinetic energy of jet particles (losses are not accounted for).

II

One may follow the solution of the problem of the rectilinear movement of the rocket in a homogeneous gravitational field of the Earth assuming that

$$M = M_0 e^{-\alpha t}, \quad \alpha = \text{const.}$$

In that case the thrust force will be $\phi = - \frac{dM}{dt} V_1 = (\alpha V_1) M$

The rocket movement equation will be written in the form of:

$$M \frac{dv}{dt} = \alpha V_1 M - Mg$$

or

$$dv = (\alpha V_1 - g) dt \quad (5)$$

Assuming that $t = 0, v = 0$ from equation (5) we find through integration that

$$v = (\alpha V_1 - g)t \quad (6)$$

If the combustion time is preset at ($t = t_2$), then from equation (6) we find that:

$$v_2 = (\alpha V_1 - g)t_2 \quad (7)$$

Let us analyze the same rocket, but let it move in free space t_2 seconds; then

$$v_{\max} = (\alpha V_1)t_2 = V_1 \ln(1 + z) \quad (8)$$

Excluding time t_2 from equation (7) and (8), we find that:

$$v_{\max} = v_2 \cdot \frac{\alpha V_1}{\alpha V_1 - g} \quad (9)$$

Designating αV_1 by ρ , we obtain

$$v_2 = v_{\max} \cdot \frac{\rho - g}{\rho} = v_{\max} \left(1 - \frac{g}{\rho}\right) \quad (10)$$

Formula (9) and (10) coincide with formula (34) given by Tsiolkovsky.³

Tsiolkovsky correctly pointed out that ". . . if ρ is infinitely large, or if the ignition is instantaneous, then speed v_2 of the rocket in a gravity medium will be the same as that in a medium without gravity,"⁴ i.e., if

$$P \rightarrow \infty, \frac{g}{P} \rightarrow 0, \text{ then } v_2 = v_{max}$$

But at larger values of $P = \alpha V_1$ "a stronger and more massive rocket is required, . . . objects and apparatus inside the rocket need be stronger as the relative gravity in it will be very strong and particularly dangerous for a live observer, if such is launched in the rocket."⁵

III

The solution of the basic problems of rocket dynamics, "scientific calculation," as Tsiolkovsky used to say, is the main feature in the creative work of Konstantin Eduardovich. But his articles on the theory of rocket dynamics also dealt with practical issues of rocket building, with the peculiarities and concrete design of individual assemblies, and of the rocket as a whole. Thus, for example:

a) In 1903 Tsiolkovsky suggested using fuel components to cool the walls of the rocket engine. He recommended that the walls of the engine chamber and nozzle be made of two layers, and that the liquid fuel be pumped through one of them. The flowing substance thus cools the hot wall of the engine. It also would be necessary to make the inside surface of the chamber and the nozzle of a material with high heat conducting properties to provide for more efficient heat removal. This forced cooling of the hot engine wall would ensure continuous operation of the rocket engine, and is a widely used practice in the present day construction of liquid-propellant rocket engines.

b) Tsiolkovsky gave the following description of a rocket in his work of 1903: "Let us imagine the following rocket: an oblong metal chamber (of a minimum resistance form), supplied with light, oxygen, an absorber of carbon dioxide, a vaporous atmosphere and other living organism secretions, intended not only for housing different physical instruments, but also an intelligent being operating the chamber The chamber has a large stock of propellants which instantaneously form an explosive mass when mixed. These substances, flowing properly, and sufficiently uniformly burned at a definite spot inside the pipe that widens towards the end, resembling a horn or a musical wind instrument. . . . It is obvious that this device, . . . will provide definite conditions for moving upwards."⁶

c) For maintaining the rectilinear forward movement of the rocket, Tsiolkovsky recommended that the rocket engine be secured on Cardan joints so as to eliminate the pitch, roll, and yaw by means of respective inclinations (gimballing) of the engine

nozzle. In his work of 1911, which briefly described the content of his article of 1903, Tsiolkovsky asserted: "The turning of the funnel, or a rudder in front of it, is the most simple method of guiding the rocket's flight."⁷ Let us note that jet vanes placed inside the jet of hot gases flowing from the nozzle, and gimbaling the entire engine, are widely used in present-day rocket engineering.

d) Tsiolkovsky also provided a formula for determining the propellant stock necessary to furnish the rocket velocity and to "quench it," i.e., solve the problem of a soft landing on a planet without an atmosphere. He declared; "its [the rocket's] velocity can grow in the desired progression and in the desired direction; it can be constant and it can be uniformly throttled down to provide for a safe landing on a planet (underlined by Tsiolkovsky). The matter rests with a good burning controller."⁸

e) In his 1903 work, Tsiolkovsky repeatedly stressed that the propellant he suggested (liquid oxygen + liquid hydrogen) was one of the most efficient. He said: "Let us imagine a number of points whose abscissas express the sum (or a product) of atomic weights of the connected common bodies, and the ordinates express a corresponding energy of a chemical compound, then, drawing through the points . . . a smooth curve, we shall observe a continuous decrease of ordinates as abscissas are increasing, which proves our viewpoint."⁹

Tsiolkovsky's deep and broad understanding of the most difficult problems of rocket engineering is really quite astonishing, especially when we consider that he did not receive a systematic education, and was essentially a self-taught person.

IV

Late in the nineteenth century, in the years which saw the foundations of variable mass point dynamics created, Ivan Vsevolodovich Meshchersky was a Master of the Petersburg University, and a disciple of the famous mechanic, University Professor D.K. Bobylev (1842-1918). The following words of A.M. Lyapunov (1857-1918), a world-renowned mathematician and mechanic, were a watchword for the pre-revolutionary Petersburg school of mechanics and specialists in applied mathematics: "As soon as we undertake to solve a definite problem (either a problem of mechanics or physics--no matter) set very strictly from the viewpoint of mathematics, then the problem becomes, in such an approach, a problem of pure analysis and it should be interpreted as such a problem."¹⁰ Meshchersky's work "Dynamics Of A Variable Mass Point," his master's thesis, is irreproachable from the mathematics point of view, and the author writes in such a way that "there is no space for words and a lot of space for thought."

His thesis contains seven chapters and, in reality, laid the foundations for a new section of theoretical mechanics. In Chapter II, Meshchersky obtained differential equations for the movement of the point of a variable mass, and analyzed the major con-

sequences when taking into account different forces and conditions. Chapter III dealt with studies into rectilinear motion of the point, and two pages of the chapter were devoted to the "ascending movement of a rocket in a resisting medium." Meshchersky noted that the rocket's ascending movement was described by the Riccati equation, "air resistance is assumed to be proportional to the velocity squared." Chapter IV dealt with the motion of the variable mass point in a homogeneous gravitational field. Page 121 described, irrespective of Tsiolkovsky's work, the basic rocket equation (Tsiolkovsky's formula) in the form of:

$$\dot{x} = a \ln f + (\dot{x})_0$$

where f is the dimensionless mass, $a = \text{const.}$

On page 122 there is a brief mention of the problem of motion of a point in a homogeneous gravitational force field when $f = e^{kt}$ i.e., the point mass changes in accordance with the exponential law.

The last chapter of the Meshchersky dissertation investigated the problem of motion of a variable mass point under the action of a central force (pp. 136-157).

V

The method of motion transformation first suggested by Meshchersky turned out to be very successful in dealing with problems of a variable mass point. His idea of the method was as follows: there are certain transformations from real variables (x, y, t) to new variables (ξ, η, τ) , such that the equations of motion of a variable mass point are converted into equations of motion of a constant mass point.

Meshchersky's transformation formula established a clearly interpreted correspondence between the motion elements of the auxiliary point in auxiliary space and the motion elements of the real point.

Let us illustrate this method with the following problem: determine the motion of the point of a variable mass drawn towards the origin of the coordinates by a force proportional to the point mass and inversely-proportional to the square of the distance from the chosen beginning, assuming that a point mass is growing in accordance with the following law:

$$M = \frac{M_0}{1 - \alpha t}$$

and the absolute velocity of the connected particles is equal to zero.

The vector equation of the point motion can be written in the form of

$$M \frac{d\vec{v}}{dt} = - \frac{k M r}{r^3} - \frac{dM}{dt} \vec{v} \quad (11)$$

In this case the point trajectory is a straight line. Then, placing axes Ox and Oy in this plane and projecting equation (11) on those axes results in the following two scalar equation:

$$\left. \begin{aligned} \frac{d^2x}{dt^2} &= -\frac{kx}{r^3} - \frac{\alpha}{1-\alpha t} \frac{dx}{dt} \\ \frac{d^2y}{dt^2} &= -\frac{ky}{r^3} - \frac{\alpha}{1-\alpha t} \frac{dy}{dt} \end{aligned} \right\} \quad (12)$$

where

$$r^2 = x^2 + y^2$$

let us introduce new variables ξ, η, τ , assuming:

$$\xi = \frac{x}{(1-\alpha t)^2}; \quad \eta = \frac{y}{(1-\alpha t)^2}; \quad d\tau = \frac{dt}{(1-\alpha t)^3}$$

The equations of the reflected motion in the auxiliary space (ξ, η) with the new time of τ will be

$$\frac{d^2\xi}{d\tau^2} = -\frac{k\xi}{\rho^3}; \quad \frac{d^2\eta}{d\tau^2} = -\frac{k\eta}{\rho^3} \quad (13)$$

where

$$\rho^2 = \xi^2 + \eta^2$$

Equation (13) is the equation of motion of a constant mass point under the affect of a central force, and the integrals of those equations have been studied substantially. Knowing the solution of equation (13) and the coordinates and time transformation formula, it is easy to find all the characteristic properties of motion of a variable mass point.

In celestial mechanics problems, Meshchersky was the first to analyze a number of partial laws of mass variation, assuming that

$$M = \frac{M_0}{1+\alpha t}; \quad M = \frac{M_0}{\sqrt{1+\alpha t+\beta t^2}}; \quad M = \frac{M_0}{(1+\alpha t+\beta t^2)^2}$$

where α and β are constants.

These suppositions by Meshchersky, made in purely theoretical deliberations and subjected to extensive analysis in a large number of works by prominent astronomers

have received good confirmation. Now these hypotheses are called "Meshchersky laws" in the literature of celestial mechanics.

Meshchersky obtained one more result pertaining to the study of the motion of comets. "Let us consider, for example, the motion of a comet when it approaches perihelion, assuming that the comet mass diminishes and may be expressed by some function of the comet's distance from the Sun; then the motion equations are integrated in quadratures if we are to assume that the inertial center velocity of the separating particles is either zero, or is directed along the line of the comet velocity, the ratio of these velocities being either a constant value or some function of the distance between the comet and the Sun."¹¹

Meschersky was also the first to advance and partially study problems of the following type: find the law of a variable mass point which, effected by preset external forces, would circumscribe a preset trajectory. Meshchersky calls these problems inverse ones. Let us offer the general solution for this class of inverse problems for rectilinear trajectories.¹² Let us consider for more certainty the vertical ascent of a variable mass point in a homogeneous gravitational field, in a medium whose resistance is proportional to the velocity squared.

The equation of the point motion will be of the following form:

$$M \frac{dv}{dt} = -Mg - kv^2 - \frac{dM}{dt} v_1$$

or:

$$\frac{dM}{dt} + \frac{M}{v_1} \left(g + \frac{dv}{dt} \right) + \frac{k}{v_1} v^2 = 0 \quad (14)$$

Differential equation (14) is the linear nonhomogeneous equation with respect to M, and its common integral may be written in the following form:

$$M = e^{-\frac{1}{v_1} \int \left(g + \frac{dv}{dt} \right) dt} \left[C - \frac{k}{v_1} \int v^2 e^{\frac{1}{v_1} \int \left(g + \frac{dv}{dt} \right) dt} dt \right] \quad (15)$$

where C is the integration constant.

Equation (15) makes it simple to calculate the necessary law of mass variation (i.e., the operational regime of a jet engine), if the law of motion of a point along a rectilinear trajectory is known. It is easy to understand that formula (15) is readily generalized for the variable gravitational field and arbitrary laws of the resistance of medium. An illustration follows two simple examples to determine the

law of mass variation according to formula (15), if the point motion characteristics are given. Let the acceleration of a point, ascending vertically upwards in a homogeneous gravitational field and without resistance forces, be equal to zero. It is necessary to determine how the mass point changes to ensure such a law of motion. Assuming in formula (15) that

$$\frac{dv}{dt} = 0, \quad k = 0, \quad g = \text{const.}$$

we find that

$$M = C e^{-\frac{gt}{v_1}} \quad (16)$$

so that for $t = 0$, $M = M_0$, we shall finally have

$$M = M_0 e^{-\frac{gt}{v_1}} \quad (17)$$

Thus, a variable mass point will obtain a constant velocity in a homogeneous gravitational field where the mass point changes exponentially (17).

If we want to ensure a uniformly accelerated motion of a point with the acceleration of a in the homogeneous gravitational field, then based on formula (15), we find that the mass should vary according to the following law:

$$M = M_0 e^{-\frac{1}{v_1} (a + g) t} \quad (18)$$

For some partial problems of rocket engineering the solution of inverse problems of the dynamics of a variable mass point is of obvious interest.

VI

I.V. Meshchersky's work on the mechanics of variable mass was later published twice in the Soviet Union by Gostekhizdat, in 1950 and 1952. Regrettably, Meshchersky's master thesis "Dynamics of a Variable Mass Point" is little known in the West; we hope that this article will attract the attention of Western scientists who work in the field of rocket engineering history.

The discoveries of both Meshchersky and Tsiolkovsky in the field of rocket dynamics were made separately and individually;¹³ before the 1930s they were known only to few specialists.

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ON THE WORKS OF S.S. NEZH DANOVSKY IN THE FIELD
OF FLIGHT BASED ON REACTIVE PRINCIPLES, 1880-1895⁺

V. N. Sokolsky (USSR)⁺⁺

The history of science and technology knows a number of cases when the ideas of a scientist remained unknown for a long time, becoming the property of humanity only when they were not new any more and had been translated into reality, as well as developed considerably and supplemented by following generations. This was the case with the notes of Leonardo da Vinci on helicopters, with the aircraft scheme of N.I. Kibal'chich, the early manuscripts of U.V. Kondratyuk on interplanetary communications, and a number of other materials. The notes of S.S. Nezhdanovsky on the possibility of using jet engines to solve the problem of human flight, notes that date back to the 1880s and 1890s,⁺⁺⁺ should be included among this same group.

Sergei Sergeevich Nezhdanovsky (1850-1940) was a Soviet scientist and inventor rather widely known for his investigations in the field of aircraft science and technology. But his investigations in the field of reactive flight have been hardly ever mentioned in the scientific-engineering or in the historic-scientific literature until the 1950s.¹

Nezhdanovsky began studying the possibility of using the jet principle in solving the problem of human flight in the 1880s. In July 1880, he first advanced the idea of the possibility of creating jet aircraft, declaring in his working papers: "A jet projectile can be made with the use of an explosive; the products of its burning are discharged from an ejector type device."² At the end of 1880 Nezhdanovsky prepared some calculations for jet aircraft using gases from gunpowder as the motive force (Figure 1). He postulated two variants of an engine (under a pressure of gun powder gases equal to

⁺Presented at the Third History Symposium of the International Academy of Astronautics, Mar del Plata, Argentina, October 1969.

⁺⁺Chief Historian for astronautics and aeronautics, National Committee for the History of Science and Technology, USSR Academy of Sciences, Moscow.

⁺⁺⁺The mentioned notes were found in the working papers of S.S. Nezhdanovsky kept at present in the N.E. Zhukovsky Scientific Memorial Museum in Moscow. Unless otherwise indicated, all further references refer to the materials of the scientific archives of the N.E. Zhukovsky Museum.

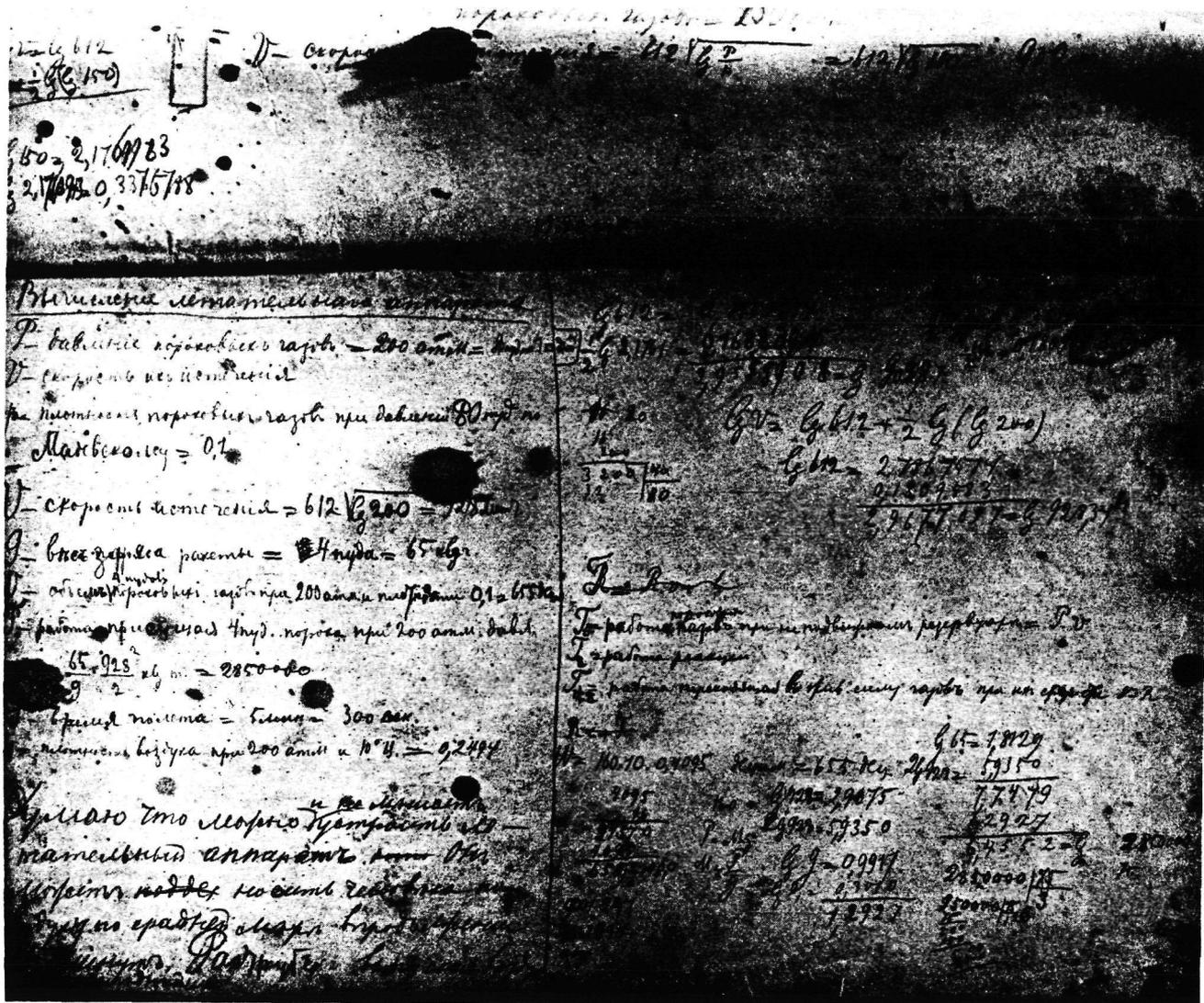


Fig. 1

150 and 200 atmospheres), and came to the following conclusion: "I suppose that we can and should build the aircraft. It would be able to carry a man in the air for five minutes at least. The funnel letting out the air with the most efficient speed will produce an economy of fuel and increase the time of flight."³

In 1882 Nezhdanovsky again returned to the possibility of producing jet propelled aircraft, discussing different variants of engines activated by the reaction of carbonic acid, water steam, and compressed air. He expressed the specific ideas of building a jet engine "after the principle of magazine or machine guns with two or three barrels with the same purpose of having the possibility of regulating the power and time

of the flight."⁴ That same year he advanced the idea of building two types of heavier than air jet aircraft with and without wings. He also pointed out the possibility of using one of the engines which he had proposed, that operated on the reaction of compressed air, for the horizontal flight of lighter than air aircraft ("an air balloon shaped like a cigar").

At the same time Nezhdanovsky attempted to calculate the work needed to carry out jet flying. One of the first tasks he set was determining the work necessary to counterbalance the gravitational force on the aircraft. As a result of his calculations, (Figures 2 and 3), Nezhdanovsky arrived at the conclusion that the work needed to support a body is directly proportional to the speed of the air flowing from the engine, and inversely proportional to the square root of the wing surface or to the square root of the section of the opening from which reaction gas exhausts.⁵

Nezhdanovsky advanced that theory in 1882. One should bear in mind that in this case Nezhdanovsky meant the air to be taken from the ambient atmosphere, as can be seen from his further notes. Therefore, he sought here to determine the work needed to balance the aircraft using the flow of ambient air compressed in a vessel and projected with a speed W in the direction of the gravitational force.

Nezhdanovsky differed from most inventors who tried to solve the problem of jet flight before him. He was little concerned with the design of the aircraft, devoting most of his attention to the problem of creating a jet engine and finding the best fuel for it. "I suppose," he wrote in some of his working papers, "it is sufficient to design and draw the engine in accordance with the above-mentioned conditions; the construction of the aircraft itself can be left to other technicians. Nevertheless, I put down the ideas referring to the construction of the aircraft."⁶

And really, in Nezhdanovsky's papers, we find many original ideas of essential significance and undoubted historical interest. Already in 1882-1884 he had proposed jet nozzles (Figure 4), through which the working fluid (steam or gas) passed, carrying with it a great mass of ambient air. According to Nezhdanovsky this would increase the reactive effect.⁷ Further, Nezhdanovsky dealt with calculations of the speed at which combustion products flow, thought of such problems as fuel feeding into the combustion chamber by means of pumps, and the use of one of the fuel components for cooling the walls of the combustion chamber.

Nezhdanovsky also devoted much thought in his investigations to the energy problems of jet engines. In his search for the most suitable source of energy, he discussed nitroglycerine, gun powder gases, compressed air, water steam, carbonic acid, and different explosive mixtures. Nezhdanovsky also proposed to use as an energy source an explosive mixture consisting of two liquids, fuel and oxidizer, which deserves special attention. In his manuscript of 1882-1884 (see Figure 5), he wrote: "On the basis of

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Движение смеси при величине внутреннего диаметра ≤ 100 мм и скорости вращающегося вала ≤ 5 оборотов в минуту, возможно.

Здесь передвигается воздушная масса сугарообразной формы в диаметре ≈ 7 мм.

Называется это *реакция* парциал в воздухе с помощью смеси. Диаметр расширяющейся сугаро воздуха, т.е. *сугаро* реакции *вытекающей* расширяющейся сугаро, *сугаро* для поддержания 50 клз (длина вентильная) столько лошадиных сил сколько метров в скорости расширяющейся воздуха, *тоже* и в сугаро когда поддерживается *масса* *внутри* *используют* *интервалы*. Скорость сугарообразной воздуха зависит от величины диаметра *из* которого *истекает* воздух (в сугаро реакционного диаметра), *и* от величины кривизны. Скорость поперечной смеси обратно пропорциональна V из *поверхности* кривизны или V из *поверхности* диаметра *из* которого *вытекает* реакция воздуха *и* *сугаро*.

Вот математическая выкладка *вытекающей* теоремы: Работа *пропорциональна* скорости воздуха *вытекающей* из диаметра J - работа диаметра (сугарообразной смеси) *пропорциональна* скорости J_1 - работа реакции; V_1 - скорость *под* *массой*.

Fig. 2

реакции;

T_2 — работа поперечная в срединной струе

v_2 — скорость абсолютная струи.

$$T = T_1 + T_2 ; T_1 = P v_1$$

P — сила реакции = весу поддерживаемой в воздухе массы

$$T_1 = P v_1 ; T_2 = \frac{m v_2^2}{2}$$

Работа ^{по} ~~поперечной~~ ^{по} ~~поперечной~~ струе вытекает вбок от центра при

соуде с тангенциальной скоростью $v_1 + v_2$ если поперечная работа двукратна T

$$T = \frac{m(v_1 + v_2)^2}{2} = P v_1 + \frac{m v_2^2}{2}$$

$$T = \frac{P v_2}{2} \text{ м.л.}$$

$$P = \frac{m}{2} (2v_2 + v_1) \text{ ---- (A)}$$

при $v_1 = 0$ $P = m v_2$

$$T = \frac{m v_2^2}{2} = \frac{P v_2}{2}$$

Работа поперечная для поддержания ^{поддержания} ~~поддержания~~ летящей массы прямо пропорциональна скорости вращения ~~летящей~~ ^{массы} ~~двукратна~~ ^{двукратна} в воздухе.

Формула (A) позволяет определить работу поперечную для ~~поддержания~~ ^{поддержания} летящей массы.

Теорема. Работа ^{поддержания} ~~поддержания~~ обратна ^{поддержания} ~~поддержания~~ пропорциональна корню квадратному из ~~площади~~ ^{площади} поверхности ~~открытой~~ ^{открытой} (приблизительно) ~~к~~ ^к скорости течения и ~~к~~ ^к скорости вращения ~~массы~~ ^{массы} своей реакцией.

$$T = \frac{m v_2^2}{2} = \frac{Q v_2^2}{2} = \frac{K v_2^3 \cdot \Omega \cdot 10333}{8283.29809} = (\text{каждому } v_2 = \frac{25}{7}) = \frac{K \cdot \Omega \cdot T^3 \cdot 2.10333}{P^3 \cdot 8283.29809}$$

$$T = \frac{\sqrt{8283.29809}}{8.10333 \cdot K} \sqrt{P^3} \sqrt{\frac{1}{2}}$$

научит ~~обучения~~ ^{обучения} ~~считая~~ ^{считая} ~~результатом~~ ^{результатом} ~~и~~ ^и ~~каждому~~ ^{каждому}

Fig. 3

It is easy to see that Nezhdanovsky has described the operating principle of a liquid jet engine. It should be mentioned, however, that his explanation is based on operating principles only. Such important advantages of liquid-propellant rocket engines as the independence of their operation from ambient conditions and much greater power capacity, as compared with other jet engines known at that time, are not mentioned in his notes.

During the 1880s Nezhdanovsky returned time and again to the problem of the most efficient design of jet aircraft, describing different variants in his working notes (Figures 6 and 7). He discussed mainly the designs of heavier than air aircraft, with the

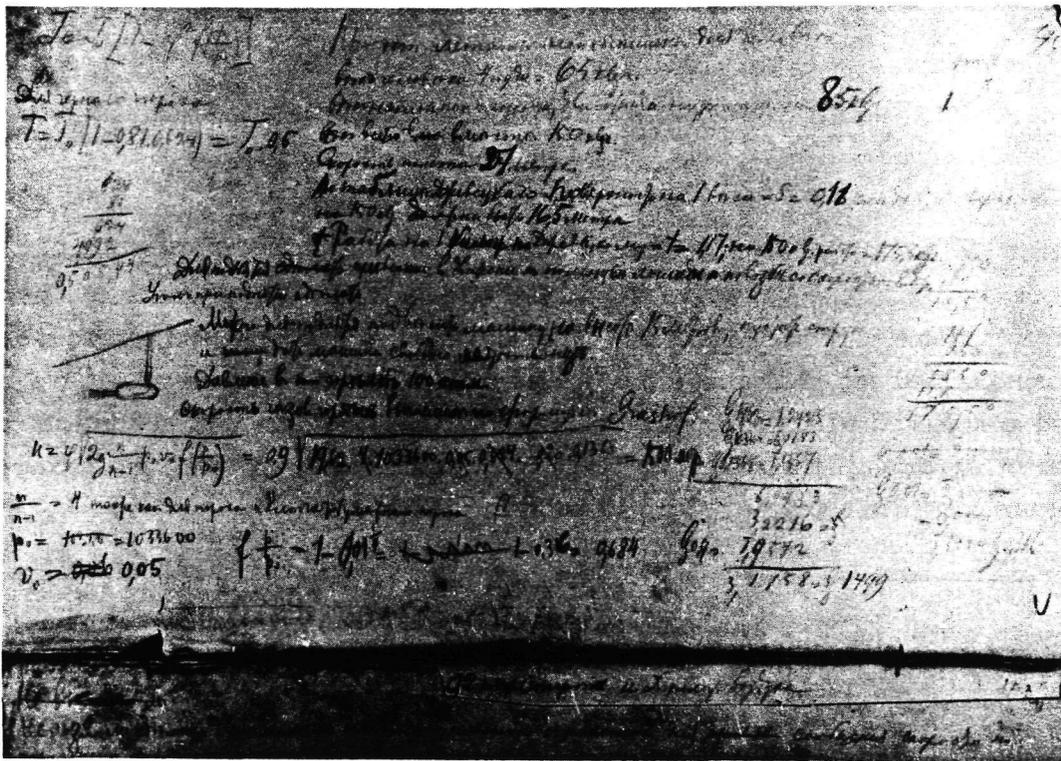


Fig. 6



Fig. 7

aerodynamic and rocket-dynamic principle of creating the lifting power. By the end of the eighties, probably under the influence of the advances obtained by that time in the field of aircraft theory and practice, Nezhdanovsky tended to concentrate more on the design of aircraft with wings (jet airplanes).

In his working papers for that period, we read: "Isn't it possible to make a flying inclined surface with a rocket to supply speed in a horizontal direction? Which is more profitable, a simple rocket or a rocket with an inclined surface? To sketch a rocket with an inclined surface, isn't it the most simple flying machine?"⁹ (Figure 8) "Hearing Zhukovsky's report on flying apparatus at the Paris Exhibition on the 15th of October 1889, and thinking of what I had read, written, and thought on the subject before, I suppose that success can be expected if we produce a machine with a mixture of nitro-

Segner wheel operating on combustion products."¹¹ According to Nezhdanovsky's idea, "jet burners" were to be mounted on the ends of the blades of the helicopter rotor. These "jet burners" were practically a prototype of the modern ram-jet engines (Figure 9). "The air should be forced with a nozzle," he wrote, "directed opposite to the reaction flow . . . the (hot) liquid should be fed in such a way that its steam should pump the air, in other words, the air should be pumped by the movement of the burner and from the suction of the steam by the fuel."¹²

Discussing the subject further, Nezhdanovsky mentioned a number of rather interesting propositions. They become especially interesting if we remember that they were expressed some decades before the creation of the first real air-jet engine. First of all, our attention is attracted to his idea of using the fuel components for cooling the walls of the combustion chamber (Figure 10). "The burners should not get overheated,"

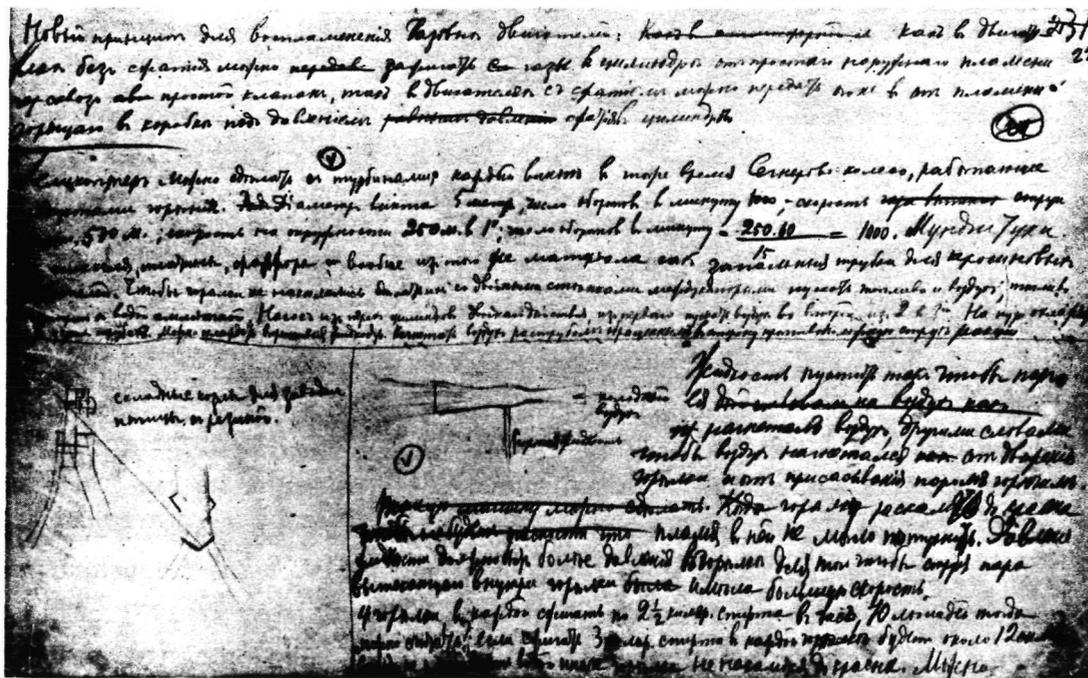


Fig. 9

combustion process in the chamber of a ram-jet engine are almost contemporary. He paid attention to such problems as the process of mixture formation, flow turbulence, and flame stabilization. He understood that in relation to the air flow it is advisable to place the nozzle in a manner to best ensure atomization, evaporation, and mixing of the fuel with air. Nezhdanovsky wrote: "It is necessary that in the burner a considerable part of the burning gas flame should return back, therefore strong benzine back flows are needed."¹⁵ And further: "All the benzine must be fed into the burner at the beginning without fear that it will immediately burn, not mixing properly with the air. On the contrary, all measures should be taken to make it start burning rapidly. To return part of the flame back, a solid obstacle made of platinum or some other fire-resistant material can be placed in the burner. (Figure 11). The benzine should be fed into the burner at its widest part to (1) decrease the resistance to the air flowing into it; (2) decrease the surface for cooling benzine, and (3) improve mixing."¹⁶

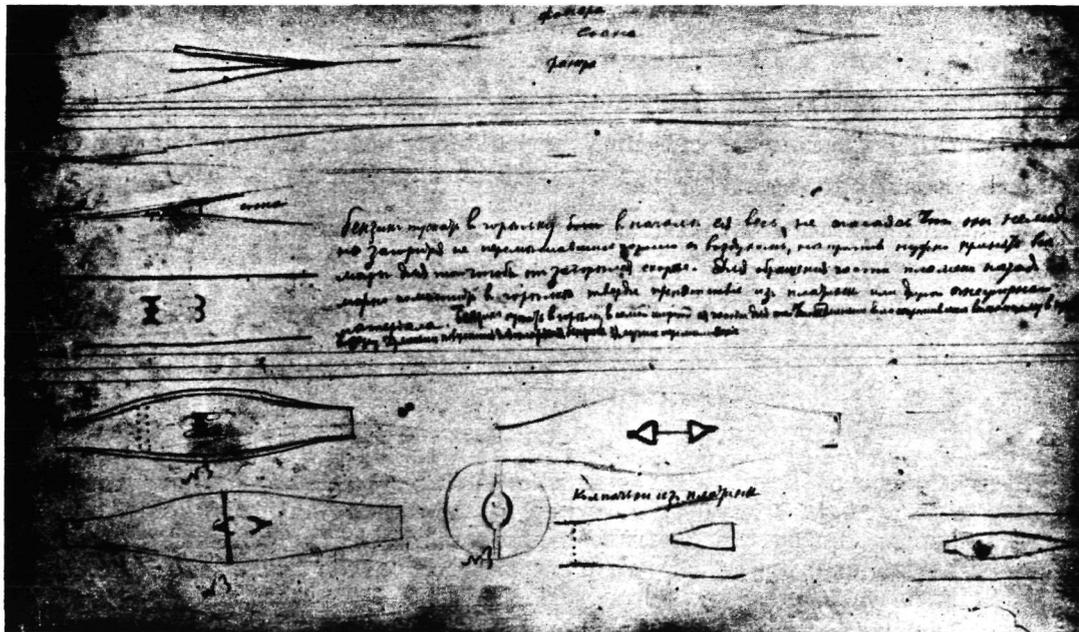


Fig. 11

It should be noted that Nezhdanovsky's papers are in the nature of working notes. In no way can they be considered a finished study or even as parts thereof. But along with his very original progressive ideas, we also find some disputable and even incorrect propositions. At the same time, many of Nezhdanovsky's ideas go far to prove that he understood the fundamentals of the theory of jet flight well enough. In particular, he often mentioned that the absolute flow speed must be as small as possible to the flight speed. His ideas on the organization of the combustion process in the chamber of the jet engine are also very interesting.

Why Nezhdanovsky did not publish the results of his investigations, and did not make them accessible to the scientific public, remains a most complicated question. Unpublished, they could not influence the development of rocket techniques. Historians of science and investigators of Nezhdsanovsky's works have expressed a number of suppositions on the subject. But they do not seem satisfactory and require further elaboration at another time.

In his manuscripts Nezhdanovsky discussed different designs of jet aircraft and their engines. He studied different kinds of jet fuels and determined the flow speed of combustion products. He proposed the use of liquid fuel in jet engines, one of the components of which were nitric oxides. He thought of such problems as fuel feeding into the combustion chamber by means of pumps, and the use of one of the components for cooling the walls of the combustion chamber. He paid attention to the problems of determining the energy quantity needed for jet flight. He proposed to use ram jet engines for jet helicopters of one- and two-rotor designs.

The scientific inheritance of S.S. Nezhdanovsky concerning the problems of jet flight contains a number of original propositions which are of fundamental importance. It is of considerable interest for the history of development of the ideas of reactive flight, and deserves a more detailed investigation. It should become the object of further studies of historians of science and technology.

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3. No. 1079, page 82.
4. No. 2990/1, page 131.

5. No. 2990/1, page 135.
6. No. 2990/2, page 1.
7. We mentioned that the proposition was first published by F. Geshvend in his paper, "General Foundation of the Design of an Airborne Steam-Driven Ship (Steamcraft)," Kiev, 1887.
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GUIDO VON PIRQUET
AUSTRIAN PIONEER OF ASTRONAUTICS⁺

Fritz Sykora (Austria)⁺⁺

INTRODUCTION

If you look under the heading "Rockets" in the Encyclopaedia Britannica, you will find in the History sub-section that a third of the early pioneers of astronautics in the 1920s and 1930s came from Austria-Hungary.¹ Fritz, the director of the former Rocket Museum in Stuttgart, once observed that it seemed then as if Austria-Hungary had a monopoly on rocketry. Heinz Garthmann, a German rocket expert, declared in a lecture that at that time the subject might well have been called Austro-nautics instead of Astronautics.

Let us remember first of all, Hermann Oberth, the founder of modern rocket engineering; he was born at Hermannstadt in Austria-Hungary. Others who ought to be mentioned are: Max Valier, Hans Hoeffft, Guido von Pirquet, Hermann Potocnik--who became well-known under the pseudonym Noordung--Friedrich Schmiedl, Eugene Sänger, and last but not least Theodore von Kármán. Franz Abdon Ulinsky should also be mentioned, for, although his projects were to some extent impractical, he was after all the first to suggest electronic propulsion, where the energy needed is derived from solar energy.

BIOGRAPHY OF GUIDO VON PIRQUET

Guido von Pirquet was born on March 30, 1889, at Hirschstetten castle, the son of Peter (Baron) Pirquet von Cesenatico. (Hirschstetten, at that time a little village near Vienna, is now part of the city proper.) His brother Clemens von Pirquet is particularly worthy of mention since as a physician and professor at the University of Vienna, he gained a world-wide reputation for his achievements in pediatrics and

⁺Presented at the Fourth History Symposium of the International Academy of Astronautics, Constance, German Federal Republic, October 1970.

⁺⁺Consultant Engineer, Waagner-Biro AG, Vienna, Austria.

research into allergies and tuberculosis. Guido von Pirquet lived at Hirschstetten castle until 1952, when he moved with his wife Frieda (née Pramer), whom he had married in 1922, to his apartment in Vienna. There he remained for the rest of his life. He died on April 17, 1966. Figure 1 shows Guido von Pirquet at home when he was about 80 years old.



Fig. 1

From 1898 to 1903 Guido von Pirquet studied mechanical engineering at the Technische Hochschule (Technical Institute) in Vienna and Graz. In later life he returned twice to his studies at the University. Between 1931 and 1932 he studied

physical chemistry and mathematics at the Technische Hochschule, and, between 1952-1956, pre-history and the history of science at the University of Vienna. This alone shows the breadth of his interests. In fact, his technical works and studies were not confined solely to rocketry and astronautics, they also included new studies in power engineering that dealt with solar and tidal power stations. He made several inventions and served in 1926 as chairman of the Technical Testing Committee of the "Österreichischer Erfinderverband" (Austrian Society of Inventors).²

PIRQUET'S EARLY WORKS ON ROCKETRY AND ASTRONAUTICS

As is generally known, Guido von Pirquet gained a world-wide reputation for his pioneering works on rocketry and astronautics. With specialized knowledge of thermodynamics, ballistics, and, as he said himself, a "great but unsatisfied love for astronomy," in 1926 he joined a committee which founded the "Wissenschaftliche Gesellschaft für Höhenforschung" (Scientific Society for Exploration of the Atmosphere). He soon became the secretary of this society, and started extensive studies that led Willy Ley to invite him to contribute to his book Die Möglichkeit der Weltraumfahrt (The Possibility of Space Flight)--a book on which most important experts of that time cooperated.³ Chapters were contributed by Willy Ley, Karl Debus, Hermann Oberth, Franz von Hoefft, Walter Hohmann, Guido von Pirquet and Friedrich Wilhelm Sander.

Pirquet's early reputation was established when his conclusions were mentioned in the chapters written by Oberth, Hoefft and Hohmann. Pirquet himself authored the chapter "Die ungangbaren Wege zur Realisierung der Weltraumschiffahrt" (Ways in which space travel will not be realized) which was, of course, a very thankless task. He provided general view of the state of astronautics at that time and, by means of a simple calculation, demonstrated the advantages of a hyperbolic route which--from the energy point of view--he found preferable to a parabolic one with a subsequent course correction. Then Pirquet described the various impracticable projects: the shot to the moon as described in the book by Jules Verne, the electromagnetic gun, and pneumatic acceleration in a tunnel as devised by Drouet and Ulinsky's project. The idea of electronic rocket propulsion derived from solar energy made its first appearance here. At the end of his chapter, Pirquet developed a research program subdivided into several stages: first, ascent to a height of some hundred or two hundred kilometers, then a ballistic flight over a range of 300 km or more above the Earth's surface; next, a flight to the Moon; and finally, manned interplanetary space travel. Pirquet emphasized that the reason for this detailed description of the impracticable projects thereby separated the scientifically justified efforts from the unjustified ones.

THE ROUTE TO VENUS

Though counted at this time among the most famous rocket pioneers, nevertheless, Pirquet's most important and ingenious work was certainly the series of articles, entitled "Fahrtrouten" (routes for space travel) which he published in the journal Die Rakete between May 1923 and April 1929. Hailed as the most noteworthy of the year in astronautics, these articles dealt with the possibility of realizing manned interplanetary space flight.⁴ Two results are of special importance: First the route to Venus calculated by Pirquet was in fact followed by the first Russian rocket to Venus, launched on February 2, 1969.

Figure 2 shows the diagram of the route to Venus printed in Pravda (February 26, 1961); Figure 3, which is the diagram by Pirquet himself, contains his proposal of 1928.

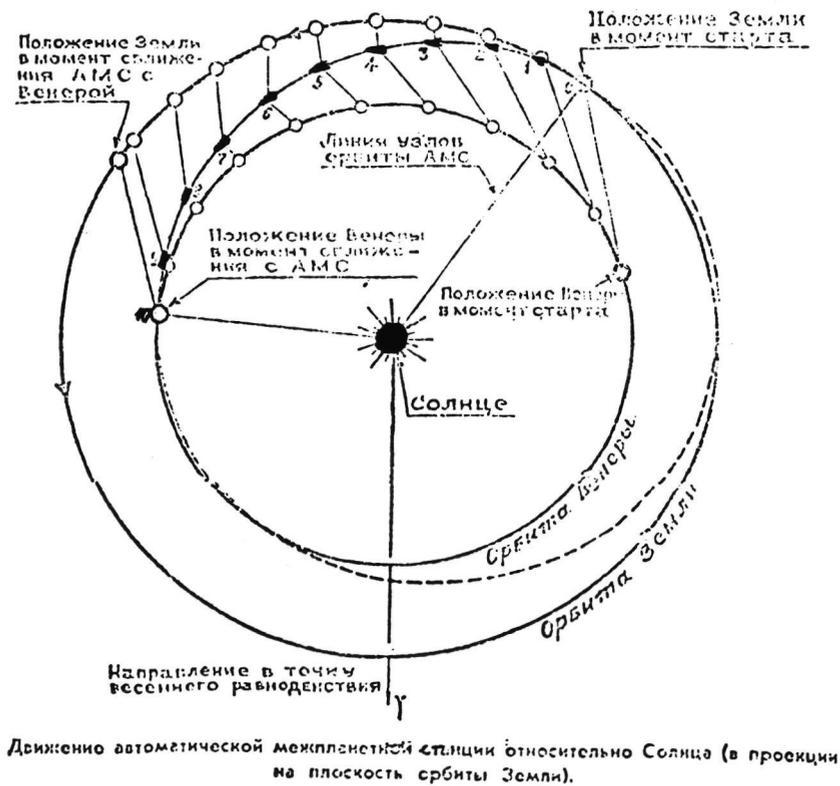


Fig. 2

One can see for himself the close correlation of these trajectories. The outer ellipse in Figure 3 represents the orbit of the Earth, the inner ellipse the orbit of Venus. Point D marks the position of the Earth at the time of the launch, while point O shows the position of Venus at the same moment. The alternate dashes and dots represent the

path of the rocket. The corresponding positions of the Earth, Venus and the rocket are marked at intervals of ten days. One can see that after a flight of 97 days the rocket meets Venus at point Z. Also shown are the velocity triangles, the triangle for the start from the orbit of the Earth, as well as the triangle for the arrival in the orbit of Venus. At the start of the journey the velocity of the Earth is 29.8 km/sec, the required velocity of the rocket 26.8 km/sec; the vector of the difference in velocity is 4.2 km/sec. Upon arriving at Venus the velocity of the rocket is 37.4 km/sec and the velocity of Venus 35.1 km/sec. The vector of the difference in velocity--the gravitational field of Venus aside--is 3.6 km/sec. To realize the importance of this graph one must bear in mind the state of rocketry and astronautics at that time.

Considering interplanetary routes, first of all Walter Hohmann's book Die Erreichbarkeit der Himmelskorper (The Possibility of Reaching the Stars), should be mentioned.⁵ In this book Hohmann discussed three kinds of interplanetary routes contained in Figure 4, drawn by Pirquet himself. The outer and inner circles represent the orbits of two planets with the Sun as center. Hohmann discussed the

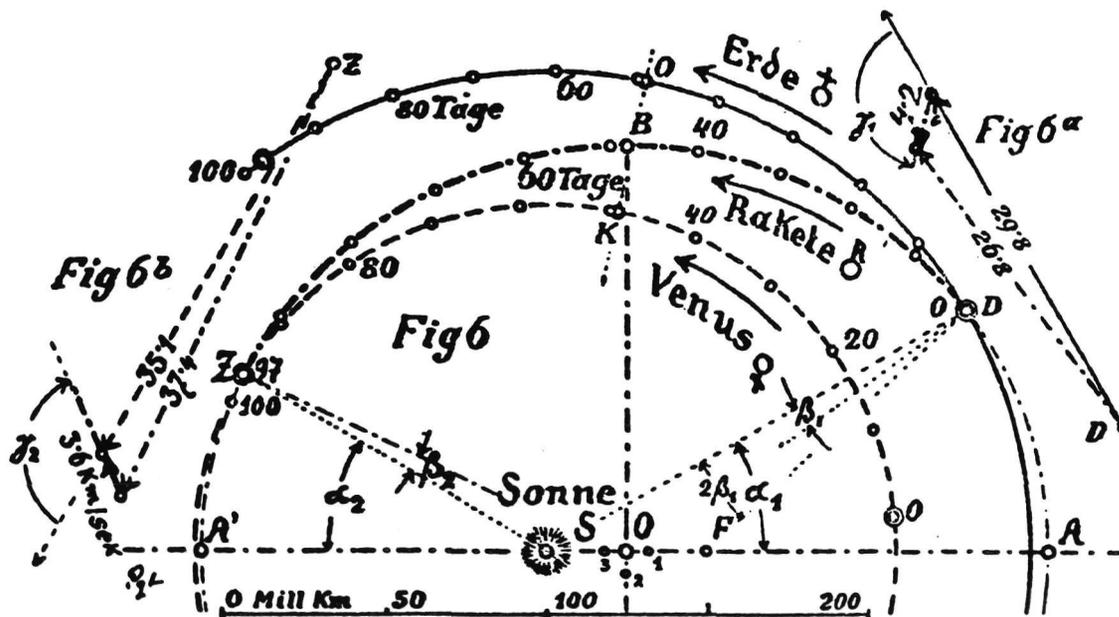


Fig. 3

TABLE I

COMPARISON OF HOHMANN'S ROUTES TO
THE PROPOSAL OF PIRQUET

Route (See Figure 4)		A	B	C	O
Velocity Required for Injection Into the Rocket-Trajectory*	km/sec	2.4	5.6	3.0	4.2
Velocity Required For Injection Into the Route Of The Planet*	km/sec	2.6	3.5	5.65	3.6
Sum	km/sec	5.0	9.1	8.65	7.8
Duration	days	146	102	109	97

* without accounting for surmounting the gravitational fields of the Earth and the planet

Pirquet on the other hand, proposed route O, where the additional velocity required for switching from the orbit of the Earth into the trajectory to Venus is 4.2 km/sec, and for switching from that trajectory into the orbit of Venus 3.6 km/sec; the total is therefore 7.8 km/sec while the trip lasts 97 days (Figure 3). We find this route superior to Hohmann's routes B and C mentioned above, for in spite of a shorter duration it also demands less in additional velocities--a total of 7.8 km/sec additional velocity as against 8.65 km/sec and 9.1 km/sec, respectively, for Hohmann's route B and C. Compared with Hohmann's route A, Pirquet's route O admittedly needs additional velocity (7.8 km/sec as against 5 km/sec), but on the other hand it shortens the flight duration considerably: from 146 to 97 days. Although the energy demand needed to overcome the gravitational fields of the planets is not included in the above mentioned velocities, it is, though, essentially equal for all routes. However, if one accounts for the gravitational fields of the Earth and the planets, the ratio of energy demanded for routes O and A is much lower, and one must consider whether perhaps other

factors, such as oxygen and food, or other requirements, make the shorter duration preferable. The difference in time needed for a journey to the inner planets involves some months, to the outer planets some years. Possibly a compromise between routes A and O will prove preferable.

THE ASTRONAUTICAL PARADOX (SIGNIFICANCE OF THE SPACE STATION)

The second and most important point brought out by Pirquet's series of articles involved the so-called astronomical paradox, where a trip from Earth to a space station requires more energy than a trip from the space station to the planets, even though the distance of the space station from the Earth's surface is only a few hundred or thousand kilometers, while the planets are millions of kilometers away. Here Pirquet thoroughly analyzed the technical details of manned interplanetary flight, a part of rocket technology that is yet to be realized. In his analysis he compared three alternatives:

liftoff from Earth,
liftoff from a space station,
liftoff from the Moon.

As far as a liftoff from the Moon is concerned, Pirquet made it quite clear that he included it for comparison's sake only, and that mode should most decidedly be forborne since for the time of liftoff for an interplanetary trip the relative positions of the Earth and the planet in question are significant, while a liftoff from the Moon only made sense at a moment when the Moon's velocity happened to add itself to that of the Earth. The combination of a favorable position of the Moon with respect to the Earth and of a favorable position between the Earth and the target planet would be a rare coincidence indeed. In computing his interplanetary routes, Pirquet used a graphic method of maximum clarity. In a diagram with a logarithmic-scale ordinate, the relationship between velocity and mass of a rocket according to the equation

$$m_0/m = c^{v/c}$$

appears to be represented by a straight line (AB in Figure 5). If, for instance, the entire rocket has an initial mass m_0 of 130 metric tons (point A), an exhaust velocity c of 4 km/sec will give it, after consumption of 90 metric tons of fuel, a mass of 40 metric tons and a proper velocity v of 4.71 km/sec (point B). If the empty mass of the first stage, assumed to be 10 metric tons, is shed at this point, 30 metric tons remain for the other stages (point C). If the ratio of payload-to-empty mass-to-fuel is the same for the second stage as for the first--an assumption made in approximation, but impossible to realize exactly--the second stage will attain twice the

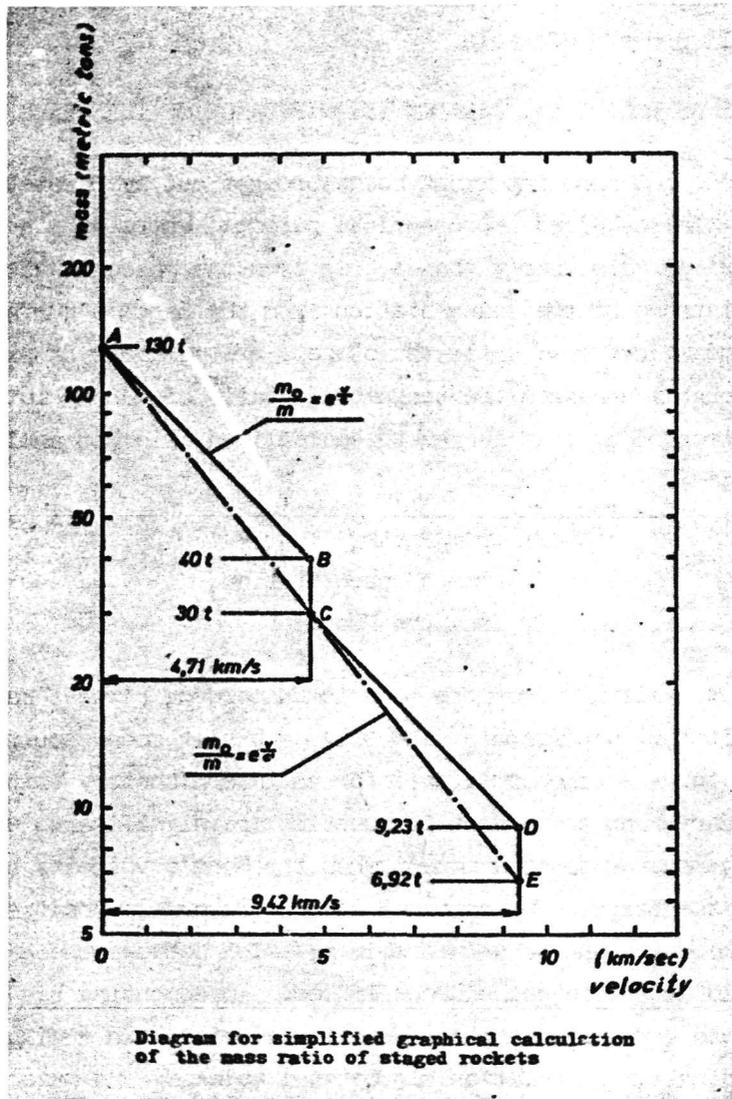


Fig. 5

previous velocity, i.e. 9.42 km/sec. At "brennschluss" its mass will be $30 \times \frac{40}{130} = 9.23$ metric tons, reduced after shedding the empty second stage to $30 \times \frac{30}{130} = 6.92$ metric tons at point E. It then becomes possible to connect points A, C and E by a straight line (dash-dotted in Figure 5) which, for purposes of computation we may apply the same formula for the single-stage rocket (with the difference that a fictitious exhaust velocity c' whose value is 3.21 km/sec in our case, must be used for computation). Thus, it is possible to use the single-stage rocket formula, in

the form

$$m_0/m = e^{v/c'}$$

at least as an approximation for the multi-stage-rocket. This method appears particularly well suited for rough initial calculations. It requires certain assumptions concerning the ratio of payload to total rocket mass and the empty mass of the individual stages, depending on the final velocity to be reached and the number of stages.

Figure 6 is an original draft by Pirquet, with Diagram III representing

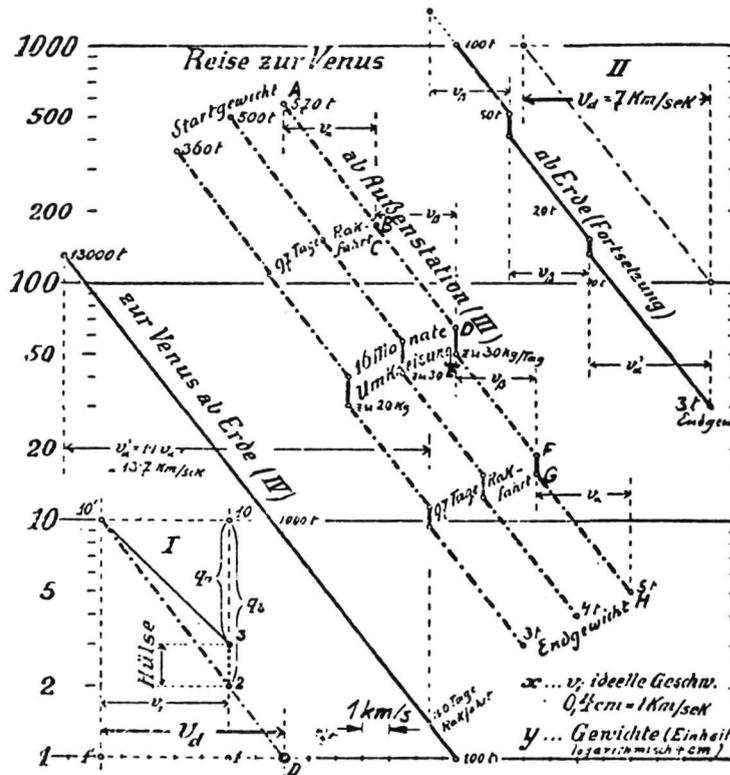


Fig. 6

a trip to Venus from a space station and back. Pirquet chose 10% of the total weight of the rocket as the empty weight of the first stage, and 20% of the total weight of the rocket as payload, or weight of all succeeding stages. He made proportional assumptions for the second and succeeding stages. The 10% assumed for the empty weight of the first stage has already been undercut in our day, with less than 5% used in the Apollo project; but at the time such a value would have been considered presumptuous. Pirquet contrasted three variants with final masses of 3, 4 and 5 metric tons respectively, corresponding to initial masses of 360, 500 and 570 metric tons.

Initial and final masses fail to be in proportion because Pirquet made different assumptions for oxygen and food for the various alternatives, viz. a reduction of mass of 20 kg per day in the 3-ton project and of 30 kg per day in the other projects. The dash-dotted lines represent the relationship between rocket mass and velocity, with staging already taken into account as discussed in the description of Figure 5. Changes of mass at constant velocity are therefore not caused by staging but by the reduction of mass due to the crew's oxygen and food consumption. The effective exhaust velocity c was assumed to be 4 km/sec; a value not yet attained for large rockets. Pirquet adds a 10% safety margin for course corrections, etc. to his rocket speeds, and took the gravitational fields of the Earth and Venus into account in the above example. Choosing an orbit for his space station, Pirquet worked according to the philosophy of maximum universal usefulness for interplanetary trips, coming to the conclusion that the radius of the space station's orbit should be three times the radius of the Earth. In Figure 6 the change of rocket velocity in km/sec is plotted on the abscissa and the mass in metric tons on the ordinate.

In order to attain a Venus-bound route from this space station orbit, Earth's gravity and the proper speed of the space station require an additional velocity of $v = 3.14$ km/sec, with 10% safety margin added for course corrections. This calls for a reduction of the initial mass from 570 metric tons to approximately 182 metric tons (point B). Ninety-seven days of free flight follow, with an assumed mass reduction of approximately 3 metric tons due to consumption by the crew (point C). This reduction in mass is barely significant for a rocket mass of 179 metric tons, and can hardly be represented in the diagram. Injection into Venus orbit requires a change of velocity of $v = 2.76$ km/sec with due consideration of the gravitational field and the orbital velocity. Again, considering a 10% safety margin for course corrections, the rocket mass is reduced to approximately 66 metric tons (point D).

This is followed by orbiting Venus for 16 months, with a reduction of mass of approximately 15 metric tons due to the crews biological needs (point E). The rocket mass is now approximately 51 metric tons. Injection into the return-to-Earth route follows at $v = 2.76$ km/sec, with the rocket mass dropping to approximately 18.7 metric tons (point F). During the free return flight to Earth, again claiming 97 days, the rocket mass diminishes by approximately 3 metric tons to approximately 15.7 metric tons (point G). It can be clearly seen that the astronauts' food consumption plays a far more important role now than on the outward trip, where the rocket was still considerably heavier, with food consumption the same. Finally, insertion into the space station's orbit requires another change of velocity $v = 14$ km/sec, and leads to a reduction of mass down to 5 metric tons. This simple method is seen to afford a surprisingly rapid overview of the conditions of an interplanetary trip. It seems, however, that the final mass of 5 metric tons appears somewhat too low for an inter-

planetary trip, so that an increase in this respect seems indicated.

Table 2 tabulates the results of Pirquet's calculations for interplanetary trips to Venus and Mars. His assumptions are again the same as in the previous example, with the exception of an increase in the fictitious exhaust velocity mentioned above by 1.4%. Explaining the reasons for this assumption would exceed the scope of this paper. Pirquet contrasted the conditions for liftoff from Earth, from a space station, and from the Moon. On the return to the Earth, he assumed a reduction of velocity by rocket thrust before atmospheric reentry of 4 or 4.5 km/sec for the Venus and Mars trips respectively. A trip to Venus required 3,200 metric tons of Earth-lift-off weight for every metric ton of final weight, while the figure is only 90 metric tons for liftoff from a space station. For Mars the figures are 7,400 metric tons from Earth, but only 235 tons from the space station. With progress in light construction and by braking the total reentry velocity in the atmosphere, the mass ratio may be made much more favorable than Pirquet computed at the time. Even so, the exhaust speed of 4 km/sec assumed by him has not been attained yet, so that the mass ratio becomes less favorable again.

Based on the above numerical results, Pirquet concluded that a manned interplanetary liftoff from Earth is impossible, since the spacecraft would become so heavy that the total cross section of thrust jets would be far too large to be accommodated structurally in even the largest imaginable base area of a spacecraft. But at the same time Pirquet, by computing the situation for liftoff from a space station, proved the feasibility of interplanetary flight. These two conclusions are the core of his work and show the importance of a space station as a necessity for manned interplanetary flight. We should mention in this context that a space station orbiting the Moon has already been realized in the lunar flights of Apollo. Requirements for a lunar landing have been essentially reduced by this method.

Pirquet in his time summarized his results as follows: "Thus the whole problem is reduced to theoretical feasibility, to the question whether construction of the space station is structurally feasible" Therefore: "In order to realize space flight, it will suffice to realize the space station." Even today the magnitude of a rocket needed for liftoff from Earth to neighboring planets with manned spacecraft presents a problem, whereas rockets required for building a space station and for a flight from the latter to the planets already exist. Pirquet pioneered the space station, and he kept making interesting proposals in this connection, proposals that were often so progressive that even experts opposed him. He intended to publish a paper on an unmanned orbiting observatory for the International Astronautical Congress in Rome, but was dissuaded from doing so; it was this very project that he tackled before his death.

TABLE II
 VELOCITIES REQUIRED FOR A MANNED SPACE-FLIGHT TO VENUS AND MARS
 CALCULATED BY PIRQUET 1928⁴

Liftoff	TRIP TO VENUS			TRIP TO MARS		
	From Earth	From The Moon ²⁾	From a Space Station	From Earth	From The Moon ³⁾	From a Space Station
Velocity Required For Launching	12.2	4.4	3.14	12.8	6.8	3.73
Injection Into the Planet's Orbit	2.76	2.76	2.76	3	3	3
Velocity Required For Injection Into The Earthward Route	2.76	2.76	2.76	3	3	3
Velocity Required For Landing	4.0	4.4	3.14	4.5	6.8	3.73
Sum + 10% Safety Margin	23.9	15.7	13.0	25.6	21.6	14.8
Total Mass Ratio ¹⁾	3200	210	90	7400	3000	235

- 1) Accounting also for food consumption of the crew
- 2) When the Moon's velocity happens to add itself to that of the Earth
- 3) When the Moon's velocity is in opposition to the velocity of the Earth

INTERSTELLAR SPACE-FLIGHT

Pirquet's publication in the Journal of the British Interplanetary Society in 1950⁶ provides an interesting parallel to his paper of 1928. In it he stressed the dangers threatening a rocket that might attempt to reach even the nearest fixed star. Such an attempt would obviously require very high velocities in order to conclude the trips during a human lifetime. If the distribution of cosmic dust is assumed to correspond to Clarke's model as published in the same journal,⁷ such a fast spacecraft would have to cross clouds of cosmic dust. Cosmic dust may be compared to raindrops whipping into a motorcyclist's face; the faster he drives the harder he feels them. Applying this to rocket flight, Pirquet concluded that these dust clouds represent no risk to inter-

planetary rockets with their velocities of several dozen kilometers per second, but for interstellar rockets to the stars with required velocities of a magnitude of 100,000 km/sec they constituted an insurmountable obstacle; even if they failed to penetrate the rocket wall, the small particles would produce enough frictional heat to make the spacecraft red hot. Pirquet demonstrated the possibilities open to man in his 1928 paper; similarly, he pointed out just as clearly in 1950 that there are limits that nature has set to man's efforts.

CONCLUSION

Guido von Pirquet was recognized as a pioneer of rocketry in his own day, and received honors and distinctions in his old age. The key importance of his work is still recognized, with Wernher von Braun, among others, giving him repeated credit.⁸ We have attempted to comment briefly on Pirquet's major works and to contrast them with the present state of the art. Some of his projects have already been partially realized, e.g. the Venus route, while work is still in progress on other parts. The validity of Pirquet's statements remaining unchallenged. Of particular topical interest is the space station, a valuable construction Pirquet demonstrated, and one that will likely be realized in the very near future.

APPENDIX A

HONORS AND DECORATIONS AWARDED GUIDO VON PIRQUET

- 1948 Honorary member of the "Deutsche Gesellschaft für Raketentechnik und Raumfahrtforschung" (German Society of Rocketry and Research into Space Flight).
- 1949 Honorary member of the British Interplanetary Society.
- 1951 Honorary President of the "Österreichisches Ehrenkreuz für Wissenschaft und Kunst Erster Klasse (Austrian Cross of Honor of Science and Arts, 1st Class).
- 1956 Awarded the 6th Hermann Oberth Medal for exceptional merits in space flight.
- 1960 Awarded the Österreichisches Ehrenkreuz für Wissenschaft und Kunst Erster Klasse (Austrian Cross of Honor of Science and Arts, 1st Class).
- 1965 Awarded the Prechtl Medal of the Institute of Technology in Vienna.
- 1965 Honorary member of the International Academy of Astronautics.

APPENDIX B

PUBLICATIONS OF GUIDO VON PIRQUET

"Die ungangbaren Wege zur Realisierung der Weltraumschiffahrt" ("The Impossible Ways Towards Realization of Space Flight") in Die Möglichkeit der Weltraumfahrt (The Possibility of Space Flight), edited by W. Ley, published by Hachmeister & Thal, Leipzig, 1928.

"Interplanetare Fahrtrouten" (Interplanetary Travel Routes") a series of articles in the journal Die Rakete (The Rocket), May 1928 through April 1929.

"Thermodynamik der Rakete" ("Thermodynamics of the Rocket"), Der Maschinenkonstrukteur (The Technical Designer), No. 8, 1929.

"Beweis der Übereinstimmung der vorliegenden Raketentheorie mit dem Energiegesetz" ("Demonstration of the Compatibility of the Current Theory of Rockets With the Law of Energy"), Der Maschinenkonstrukteur (The Mechanical Designer), No. 14, 1929.

Report on Pirquet's paper on the occasion of the reforming of the "Österreichische Gesellschaft für Raketentechnik" (Austrian Society of Rocketry) Der Flug (The Flight), No. 4, 1931.

"Über den Wirkungsgrad des Raketenantriebes" ("On the Efficiency of Rocket Propulsion"), Raketenflug (Rocket Flight), No. 6/7, 1932.

Autobiography and report on his own works on rocketry in Männer der Rakete (Rocket-Men), edited by Werner Brügel, published by Hachmeister & Thal, Leipzig, 1933.

Five papers in Das neue Fahrzeug (The New Vehicle), journal of the "Verein für fortschrittliche Verkehrstechnik," (Society for Progressive Technics in Transport), Berlin, 1934-1936.

Paper in Weltraum (Space), journal of the "Gesellschaft für Weltraumforschung" (Society for Space Research), Cologne, No. 3/4, 1939.

"Die Aussenstation, das Sprungbrett ins Weltall" (The Orbital Station, Spring-Board into Space, in Weltraum--Utopie? (Space Travel--Utopia?), published by Natur und Technik, Vienna, 1949.

"Meteors and Space-Travel" (Journal of the British Interplanetary Society), No. 4, 1950.

"Die Gründung der Aussenstation" (The Foundation of the Orbital Station), read by Prof. Dr. Hecht at the Second International Congress of Astronautics in London, 1951, published in Zeitschrift für Natur und Technik (Journal of Nature and Engineering), Vienna, No. 2, 1952.

Pirquet also published many popular papers in various journals and newspapers.

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3. W. Ley, ed., Die Möglichkeit der Weltraumfahrt (The Possibility of Space Flight), Verlag Hachmeister & Thal, Leipzig, 1928.
4. G. von Pirquet, "Fahrtrouten," Die Rakete, 2 ("Interplanetary Travel Routes," The Rocket, Vol. 2), (1928), pp. 67-74, 93-94, 107-109, 117-121, 134-140, 155-158, 169-171, 183-190.
5. W. Hohmann, Die Erreichbarkeit der Himmelskörper (The Possibility of Reaching the Stars), Verlag R. Oldenburg, München, 1925.
6. G. von Pirquet, "Meteors and Space-Travel," Journal of the British Interplanetary Society, No. 4, 1949.
7. A.C. Clarke, "Meteors as a Danger to Space-Flight," Journal of the British Interplanetary Society, No. 4, 1949.
8. W. von Braun, Letter to Prof. E. Dolezal, Vienna, Dec. 1963.

EVOLUTION OF SPACECRAFT ATTITUDE CONTROL
CONCEPTS BEFORE 1952⁺Robert E. Roberson (USA)⁺⁺

Of the many kinds of astronomical operations that can be carried out by a spacecraft, a number involve the orientation⁺⁺⁺ or rotation of the craft in an important way. A parallel exists with early aircraft whose missions were single-purpose and quite specific: if the operation required pointing (for example, a gun or camera), it was normal to fix the object to be pointed with respect to the aircraft body and then to point the whole craft. As the vehicles developed into multi-purpose devices functioning further from their operating limits, conflicts in the pointing demands of its various subsystems could be resolved by gimbaling some of them and pointing them independently. But even today there exist some operational requirements for pointing the whole aircraft (e.g. for rocket launching) in addition to the general pointing requirements imposed by the need to control the craft's path by controlling its orientation.

So it is with spacecraft. A general requirement for orientation control exists during powered flight because the path is determined by its orientation. Beyond this, while the spacecraft is in free flight in space, its function often is facilitated or made possible by pointing the craft in a certain direction or imparting to it a certain state of rotation. Again, whether this is done depends partly on whether the spacecraft operation is single-purpose or multi-purpose. If communication between a satellite and the Earth is an incidental function in a system whose primary purpose is something else, the vehicle pointing requirements might be preempted by the "something else," so communication is achieved by omnidirectional or gimballed antennas. But

⁺Presented at the Fifth History Symposium of the International Academy of Astronautics, Brussels, Belgium, September 1971.

⁺⁺Professor of Engineering Science, University of California at San Diego.

⁺⁺⁺A word of warning: in much of the astronomical literature the term "orientation" means "position in space." This is a perversion of its usual meaning in the science of mechanics, where it refers to the angular relationship between two sets of base vectors. The latter is the meaning here.

if it is a communications satellite using a large directional antenna, then the entire craft might be oriented so the antenna axis points toward Earth. Or if it is a communications satellite in which other communication techniques can be used, the craft might be put into a spinning rotation to stabilize one of its axes in space. The need for control of orientation is equally evident for satellites whose major operational purposes require observing the Earth. Orientation of the craft or sizeable portions of it can be involved in solar power collection, in docking, in astronomical observation, in preparation for thrusting maneuvers. One can say in general that the proper functioning of any astronomical system involves the transfer of information, or energy, or mass, and that each of these transfers has some implications to the state of rotation of the spacecraft.

The control of the rotational state--orientation and/or angular velocity--of a spacecraft during its free-flight regime is here called "spacecraft attitude control." A related term, "stabilization," also is used in the literature, but not always with the same meaning from author to author. This paper concerns spacecraft attitude control prior to 1952, which means, of course, that it concerns only control concepts. It explicitly excludes the similar control phase during powered flight except for very brief, quasi-impulsive, thrust periods in space. The rationale for exclusion is simply that in free space flight the rotational state can be separated cleanly from the translational state of the craft, whereas in powered flight the two are strongly coupled.

The pioneers of space flight were quite naturally preoccupied by problems of propulsion. Without adequate propulsion their vehicles would not leave the ground and questions of auxiliary functions like attitude control, however important they ultimately might be, were academic. But even understanding this, it is surprising that the attitude control problem was so slow to be recognized as having a critical role in the operational utility of the craft. From the earliest astronomical systems until 1952 attitude control was scarcely mentioned, and then mainly in an off-hand way. Only in 1952 did the first systematic studies begin of the problem as a separate and important subsystem.

The period to 1952 is chosen for this historical survey for two reasons.⁺ One, of course, is the "20-year rule" normally adhered to in historical papers presented at the annual Congress of the International Astronautical Federation. But another is the fact that the 1952 date is the most natural one to mark parturition of spacecraft attitude control, as we shall see. To be sure, exploitation did not occur for another

⁺To the author the 1952 date has a further personal meaning. It marks the beginning of his own involvement in the subject.

half-decade, but in the interim there was no doubt that the subject was a sturdy infant, whereas the period before 1952 was definitely a gestation period for attitude control concepts.

Let us now see how these concepts developed.

ESSENTIALS OF ATTITUDE CONTROL SYSTEMS

First, we must recognize the several major ingredients of an attitude control system, and introduce a bit of terminology we need for subsequent discussion. The rotational behavior of a spacecraft without attitude control is described schematically in Figure 1. Torques act as inputs to the vehicle rotational dynamics and kinematics,

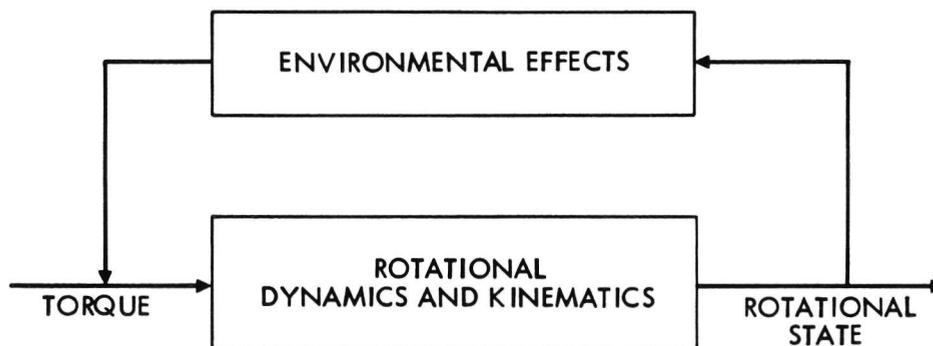


Fig. 1

the result being a vehicle orientation and angular velocity--i.e. a "rotational state." In general, natural effects of the environment, such as the gravitational and magnetic fields in which the spacecraft is immersed, produce torques on the body that depend on its rotational state, thereby producing a feedback loop as shown in the figure.

The simplest kind of attitude control is the stabilization of a single axis of the body by making its motion less sensitive to the external torques. It is

accomplished by spinning the vehicle about the axis to be stabilized. This does not change the form of the block diagram of Figure 1, but merely represents a change in the input-output relationships represented by the dynamics block. In the sequel, this method is called "spin stabilization."

A second form of attitude control based on the same schematic is called "passive stabilization." It is a method that takes advantage of the fact that the torques produced by the environmental effects sometimes act on the vehicle in a way that tends to keep its orientation approximately as desired for operational purposes. The environmental torques therefore can be turned into practical control torques merely by augmenting them sufficiently, normally by choosing an appropriate shape or other physical characteristics of the craft.

The most general and most flexible form of attitude control, called "active closed-loop control," involves the addition of a feedback control loop to the basic system, as shown in Figure 2. Three functions are performed in this instance. First,

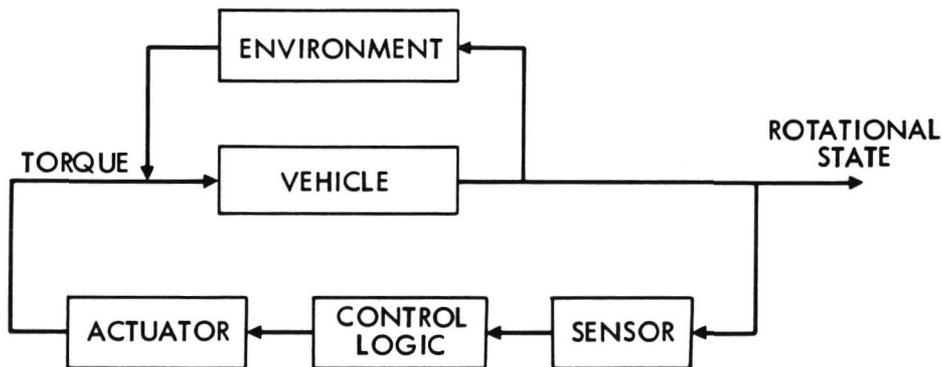


Fig. 2

some aspect of the rotational state is measured by a physical device called a sensor; for example, deviation of one vehicle axis from the line connecting the vehicle with the center of the Earth is measured by a horizon scanner. Second, a computer or passive network processing of the sensor output signal is used to determine the proper input to the third and final functional block. This intermediate step is labeled simply

control logic. Third, one or more torque-producing devices of some kind, called actu-ators, are brought into play to enforce the desired state.

Each of the three basic types of attitude control has its own story of development, as does each of the three functional ingredients of the active closed-loop system.

SPIN STABILIZATION

The knowledge that a spinning object tends to keep its spin axis fixed in direction must date from antiquity, for spinning tops were used as toys long before the Christian era. The Greeks distinguished at least two varieties in Plato's day, the type wrapped with string and then cast to spin on its point (*βέμβλιξ*), and a humming top spun by a string and handle (*στρόβιλος*); the *στρόμβος* mentioned by Homer is thought to be the latter. The stability of the top itself, however, does not seem to have resulted in any technological application until about 1742, when Serson in England invented an artificial horizon utilizing a top. (I described the history of this device in some detail in Reference 1. Parenthetically, I might say that the first gyroscope, v. Bohnenberger's machine, was not invented until about 1817.)

The ordinary top, however, is an essentially terrestrial device, for it needs some place to rest one of its points. As the early prototype of spin-stabilization in space, I would cite "yo-yo"-like devices: either the yo-yo as known today, with attached string, or the free-spinning cylinder with conical ends set spinning by contact with a string connecting two sticks manipulated by the user, then thrown into the air and caught again on the string. Mohr in 1868² commented on the device,⁺ saying that it was hardly new, even in Europe, having been brought from India to London in 1791. He went on to tell an anecdote about its popularity as a toy during the French revolution, when its casual use by a person on the street was supposed to ward off any suspicion that the person might harbor sinister or dangerous political thoughts.

In free-flight stability of a spinning body found its technological outlet in the early sixteenth century, with the invention of rifled gun barrels for imparting a stabilizing spin to the projectiles. Originally the purpose of grooves in the barrel may have been simply to delay the clogging of the barrel with fouling, but the fact that the grooves were soon made helical showed the intent to spin the projectile. The use of rifled arms grew slowly until the nineteenth century, when they finally displaced

⁺It was not clear which form he was really referring to, since his comments were in response to a note of Kommerell³ in which its description is rather obscure. Mohr, incidentally, was not Otto Christian Mohr, a famous mechanician who in 1868 was a professor at the Technische Hochschule, Stuttgart, but Carl Friedrich Mohr, an Extraordinary Professor of Pharmacy at the University of Bonn.

smooth-bores for the firing of single projectiles. Ballisticians like Robins and theoreticians like Euler argued the merits of rifled cannon in the mid-eighteenth century,⁺ but the general adoption of these weapons awaited the second half of the nineteenth century when Krupp and other steelmakers learned to manufacture sufficiently large steel billets for cannon.

Therefore, by the end of the nineteenth century when Tsiolkovsky began the first systematic studies of astronautics, and into the early twentieth century when the subject was taken up in Germany, there was ample precedent for the stabilization of traveling bodies by spinning. It was a small step from a projectile to a space vehicle.

Nevertheless, spin was not immediately seized upon as a spacecraft stabilization method. My own belief is that it was considered and discarded without mention, because almost every spacecraft concept of the period predicted a manned vehicle. At the customary spin rates of projectiles (60 or more revolutions per second), human occupants would be given a giddy ride. In short, spin stabilization and human occupancy were incompatible for thrusting periods and passage through the atmosphere where the requisite degree of stability could only be had by high spin rates.

Further thought apparently was given to this method for use in space, where it did not need to stabilize the vehicle against severe disturbances such as those imposed by the booster rocket, and in consequence its spin rate could be much less. But then it appears not as a method whose primary intent was stabilization, but as one designed mainly to provide an artificial gravity to promote the comfort and physical well-being of the astronauts. Hermann Noordung,⁴ for example, proposed a wheel-like arrangement with cable-linked parts, about 30m in diameter and rotating at 1 rps. Robert Esnault-Peterie⁵ also alluded to spin for providing a suitable physical environment, (his "conditions d'habitabilité"), and Herman Oberth included vehicular rotation in the concepts he formulated.⁶ In connection with his space mirror, Oberth suggested the further possibility of structural stiffening by rotation, though he remained uncertain whether he would actually let the mirror spin. I do not know which of the pioneers was actually the first to propose the large, solid spinning-wheel satellite that later became quite prevalent in popular astronautical literature.⁺⁺

However, I repeat that the purpose of spin in these cases was not stabilization.

⁺Specifically, whether rotation was responsible for observed, undesired lateral drift.

⁺⁺Although it was copyrighted three years after the period we are considering, we can cite Reference 7 as typical.

Noordung, in fact, indirectly and probably unintentionally, nicely illustrates one of the disadvantages of such systems when he described a steerable solar parabolic mirror for optical communication with Earth.⁺ The problem is that any line of sight to be established from a spinning spacecraft toward the Earth, another spacecraft, or any celestial body, necessarily rotates with respect to the vehicle. If it is a line of sight embedded in a physical device (a telescope, antenna, etc.), the physical device must in some way be "de-spun" relative to the spinning vehicle.

The fact that spin stabilization is attractive for powered flight of unmanned craft meant it was not totally overlooked in the early astronomical literature. Tsiolkovsky⁸ alluded to it under the general heading of "Control of the Rocket," when he mentioned a small plate that rotates about the axes of the rocket causing a rotation of the gas flow, the vortex motion causing the projectile to rotate about its longitudinal axis. Robert Goddard used it in tests in January 1929, and recalled that it had been discussed at the time of World War I (obviously as a carry-over from projectile rotation). Nonetheless, not until the advent of serious proposals for small, unmanned satellites and lunar probes in the mid 1950s did spin-stabilization in space finally come into its own as a practicable and often very desirable technique.

PASSIVE STABILIZATION

The physical environmental factors that might be used--indeed, now have been used--for stabilization, involve the gravitational and magnetic fields of the Earth and the radiation from the Sun. All of these forces were understood well enough before the twentieth century to have permitted their application. For example, the torque on an orbiting body near the Earth was calculated by d'Alembert in 1749 and in the same year, in a much more comprehensible form, by Euler;⁹ correspondingly, a general mathematical form for the Earth's magnetic field as well as numerical values for its parameters, was given by Gauss in 1838.¹⁰ The gravitational torque was known to be responsible for the observed rotational behavior of the Moon as embodied in the Laws of Cassini, the stability analysis having been done by Lagrange in 1764 and 1780.¹¹ Oberth displays his recognition of the effects of differential gravitational forces when he declared: "Care must also be taken to make sure that the net is not torn apart by tidal forces during its construction."¹²

Nevertheless, the astronomical pioneers did not suggest these passive methods for spacecraft stabilization. To seek a reason one need only make a few approximate

⁺Oberth, in Reference 6, also includes steerable mirrors in gimbals (so-called "Cardan suspensions," though not invented by Cardano).

calculations of the control torque available for such sources. Typically of the order of hundreds of dyne-cm, these minuscule torques are but a tiny fraction of the torque needed to dial a telephone. Practical people would have been rightly skeptical about the efficacy of such small effects to stabilize such large bodies. With manned systems the skepticism would have been fully justified, for the internal disturbances from man's motion might easily dominate stability from the environment. They could not guess that spacecraft later would be built which were so quiescent that gravitational torque would provide quite adequate stability, while the weak solar radiation pressure, in combination with thermoelastic distortion, could become a fierce disturbance.

ACTIVE CLOSED-LOOP CONTROL

The development of concepts for active closed-loop control is cloudy, for the early framers of these concepts did not deal in closed-loop control systems, nor did they couch the descriptions of their methods in terms appropriate to control technology. It is not always clear, therefore, whether their proposed devices should be treated as sensors, or actuators, or complete systems. In most cases their descriptions are fragmentary and/or casual, and it is clear with hindsight that their concepts were incomplete until almost the end of the period we are considering: one or more items was always omitted from the feedback link in Figure 2. It is therefore simpler to describe developments author by author rather than attempt to single out specific parts of the active control system and follow their progress.

It seems always to have been implicit, if not explicit, that attitude control in space would be achieved by inertial reaction; either by mass-expulsion-like propulsion or by the inertial reaction of internal moving parts. The first clear expression of the latter, however, is that of Hohmann.¹³ He presented the physical mechanism for doing this in Figure 3: feasible in principle under sufficiently restrictive conditions, if somewhat naive, his crew clambers around the walls in order to turn the spacecraft in any desired direction by application of the principle of conservation of angular momentum. The scale factor incidentally, was 120 circuits of the astronauts (at 6 sec per circuit) per turn of the spacecraft.

Oberth, in Chapter 13 of Reference 6, described the use of gyroscopes in space under the title "Die Aktive Steuerung (Steuerung durch Kreiselkompass)."⁺ His gyroscope had an orientation fixed in space, and he was very explicit that it would be used as a sensor, not a direct spin-stabilization device (i.e. actuator): "Die Kritik hat mich hier vielfach miss verstanden. Man glaubt, ich wolle einen gross en schweren Kreisel mit der Rakete fest verbinden, so dass hierdurch die Achse der Rakete im Raum fest-

⁺This material is contained only in the 3rd edition of 1929.

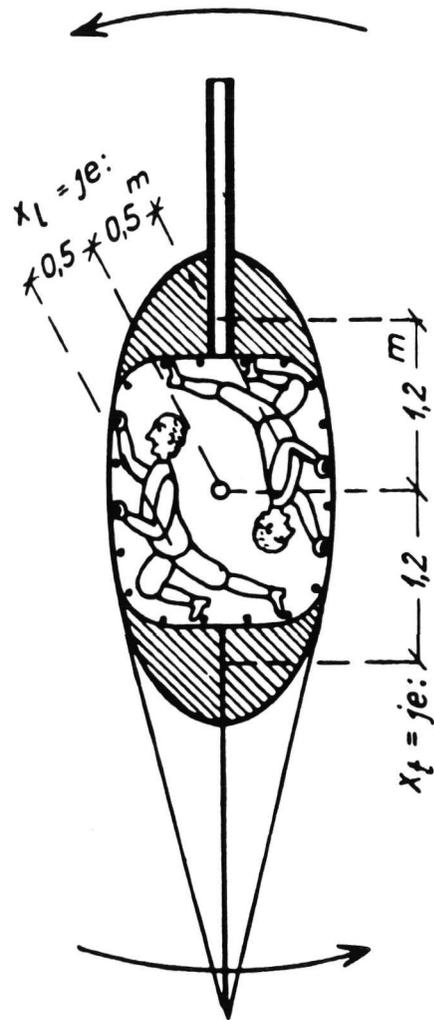


Fig. 3

gehalten wurde." He continued to make the point that the gyro was only a sensing device, used to control the fins or jet vane actuators. He cited a work of fiction by Gail⁺ which said: ". . . the directional gyro began to buzz and whistle, the spacecraft

⁺This work, Stein von Mond, Bergstadt-Verlag, Breslau, has not been available to me.

slowly turned until the rocket engine pointed exactly" Expressing the hope that his own "gyrocompass" would not buzz and whistle, Oberth reported that Gail's concept was to set the spacecraft into rotation by rotating internal wheels, commenting that the idea wasn't bad--certainly better than Hohmann's. Continuing his critique of attitude control methods, Oberth said he preferred the rotor method to the jet method[†] of rotation "because the latter can easily leave some residual rotation if the thrusts are not balanced." (He concluded by mentioning spin-stabilization as a remaining alternative, conjoining the names of Goddard and Unge without specific references.)

Goddard's practical rocket problems concerned flight within the atmosphere. Within that framework there are numerous references to gyroscopes in his works, all in connection with its use as a sensor. In his Report to the Smithsonian Institution Concerning Further Developments of the Rocket Method of Investigating Space,¹⁴ under the topic "Guiding of Apparatus," he mentioned a gyroscopic reference axis and side jet actuators "on multiple charge principle." I believe that his only comment that can be interpreted unambiguously as applying to unpowered flight in space is the note appended in August 1929 to this work: "It should be noticed that the rocket as a whole can be rotated on its axis by rotating an internal member, such as a gyroscope, in the opposite direction, this being at once evident from the conservation of angular momentum." Some diary entries are also relevant to the attitude sensing problem:

4 November 1928 "Thought of gyroscopic vane control of air
and ejected gasses."

17 November 1928 ". . . thought of using gyroscopic or pendulum
control of rocket model I am working on . . ."

4 January 1929 ". . . planned on gyroscopic stabilizer, using
gyro to operate four guide vanes at nozzle, directly."

The latter shows the gyro in the light of both sensor and partial actuator, for there was no active servo boost of the output signal from the gyro to power the jet vanes--the gyro provided the torque to move them as well as the inclination to do so. Various other entries on gyros are found throughout Vol. II of Reference 14. I suspect that Robert Goddard's many technological capabilities embraced a fairly complete appreciation of the practical ways of controlling orientation in space when continuous jet power was no longer available. Unfortunately, his virtues were accompanied by a cryptic and not always unambiguous style of exposition, so we shall never know.

Perhaps the best of the early descriptions of the attitude control problem and

[†]He attributed the initial suggestion of jet orientation control to Hoefft, without citation.

how to solve it was given by Robert Esnault-Peterie.⁵ He clearly stated the problem, mentioned two solutions, and identified a basic trade-off relationship (energy vs. mass) in what is a model of futuristic, "System-oriented" thinking. His comments are not dated by the passage of two-score years:

What has just been said applies to the case where the pilot desires to change orientation while the rocket engine is on, but it may be necessary to change orientation when there is no rocket power, be it to make an astronomical observation or for another reason which will be indicated in the paragraph 'Conditions of Habitability.'

One must not imagine that in this case the pilot cannot act. He could, for example, have at his command some small suitably placed squibs which he could fire at will. But this would consume precious combustible material and it is simpler to copy the 'back-twisting' of a cat which consumes only energy. In practice it is enough to provide a set of three little electric motors, each with a sufficient rotational moment of inertia, having their axes orthogonal to one another. As soon as one of these motors is started, the entire vehicle turns in the opposite sense, the two angular velocities being inversely proportional to the respective moments of inertia, and each of these angular motions ends simultaneously with the stopping of the corresponding motor. In this operation friction plays no role, the (wheel) coming completely to rest in any case since there was no initial rotation.

The details are a little different today, but the principles are quite unchanged.

We now move to the more serious and substantive attacks on the attitude control problem that occurred toward the end of our period, in the late 1940s. Hall has set the stage in Reference 15 for the studies of "high altitude" test vehicles (read "satellites") sponsored by agencies of the United States government that resulted in Reference 16 through 19. The following remarks concern the portions of these references that treat attitude control.

The first Douglas Aircraft Co. study in 1946¹⁶ recognized the problem: "Once the vehicle has been established on its orbit, the question arises . . . can its orientation in space be controlled?" It also supplied the general answer: "Either small flywheels or small jets of compressed gas appear to offer feasible methods of controlling the vehicle's orientation after the cessation of rocket thrust." Chapter 11 of this report, by Wolfgang B. Klemperer, examined "Problems after Orbit is Established," beginning with "Attitude Control by Recoil." "Klemp," as he was affectionately known to his friends, discussed the needs for attitude control and the general solutions of flywheels and jets. He mentioned the important problem of flywheel momentum saturation under bias torque, specifically torque from residual aerodynamic effects, and referred also to the gyroscopic cross-coupling effects such wheels introduce into the spacecraft's rotation. His mass expulsion actuators expelled solid projectiles rather than gas. Perhaps the most noteworthy step forward was the quantitative calculations on attitude

control methods he prepared, calculations that were conspicuously absent from earlier work. It was a brief but respectable beginning.

The 1946 North American Aviation study¹⁷ was not really concerned with the attitude control problem. It included a short description by R. G. Knutson of the guidance and control problem during ascent to orbit, including a few words on position monitoring while in orbit, but comes no closer to our subject area. The most meaty attitude control investigations of those days involve References 18 and 19. The former phrased the problem for the first time in modern control terminology; and for the first time a control system block diagram was given. For attitude measurement, Frick proposed a molecular beam for heading (his craft was in the fringes of the atmosphere), and the Earth's magnetic field for roll. Actually roll would be sensed on a short-term basis by a roll gyro, whose steady-state drift rate would then be corrected by the magnetic reference. His actuators were flywheels. The work qualifies as a quantitative treatment, though the analysis is not as elaborate as in Reference 19.

The rationale used for the control study in Reference 19 was not unreasonable: "Although the original HATV research program is primarily a structural study, a preliminary analysis of the control problem is considered essential to estimate the weight of structure and components involved in steering the vehicle to its final orbiting path." However, the treatment of attitude control was then carried somewhat beyond the basic needs of the original study. In any case, the results were the proposal of a sensing system involving the Earth's magnetic field and the line of sight to the Sun (at least intermittently). These sufficed for the specific application only because an equatorial orbit was considered for the spacecraft. For actuators, Devaud spoke of "rotational gyros," which apparently are what we would call today "control moment gyros." His treatment of the control logic link between sensors and actuators is certainly the best of these early works.

Thus we come to the end of the 1940s. Most of the basic sensing and actuating alternatives had been explicitly mentioned, discussed, or analyzed to at least a modest extent. The attitude control field, however, was still diffused and badly wanted integration. More significant, however, no serious quantitative work on attitude control had as yet been published in the open archive literature: it all was "unpublished," both because it existed in company reports, and because it had a military security classification. (Hence, it was "doubly unavailable.")

A GLIMPSE OF THE SEQUEL

The earliest systematic work specifically directed toward attitude control in the United States was sponsored by the Rand Corporation, motivated by certain mission implications of satellite orientation. Under a Rand subcontract, about March of 1952, attitude control investigations began in the Electromechanical Engineering Department

(later the Autonetics Division) of North American Aviation. (It was at this time that I became personally involved.) Limited open documentation exists in the form of two patents released to the open literature 10 years later, and in Reference 20, written in 1952 and only available within the past few years. These more extensive studies continued during 1953, and were paralleled at about that time by analogous studies at the Instrumentation Laboratory of MIT. To the best of my knowledge, none of this work has become part of the open literature except by publication in bits and pieces, and by rediscovery.

By the middle of the 1950s some isolated papers dealing with specific attitude control sensors or methods began to appear in open literature. In 1957 I surveyed the subject, attempted to establish its ingredient problem areas, and treated these quantitatively to the extent possible at that time. By that time the nature of the attitude control problem was fairly well understood, and the way opened for the rapid growth of the pertinent literature to the several hundreds of papers that now constitute it.

ACKNOWLEDGMENT

I wish to acknowledge with sincere appreciation the benefits I have gotten from my discussions with R. Cargill Hall during the preparation of this paper. He very helpfully made available not only his own knowledge, but several documentary sources I would not otherwise have been able to consult.

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THE IDEAS OF K. E. TSIOLKOVSKY ON ORBITAL SPACE STATIONS⁺I. A. Kol'chenko and I. V. Strazheva (USSR)⁺⁺

One fundamental thrust in modern astronautics is the building of long-lived space stations orbiting about planets of our solar system. Constructing these stations is enormously important, scientifically and from the national economic viewpoint. Accordingly, interest is drawn to studying the history of the inception and shaping of the related ideas of scientists dealing with problems of the mastery of space.

The idea of building orbital space stations was first expressed and substantiated at the end of the 19th and the beginning of the 20th century by the Russian scientist and founder of astronautics, Konstantin Eduardovich Tsiolkovsky (1857-1935). During his many years of scientific creativity, this scientist turned to work on this idea again and again. Today the portion of the rich scientific legacy of Tsiolkovsky, in particular that portion dealing with questions of building orbital space stations, is kept in the archives of the USSR Academy of Sciences where it is being studied and readied for publication. In our paper we will briefly review some of Tsiolkovsky's ideas on orbital stations, referring to some of his works which are still unpublished.

The Archives of the USSR Academy of Sciences contain some sheets and notebooks of the youthful Tsiolkovsky that preserve his first reflections on space journeys, going back to 1878-1879.¹ In many of these papers the author examined especially closely the aspects of life and organization of manufacturing in outer space in the absence of gravity. One of Tsiolkovsky's drawings shows the planet Saturn; beneath it he wrote his first hints on the possible design for an orbital station: "Phenomenon on a rotating planet. One can move easily in all directions with an artificial ring, like Saturn's " (p. 437). From the very outset of his search to find whether space flight was possible, he tried to show how much mankind would gain when space flight was mastered.

Tsiolkovsky's monograph on interplanetary journeys "Svobodnoye prostranstvo" (Free Space) was written in 1883² (pp.25-68). Even at this date he so precisely described man's behavior in weightlessness that three-quarters of a century later cos-

⁺Presented at the Fifth History Symposium of the International Academy of Astronautics, Brussels, Belgium, September 1971.

⁺⁺Biographical information unavailable.

monaut Yuriy Alekseyevich Gagarin could say: "I am simply amazed how accurately our remarkable scientist could have foreseen everything that I have just now encountered, that I had to experience for myself." In pondering the idea of interplanetary flights and sketching an imaginary picture of the first human settlements around the Earth and the minor planets, Tsiolkovsky quite concretely spoke of the need to build a system of orbital Earth stations: "Our planet's population of many millions lives on only part of it," we read in his famous science fiction book "Frezy o Zemle i nebe i efekty vsemirnogo tyagoteniya" (Musings on Earth and Heaven and Effects of Universal Gravity) (1895)³, "but for the most part, in pursuit of light and habitat, they will form around the planet—with their machines, apparatus and structures—a moving swarm wheel-shaped, like Saturn's ring, only comparatively larger"⁴ (p. 81). And further: "Around this planet, precisely as does a smaller planet, revolves a living ring receiving energy from the Sun sufficient to sustain life for 20 billions of inhabitants" (p. 83). In this science fiction book Tsiolkovsky proposed producing artificial gravity by rotating the orbital space stations; changing the speed of rotation would then change the force of gravity. Tsiolkovsky's ideas on mastering space found their scientific-technical substantiation in his work "Issledovaniye mirovykh prostranstv reaktivnymi priborami"⁵ (Exploring Universal Expanses with Jet Instruments), first published in 1902 and elaborated and supplemented in editions of 1911-1912.⁶ He concluded: "To set foot on the soil of asteroids, to lift a rock with one's hand on the Moon, to place traveling stations in space, to form living rings around the Earth, Moon, and the Sun, to observe Mars at distances of several tens of versts (1.067 km), and to land on its satellite or even on its surface, what could be more mind-dazzling! Yet from the moment jet propulsion instruments are used will begin a new, a grand era in astronomy—the epoch of orbital study of the heavens. The monstrous force of gravity will not frighten us anymore!"² (p. 136). Thus wrote the scientist in 1911, gazing into a future that has in large measure become reality in our time. He reflected on man's conquest of the limitless expanses and utilizing for the needs of all at first the Sun's energy, and then the energy of other stars. In this same work of 1911-1912, he first clearly spelled out his idea of building orbital stations: "Travel around the Earth of several rockets, with all the accessories for the existence of rational beings, can serve as a base for the further dispersion of mankind" (p. 124).

Tsiolkovsky worked out various plans for building a system of orbital stations, while dealing with other problems in his program of space conquest. The notion of building a system of orbital stations always remained the very heart of the practical part of his space program. He assumed that in the first stage of building this system, the chief goals of the orbital stations would be various astronomical, astrophysical, medical-biological, and various engineering-physics and other technological investigations. These investigations not only would broaden our knowledge

of the universe, but would also help in working out the optimal variant for long-lived orbital stations. The next stage, based on the engineering-technical experience and the material-technical base already accumulated, in his view, would be constructing extensive "settlements in the ether."

By 1911-1912, Tsiolkovsky had formulated his plan for conquering interplanetary space. The scientist stressed that mastering space in the solar system and the entire universe must begin not with the conquest of the natural objects in space (planets, asteroids and so on), but with the building of artificial settlements in space, of which the simplest form are orbital stations: "I speak not of reaching such giant planets as Jupiter, Saturn and the others," he explained in particular, "because a safe landing on them would take such an enormous amount of propellant that it does not pay even dreaming about such a landing at present. It would be easier to land on their satellites, especially the more distant ones" ² (p. 126).

Tsiolkovsky presented his final plan for the conquest of the universe with orbital stations in 1926 in ⁷ "Pereizdaniye rabot 1930- i 1911 gg. s nekotorymi izmeneniyami i dopolneniyami" (Republication of Works of 1903- and 1911 with Certain Changes and Supplements). Even in a 1923 manuscript ⁸ he had outlined the main landmarks in the program of building a system of orbital stations: "We take off in a space ship . . . and stay at a distance of 2000-3000 versts from Earth, as its Moon. Little by little appear colonies with implements, materials, machines and structures brought from Earth. Gradually, independent production, though limited at first, will develop" "When life and technical industry have been consolidated in space and settlements have been formed around Earth or in the asteroid belt, in a word, where a surplus of diverse materials can be found for construction--then there will no longer be the need to take monstrous reserves of propellants from Earth " ⁸ (sheet 5) .

Tsiolkovsky considered settlements outside the Earth entirely possible using the energy of the Sun; for construction material for space settlements, rockets, and early management of the economy, he proposed using the substance of numerous asteroids. However, setting up the first extraterrestrial stations he felt could not be accomplished without close contact with Earth, which at first would supply the stations with machines, materials and food, and arrange for crew shift changes. But in the future ". . . on settling around the Earth in a multitude of rings, like Saturn's rings, . . . people would increase by 100-1000 times the reserve of solar energy available to them at the Earth's surface. But man cannot be content with this, and from his base conquered he must stretch out his arms for the rest of the solar energy, which is two billion times more than the Earth receives. In this case, the circular motion around the Earth will be applied in a similar circular path around the Sun. This will mean moving still further from Earth and becoming an independent planet, a satellite of the Sun, a 'brother Earth ' " ² (p. 125) .

With time, in Tsiolkovsky's opinion, these artificial planets of the solar system would be united into enormous "cities in space," and form a giant ring around the Sun. Scientific-technical progress would enable man to create on these rings conditions little different from life on Earth. Rotations of the rings would produce necessary gravitational forces for people to live on their inner surface and for the stability of the entire structure. Interestingly enough, Tsiolkovsky's idea of a "ring" somewhat edged out, in time, F. Dyson's proposals for building a sphere around the Sun on which Earth civilization could continue developing. As man penetrated further into the universe, Tsiolkovsky suggested building similar rings of "cities in the ether" around stars whose radiation can become a source of energy, and in whose vicinities existed matter for the construction of space cities. In his 1919 writing "Zhizn' v efire" (Life in the Ether)⁹ he treated at length the peculiarities of life in these cities in the ether, cut free from the Earth.

It is interesting that Tsiolkovsky, as a scientist and theoretician, in devising various original projects such as orbital space stations, did not confine himself to formulating and validating general ideas, but simultaneously developed an entire complex of specific scientific-technical tasks essential for successfully implementing the ideas he advanced. It is just this trait that was accented by Academician A.A. Blagonravov, in characterizing him as a scientist: "In Tsiolkovsky's works, nearly without exception, one can see the embryo of all the scientific-technical directions developed in our country in the conquest of space. With exceptional accuracy he determined the successive path of advances in equipment for reaching this goal. Therefore it is quite natural that with each new achievement in this field we remember the name of Tsiolkovsky, as the scientist who foresaw in one form or another the culmination of these events."¹⁰ (p. 483).

In the development of orbital space stations Tsiolkovsky can be credited as the originator of several classical ideas which to some extent predetermined many features of the present space research program. The idea of achieving a closed biological cycle on these stations is perhaps the most important one, along with substantiating the actual idea of building space stations away from the Earth. Essentially, the idea of achieving a closed biological cycle involved transporting plants and bacteria from the Earth that give off oxygen with the aid of solar energy, and chemical elements, also taken from the Earth, that form organic compounds which in turn serve as food for men and animals. The scientist also proposed several designs of space hothouses, in which a closed biocycle would be achieved. He suggested, in particular, making these hothouses rotate in order to retain soil and people in place. Tsiolkovsky's designs of various orbital stations made up of sections fabricated on Earth and brought into space for assembly are of unquestioned interest.

He was particularly absorbed in the problem of setting up industry in space--"industry in the ether"--without which cities could not be founded successfully away from the Earth. He returned to this theme many times. Even in a 1921 manuscript "Rasprostraneniye cheloveka v kosmose" (Propagation of Man in Space),¹¹ Tsiolkovsky detailed such specific problems as building machine tools and equipment for use in space, the dimensions of residences and hothouses, the layout of ventilation, cooling and heating facilities for the premises, building solar power units, and the movement of cosmonauts in free space with flexible halyards, down even to the design of bath houses.

Many of the interesting proposals on building orbital stations were illustrated by the author himself in figures for the motion picture film "Space Voyage," for which the scientist was the scientific consultant (1935).¹² Some of these illustrations have gained new vibrancy due to recent gains in astronautics (man's entry into space, docking in orbit, the behavior of cosmonauts in weightlessness and during g-loads, and in many other areas).

As we have seen, the birth of the idea of building orbital stations can be traced to the 1878-1879 works of K. E. Tsiolkovsky. This idea was clearly formulated by him in 1911-1912. Finally, he developed and substantiated the project for conquering interplanetary space with orbital stations in the mid-1920s. Acquaintance with the specific design proposals and the consistent development of the idea of building orbital stations helps us appreciate even further the role of this scientist as the founder of modern astronautics. A comparison of his projects with those of modern orbital stations, and the broad complex of scientific research underway in space today, graphically show his extraordinary farsightedness, his creative systematic approach to the problems discussed, and his profound grasp of the full importance and complexity of the problems facing mankind in the conquest of space.

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F. GOMEZ ARIAS' ROCKET VEHICLE PROJECT⁺Ramon Carreras (Spain)⁺⁺

The idea of using rockets as a propulsion system for aircraft arose in Spain about the middle of the 19th century. Perhaps one incentive that caused writers to consider this application of rockets was the diffusion required to direct aerostatic balloons. This problem reached a wide public through newspapers¹ and there were many who, even though lacking a firm scientific or technical base, expressed their ideas on the subject. Another factor, certainly, involved the controversy between the supporters of aerostatic balloons and those who supported heavier-than-air flying machines. Nevertheless, the rocket as a means of locomotion did not awaken widespread interest in the traditional field of aeronautics, as can be seen from the following extract:²

Les Moteurs a réaction dépensent beaucoup plus de gaz que les moteurs à action directe pour produire le même travail . . . il paraît donc inutile de se préoccuper actuellement des moteurs a réaction

The classic line of aeronautical research sought more powerful and lighter engines, but principally of alternative types. Among those Spaniards involved in these early studies preceding F. Gomez Arias, we can mention Enrique Heriz,³ who proposed light heat engines designed for driving a type of helicopter, and Isidro Cabanyes,⁴ who investigated the possibility of building a flying machine equipped with screw propellers moved by light turbo-engines operated by gases resulting from the combustion of smokeless powder.

ROCKET PROPULSION OF AIRBORNE VEHICLES

San Antonio M. Claret (1807-1870) was another who expressed interest in solutions to the problems of flight in the atmosphere. This author, as Archbishop of Cuba, attended a royal party held in the city of Holguin. Part of the entertainment consisted of an aerostatic balloon sent aloft. Shortly thereafter the pilot lost control, and the craft fell to Earth. Following this event, Claret dealt for a time with the possibility

⁺Presented at the Fifth History Symposium of the International Academy of Astronautics, Brussels, Belgium, September 1971.

⁺⁺Agrupación Astronáutica Española, Barcelona.

of propelling aerostatic balloons by means of rockets.

In the work 'Diario Intimo' written by Claret's secretary M. Vilaro⁵ we find on February 27, 1852, the following reference to Claret's endeavors: ". . . Surprising news, H. H. said that today, at noon, he had found a way of directing aerostatic balloons . . ." C. Fernandez, in a biography of Claret, copied down Claret's original writings. Some extracts of the Archbishop's solution appear below:⁶

. . . The thrust is given by a tube placed across the balloon boat. The tube must have a closed end at the front and an open one behind. It is filled with black powder so that, once ignited, a rocket-like forward thrust will be brought about . . . until the thrust ends, it will renew itself, igniting other parts of the powder again and again The amount of powder is in proportion to the speed required and in proportion to the resistance to the wind against which the balloon is to fly. . . .

Pedro Maffiotte (1826-1870), a fellow countryman, also preceded Gomez Arias. His work, although modest, is of greater interest than Claret's because Maffiotte conducted tests. On February 14, 1858, he sent a note to the editor of Revista de Obras Publicas in which he described the results achieved with a small model of a rocket-propelled aeroplane. In these experiments Maffiotte sought to direct and control the trajectory of a rocket:⁷

Having observed that the curve described by the rocket in its ascent, turning its concavity towards the direction of the wind, it occurred to me to discover the reason for this phenomenon and examine the possibility of building a machine which would regulate its own movement, making it describe a given line in space. My studies resulted in the construction of an elliptical kite measuring 90 x 70 cm, propelled by a small rudder and a regulating fin on its outer surface. The rocket, shaped like an iron tube, is fixed within the center of the kite's inner surface, its line of symmetry tilted to an angle of 40°

The model's total mass was 137 g, the black powder propellant weighed 4g, and the vehicle attained a speed of 2.5 ÷ 4.3 m/s. The thrust was in the region of 500 N. Concerning possible improvements, Maffiotte observed:

We are now naturally faced with the question of the possibility of building a larger model with a very small section so that its resistance to the air it passes through, that is to say, the wind's influence, becomes one of minor importance; the production of a large amount of gas flowing, either intermittently or continually through many tubes or pores on the inner surface, serve to keep the model suspended in the air, and impart a transferring movement which is capable of carrying a certain payload from one given point to another one.

Today, as the science of engineering happily moves ahead with giant strides, we can have no doubts of the possibility of building a solid, light, and larger model; but it will still be difficult to discover a chemical compound more effective than powder, having less weight while developing a greater amount of gas, and which, unlike the rocket built these days, would not be subject to unforeseen explosions. . . . Today the problem of aeronavigation lies in overcoming chemistry and physics rather than in rational mechanics. We must hope that some wealthy and disinterested person will support this field of research which requires talent, perseverance, and freedom of action. . . .

Maffiotte intended to continue his writing on the subject, but, at age 44, he died in the Canary Islands. After his death, this article and other writings on the same subject were published posthumously in the newspaper La Voz de Canarias. The newspaper mentioned other unpublished articles by the same author; however, these studies have not yet been located.

F. GOMEZ ARIAS' ROCKET VEHICLE PROJECT

Despite the interest and achievements of these pioneers, Gomes Arias remains outstanding among Spanish forerunners in this field. Indeed, this pioneer may be considered the world's first designer of a rocket propelled, manned aircraft. Born on 14 February 1828 in Salamanca,¹⁶ Arias studied philosophy, law, and nautics as a young man. After receiving a PhD he was appointed professor at the 'Escuela de Nautica' in Barcelona, in 1863, later becoming its director (Figure 1). Besides literary works, he



Fig. 1

also published tracts on teaching, and especially on inventions that led to his election as a corresponding member of the Parisien Academy of Inventors. He died on February 19, 1900.

Arias published his first work on inventions anonymously in 1854.⁸ Titled

Three Impossible Conquests, or Three Inventions of the Century, the book showed the author's early interest in solving the problem of space navigation. The study discusses a project for a cigar-shaped dirigible balloon, propelled by fins driven by heat engines. Arias never acknowledged this work as his own, however, probably because it contained some serious scientific mistakes. His most important contribution to the history of astronautics consists of his "Memoirs Concerning Aerodynamic Propulsion," presented at the Primera Exposicion Maritima Espanola, held in September and October 1872.⁹ The "Memoirs" were published four years later (Figure 2), divided under three headings:¹⁰

1. Ascent and direction of heavier-than-air machines
2. Ascent and direction of balloons
3. Useful observations for aero-navigators and for aerodynamic studies.

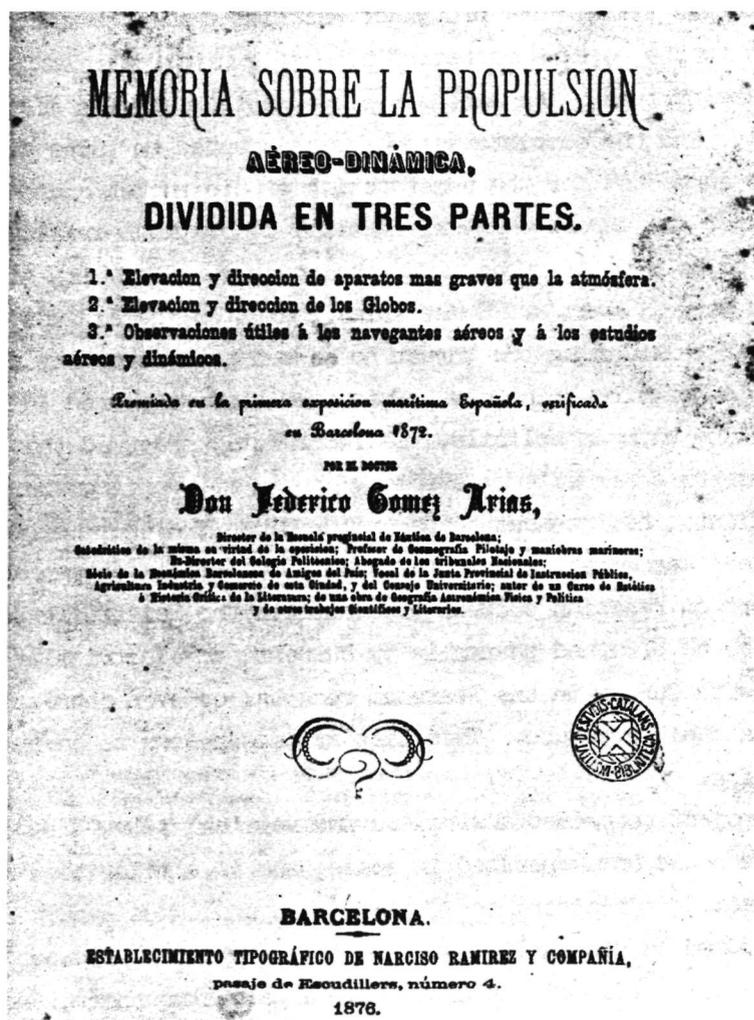


Fig. 2

In Part 1, Arias described a rocket aircraft he designed about ten years before Kibaltichich.¹¹ One interesting point of this work lies not so much in its priority, but rather in the more elaborate exposition than that offered by the Russian author. Gomez Arias's idea is summarized on page seven of his "memoirs":

. . . I believe that, among my other inventions explained in my 'Memoirs', the aero-dynamic motor-propulsor is the most adequate for an easy test because of its great simplicity, It is based on the uninterrupted production of gas which, ejected into the atmosphere at a great and calculated speed by a convenient section, causes the reactive thrust necessary for propulsion. The full description of a model apparatus suitable for the lifting is shown on sheet 1, beside the vertical and horizontal projection of its engine isolated in the scale of 0.2 in Figures 2 and 3, . . .

The motor-propulsor (see Figures 3, 4) consisted of a horizontal tube which partly formed the thrust chamber. The chamber was fed by a revolver moved by a 'moulinet' placed at one of the gas exits. The propulsor was fitted with several valves that conducted the gas glow to the nozzles either of ascending propulsion or towards those of horizontal and ascending feed. The aeronaut-pilot was housed in a little boat slung beneath the assembly, and the complete assembly was mounted on three air-cushioned feet.

Materials suggested for the construction of the rocket engine were iron, steel, and aluminum, and, for the thrust chamber, an alloy of platinum-iridium. The small passenger boat was to be made of rubber. If the motor were fed with nitrocellulose, the apparatus would burn 0.25 kg/s. Gomez Arias evaluated the exhaust velocity at 1600 m/s; however, in calculating the thrust he made a minus error by a factor of 10 in not applying Newton's Reaction Principle. This same error appeared in his other writings¹² when dealing with an eolipile. He incorrectly presumed that thrust was produced by the pressure of expelled gas acting on the surrounding air.

As propellants, he intended to use black powder, either coarse-grained or in paste, nitroglycerine, kerosene, or even, he implied, hydrogen-oxygen according to Piazz-Smith's report on reaction control presented to the Scientific Society of Manchester. Ignition was to be obtained thermally by burners, or electrically by sparks, or by coating the powder with CuS as in the Stateham rockets, or even chemically by injection of an acid through a capillary tube. This last system appears to be an early application of hypergolic ignition.

Arias's project comprised a wingless and vertical takeoff rocket-propelled flying vehicle which could have operated in space, and is similar to a modern lunar flying vehicle project.¹³ According to W. Gail,¹⁴ an analogous system of propulsion was also proposed by Goddard in his earlier years. Arias, however, did not consider the possibility of extraterrestrial flight above the earth's atmosphere, and only proposed special protection for the astronaut against the wind.

In a later work¹⁵ Gomez Arias proposed a special scaphander for the balloon's ascent into unbreathable atmospheric regions. He gave several solutions to the system of

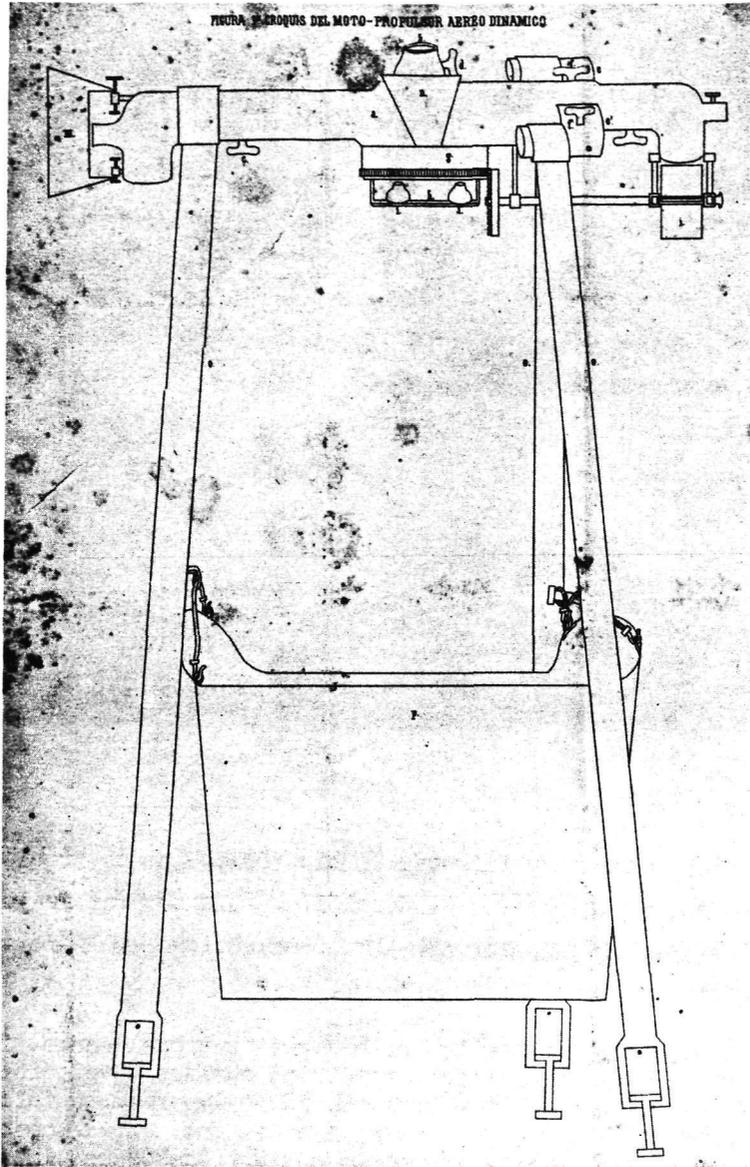


Fig. 3

air stockage and air renewal, one of them using air deposits condensed to 40 atm (Rouguairol apparatus similar to that used by divers), and another which eliminated the CO_2 by means of a NaOH washer and a dryer containing CaO. This system was probably the first space-suit design (see Figure 5). He also suggested the use of similar machines for carrying out astronomic and geodetic observations.

In his 'Memoirs,' Part 3, Arias pointed out that food would have to be carried in extract form to reduce its weight. He also made other suggestions of interest to the history of aerospace medicine. Although Arias did not directly mention

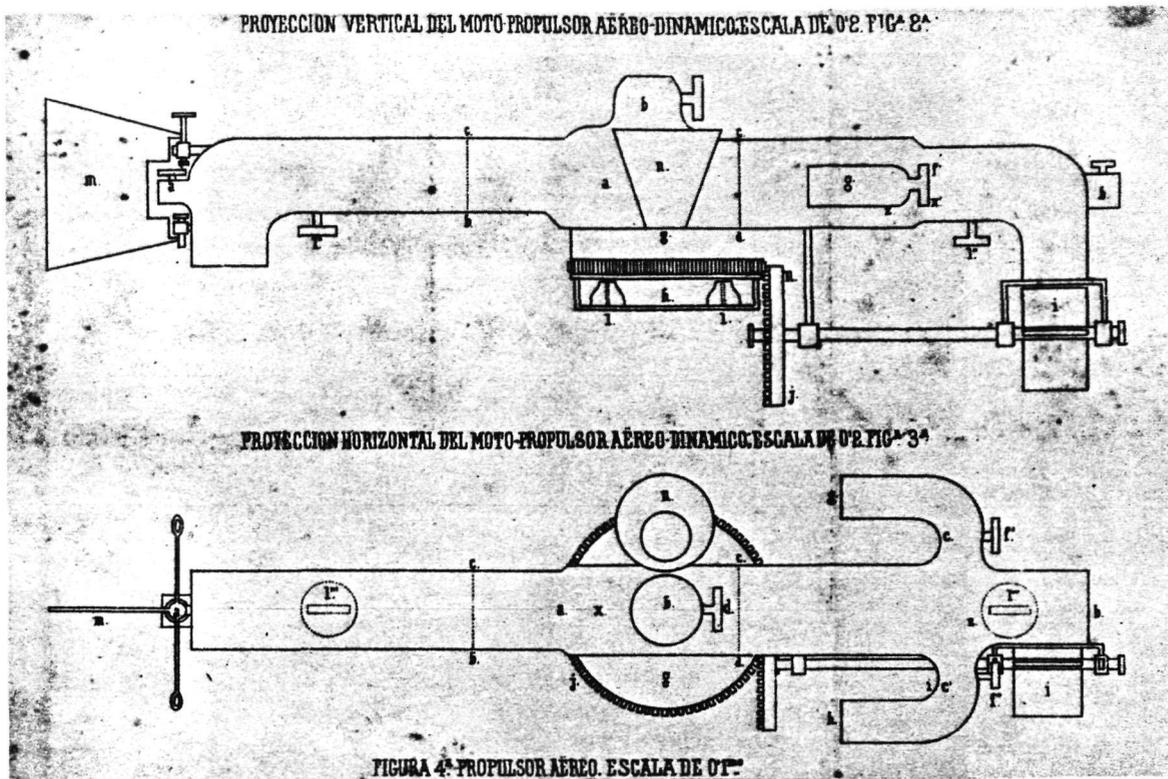


Fig. 4

the possibility of interplanetary flights, in his 'Coleccion de Problemas',¹⁶ he treated 'satellization' and escape velocity. Discussion of this subject is included in paragraph 89 of the first part. In paragraph 420, "Reflections on Inertia" (Consideraciones sobre la inercia), of part two, the text reads:

. . . a cosmic object subjected to Earth's gravitational force, falling should not achieve when rising the terrestrial surface a velocity greater than 11200 m/s, that is, the same that should be imparted to this object to lose it in space infinity and prevent its descent. When boosted horizontally, a speed of 8000 m/s is enough to convert the object into a small satellite describing a curve of greater radius than the Earth's

Gomez Arias, through his writings, appears as a restless follower of scientific and technological advances, heaping up solutions in the most diverse fields and applying these on the inventions that he studied during his free time. Despite being a reader of Flammanon and Jules Verne works, one finds no mention at all of the possibility of space travel.

His works apparently were of little interest to Spanish scientists or engineers who were more competent to undertake an improvement of his solutions and to correct some of his mistakes; nor did he have sufficient diffusion to take an interest in foreign research in these fields. Therefore, Gomez Arias should be considered as an isolated

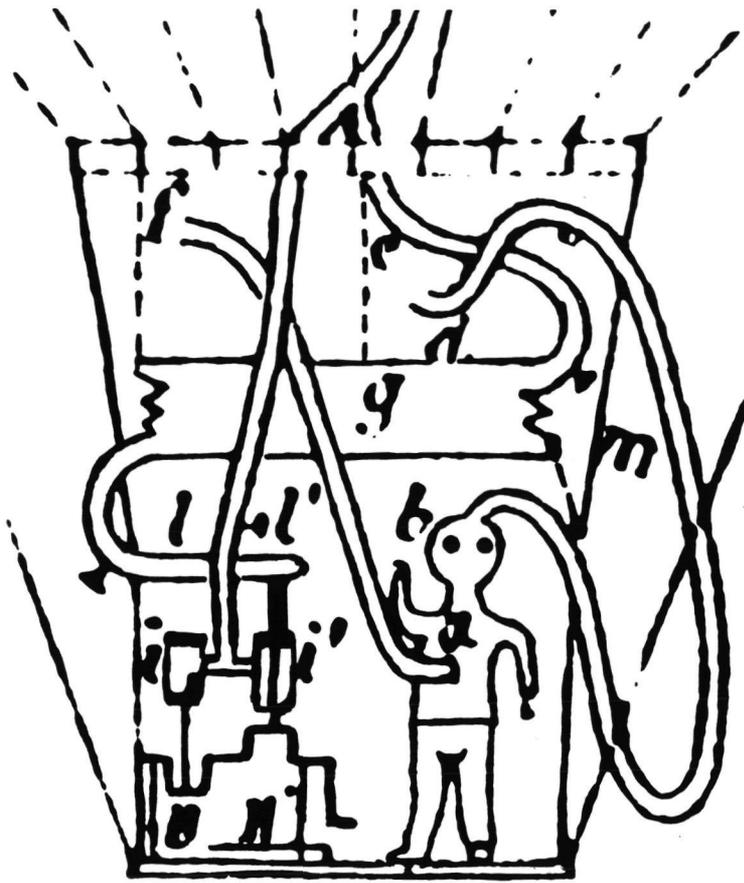


Fig. 5

case product, and a true image of the epoch in which he lived.

The author is indebted to the Excm. Diputacion Provincial de Barcelona for financial assistance in the preparation of this paper.

APPENDIX

F. Gomez Arias scientific technical works:

Tres imposibles vencidos o tres inventos del siglo, Est. Tipografico Narciso Ramirez, Barcelona, 1864 (G.A.F.), as author.

Curso compendiado y completo de Geografía Astrónomica, Física y Política Libreria especial de libros de arquitectura y agrimensura, Barcelona, 1868.

Discurso inagural que en la apertura del curso académico de 1872 a 1873 en la Escuela Provincial de Nautica leyó el Director de la misma. . . . Ed. Sucesores de N. Ramirez y Cia., Barcelona, 1872.

Memoria sobre la Propulsion Aereo-Dinamica (Premiada en la primera exposición marítima Espanola verificada en Barcelona 1872) Establecimiento Tipográfico de Narciso Ibañez y Co., Barcelona, 1876.

Discurso dedicado a la Asociación de Marina Mercante (1855) Sucesores de Narciso Ramirez y Cia., Barcelona, 1888.

Seis inventos notables con los detalles para su ejecución Imp. Jaime Jepús Roviralta, Barcelona, 1890.

Sucinto tratado de lecciones de física general que explica en la Escuela Especial y Provincial de Nautica de Barcelona. . . Litografía Hereu, Barcelona, 1893.

Colección de Problemas (2 vols:)

I) Ejercicios Geográficos

II) Ejercicios Fisico-Matemáticos

Imprenta C. Provincial de Caridad, Barcelona, 1894

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ON FUNDAMENTALLY NEW SOURCES OF ENERGY FOR ROCKETS IN THE
EARLY WORKS OF THE PIONEERS OF ASTRONAUTICS⁺T. M. Mel'kumov (USSR)⁺⁺

Interplanetary journeys and flights into space captured attention even at an early stage of mankind's cultural development. More or less serious theoretical investigations of the possibility and conditions for flight into space date back to the late 19th and the beginning of the 20th century. Naturally, the pioneers of rocket technology, based on the entire history of man, examined chemical energy in the fuel-oxidant reaction as an energy source for propulsion. From this viewpoint, various components of rocket propellants were considered with the aim of selecting those components that would yield the greatest amount of thermal energy in chemical reaction. K. E. Tsiolkovsky indicated liquid hydrogen (LH) and liquid oxygen (LOX) as components capable of releasing the greatest amount of heat by the combustion of hydrogen.¹ R. Esnault-Peterie, R. H. Goddard, F. A. Tsander and others, in compiling tables for chemical compounds, also indicated liquid hydrogen and liquid oxygen as the most efficient rocket fuel components. Later, R. Esnault-Peterie turned his attention to atomic hydrogen: in the formation of molecular hydrogen, atomic hydrogen gives up even more thermal energy than does the reaction LH + LOX.² All pioneers in rocket technology came to the conclusion that chemical energy is incapable of resolving the problem of extended interplanetary flights, therefore, other more powerful energy sources had to be sought.

In this paper we do not intend to exhaustively set forth all the ideas of all the pioneers in rocket technology oriented toward the use of other, nonchemical energy sources. Our aim is to direct attention to the fact that even during a time when rockets for space flight had not actually been built, pioneers in rocket technology already clearly understood the need to seek and use more efficient methods of propelling a craft in space than could be achieved with chemical energy.

R. H. Goddard in reference 3, written on October 8, 1907, pointed out that it was possible to use the pressure of sunlight, an idea experimentally confirmed by P. N.

⁺Presented at the Sixth History Symposium of the International Academy of Astronautics, Vienna, Austria, October 1972.

⁺⁺Biographical information unavailable.

Lebedev in 1899. Goddard observed that the "pressure induced by radiation [of the sun] equals 4 lb (1.82 kg) per square mile," and that "it has been suggested that solar energy be used for propulsion exclusively above the altitude limit of 2000 miles (3200 km)." Goddard gave no data on the possible design of the mirror [in modern terms, the "solar sail"--T. M.], its thickness, material, and possible weight. In the same work Goddard directed attention to the possibility of gaining energy for rocket propulsion via atomic fission. True, he erred, naturally if one considers when the article was written, assuming by atomic fission the total atomic ionization, that is, the release of all the electrons from the nucleus of the atom. Goddard noted that "flight into interplanetary space rests on the problem of splitting the atom."

K. E. Tsiolkovsky also channeled attention toward the use of radium as a powerful energy source.⁵ "Radium," he wrote, "decaying continuously into more elementary matter, separates at an unimaginable velocity, close to the speed of light." Further, he noted: "if the decomposition of radium or other radioactive bodies, which probably includes all bodies, could be accelerated rapidly enough, then its use would probably furnish, under otherwise equal conditions, such a velocity to the jet apparatus that the arrival at the nearest Sun [star] could be reduced to 10-40 years. Thus, a few chips of radium would be enough for the rocket weighing a few tons to wrench free of all ties with the solar system."

In reference 4, R. Esnault-Pelterie wrote: "Only the forces and energy that appear to be contained in molecules of matter could give us the concentrated power magnitude and force that we have established [for interplanetary craft flight--T.M.]. If for a moment we assume that we have 100 kg radium in our ship weighing 1000 kg, and are able to release from this amount of radium all its energy in the time required by us, we will see that 100 kg radium is more than enough for a flight to Venus and back (at constant acceleration)." Esnault-Pelterie was doubtless influenced by the recent isolation of radium and polonium by the Curies; in 1903 the Curies established that radium continuously emits large amounts of energy with practically no loss of mass.⁺

In reference 2, Esnault-Pelterie indicated even more definitively the desirability of using nuclear energy. He observed: "under the theory of relativity, matter is the only stable form of energy with its enormous reserve When we control such energy sources, travel itself will occur under very different conditions." He deemed it best that, in interplanetary space, nuclear energy be used for the direct ejection of positive ions and electrons. Tsiolkovsky and Esnault-Pelterie, independently of each other, came to the idea of using atomic energy for interplanetary flight, though radium

⁺ Later it was found that radium decomposes very slowly; thus the decay of half of radium's mass occurs in a span of 1590 years. A. F. Ioffe, "Osnovnyye predstavleniya sovremennoy fiziki" [Basic Ideas in Modern Physics], 1949, p. 238.

was not in fact the best element for this purpose; they themselves knew this full well, as can be seen from their reservations in the excerpts presented above.

In reference 5 (p. 92) Tsiolkovsky stated: "Maybe in due time with electricity we can impart enormous velocities to particles ejected from the jet apparatus." Of course, he did not give the principle or offer diagrams but--based on "cathode rays in a Crooke's tube"--he believed this could be done. He also did not explain how and from what source electrical energy could be produced on board the interplanetary ship. Goddard, in his well-known work,⁶ stressed that he was limited in selecting the type of propulsive force and settled on the expulsion of gas from a nozzle after a chemical reaction in a closed chamber, "since subatomic energy is inaccessible to us."

In reference 7, dating back to 1918-1919, Yu. V. Kondratyuk described "an apparatus utilizing solar energy." Aided by large parabolic mirrors shaped like a parabola of revolution or parabolic troughs, solar energy would be focused to heat a working body. This is the so-called solar rocket engine. Kondratyuk understood that the thrust from this engine would be small, and wrote that "probably their use [mirrors--T. M.] would be profitable where significant acceleration is not required." In the same manuscript, he wrote about "reaction from material radiation" (p. 510). In his view, "Cathode rays are material particles charged and rushing along at a speed of 200,000 km/sec. Therefore they produce a corresponding reaction--recoil, which can be utilized by bringing it to the required level." Kondratyuk's opinion regarding the possible significance of a rocket traveling in space at enormous speeds is interesting. He wrote (p. 510): "Even now a jet apparatus, based on particle radiation, strikes me as difficult and improbable, but--in any case--one must ponder and work on it. If successful, it promises to provide such an incredible velocity that it would be impossible to achieve even with the most powerful conventional rocket. With such velocities it may even be possible to test the theory of relativity. Energy for such an apparatus could be drawn from the rays of the Sun--ours or another." As we see, the Sun (a Star) was considered as the primary source. Kondratyuk also discussed the possibility of illuminating Earth objects and even cities with mirrors from space or, conversely, of eclipsing the Sun by producing a shadow with the mirrors.

One more method of producing thrust forces was advanced by Kondratyuk (see reference 7, p. 658). Essentially, this is a novel ion engine by modern terminology, with ions accelerated in an electrostatic field. From one opening positively charged particles flow out at high speed, from another opening, negatively charged particles. Both flows meet and there is electrical neutralization of flows. Kondratyuk wrote that "the velocity of these particles when there is . . . a high potential difference can be made extremely high--greater than the velocity of molecules of a strongly heated gas. This method must be heavily emphasized. It is only suitable when the rocket reaches the airless expanses." Kondratyuk gave no instructions about the method of

obtaining electrical energy on board the ship or the method of producing positively and negatively charged particles, but his thought of neutralizing the total flow of positive and negative charged particles does not far outstrip actual ion-engine developments.

In reference 22, presented in 1920 to the Smithsonian Institution, Goddard indicated that in space the Sun is the only external energy source. He believed solar energy could be focused with thin mirrors and used in special boilers to produce steam; the steam in a turbogenerator would serve to generate electrical energy, and then could be condensed and returned to the boiler. Electrical energy makes possible the production of positive and negative ions, which are introduced into the jet stream of the chemical energy source on board the spacecraft ($H_2 + O_2$), with the entire stream receiving additional acceleration electrostatically. Goddard emphasized the need to eject positive and negative ions; otherwise, "in a short period of time the positive ions could no longer escape from the rocket." This principle echoes the proposal by Yu. V. Kondratyuk.⁷ Another proposal by Goddard that "electrons emitted by heated substances are possibly the ions most simply produced in large quantities with small energy outlays," no longer contains the idea of the neutralization of the rocket and--moreover--is not of value in view of the small mass of electrons.

F. A. Tsander in reference 8, published in 1924, discussed using mirrors made of the thinnest sheets to utilize sunlight pressure. He also indicated that the velocity of interplanetary craft could be increased with the energy of sunlight collected by concave mirrors located in space and beamed to the ship. He also wrote of this in reference 9 on pp. 268-269. Distinct from other authors, Tsander defined as far as this was then possible, the mirror's design and weight. He adopted a thickness of 0.001 mm, and found for a mirror 100,000 square meters in area with structural elements, a weight of 300 kg. He further indicated that the pressure of sunlight on this mirror would be 46 g, a figure, by his calculations, that would make possible flying an elliptical path to Mars during the same time as a chemical rocket, if the latter could be used. "In interplanetary space, given its enormous distances, it is far better to use the free gift of sunlight pressure or the transmission of energy over a distance by means of the very thin mirror."

In 1926 Tsander prepared for Glavnauka [Main Administration of Scientific Institutions, Museums, and Science and Art Establishments] an outline of a paper he later published.¹⁰ In this work for the first time he presented the concept of the increase of energy of an interplanetary craft during flyby past a planet, and calculated the increment in kinetic energy of the ship via the velocity of the planet, and the relative velocity of the ship in relation to the angle at which the planet is skirted. The author found the conditions under which the increment in the kinetic energy is at a maximum. He demonstrated that, by skirting the Earth or Jupiter, one

can achieve an added velocity of 10.18 and 24.6 km/sec, respectively. Using the gravitational field of the planet and the Moon, one can not only increase, but, as desired, even reduce the craft's velocity. Tsander indicated that "during flight around celestial bodies the highest flight velocity is achieved in closest proximity to the celestial body." (p. 345).

Herman Oberth in reference 12, published in 1923 in Germany, wrote about using mirrors in space to utilize sunlight. He mentioned a 1000 km diameter mirror, made of light sheet material. This mirror, stretched on a special latticed framework, in the author's view, could concentrate solar energy and serve to artificially thaw icebergs in the North to make the boundless polar regions habitable, prevent in the lower latitudes the danger of snowstorms and avalanches, and to promote the ripening of fruits and vegetables in the fall by eliminating frosts. Oberth also suggested the possibility of orienting the entire mirror, or its individual cells.

In reference 13, written in 1924 and published much later,⁺ Tsiolkovsky wrote further about "a most fascinating method of acquiring velocity. This involves transmitting energy to the rocket on the outside, from Earth." In his view the energy is transmitted as a beam of electromagnetic waves with a short wavelength using a parabolic mirror. Further, he stated that "this parallel beam of electrical or even light (solar) rays by itself must produce pressure," though he still doubted such a possibility even though he knew of the light pressure effect. His doubt was founded on the low value of the light pressure and the consequent necessity of developing large mirror surfaces, which—he believed—was not feasible, "particularly today." On Earth a powerful electric station would be built to serve as the energy source, converting the energy into "electromagnetic" and light waves for transmission to distant spacecraft, whose velocity would increase.

Reference 13, however, contains no plans or ideas for installing mirrors, but the thought is given in its simplest form. Somewhat further on Tsiolkovsky discussed the possibility of "using negative and positive electrons" to propel the spacecraft. This idea was also given in passing. However, the electron mass is so small that it would hardly produce enough thrust to propel the craft. Evidently Tsiolkovsky understood this, since in this same piece he wrote of "the use of electricity, whose action is always attended by the ejection of helium nuclei and electrons." Further, he noted that electrical energy "can provide a very powerful flow of ionized helium, which can serve the celestial craft." In contrast to Kondratyuk, Tsiolkovsky did not think about neutralizing the electrically charged flow of particles leaving the craft.

According to a book written by Max Valier¹⁴, A. F. Ulinsky began to study rocket

⁺In the volume "Pionery raketnoy tekhniki" [Pioneers in Rocket Technology], Izdatel'stvo nauka, Moscow, 1964.

engines in 1913. In Ulinsky's view, rockets utilizing chemical energy would always suffer because the fraction of propellant in respect to the total rocket mass is very large, while the mass of the payload is very small. To remedy this deficiency, Ulinsky in the mid-1920s—relying on Edison's invention of an engine in which the thermal energy of sunlight is transformed directly into electrical energy with thermoelements—proposed placing a system that arrays thermoelements around the spacecraft to produce electrical energy. Under the electric current, electrons could be ejected from the cathodes with a speed 0.01-0.1 of the speed of light. Ulinsky calculated that such an "electronic ship" weighing 3000 kg, in relative proximity to the Earth, would need only 5 g-per second consumption. During a period of 1800 sec, the ship would acquire a parabolic velocity to overcome Earth's gravity. In the case of chemical energy, this would require—for the same result—a minimum of 30 tons of propellant, while the total outlay of electrons would be only 15 kg. Ulinsky understood that flight from Earth into space and deceleration for landing could not be achieved with the solar electronic engine, but would require a special engine. In this area he advanced a suggestion (and even patented it) that did not and could not receive practical application. Understandably, by ejecting only electrons, the craft could not remain electrically neutral; however, this question did not draw Ulinsky's attention. An address that Ulinsky made in 1927 about progress on his "electron rocket" project is noted in reference 21 by M. K. Tikhonravov (p. 619).

In reference 8 published in 1924, F. A. Tsander observed that use could be made of the unnecessary metal parts of a rocket as fuel for the rocket engine. Metals as fuel also attracted the interest of other researchers. V. P. Glushko approached the problem of using metals in rocket engine operation in a fundamentally different manner. He directed his attention to the experiments on electric explosion of metals published by the Swedish physicist J. A. Anderson.¹⁵ When large amounts of electrical energy are fed into a metal wire, gas is instantaneously formed, flying off on all sides at high speed. Glushko decided that applying this principle of (electrical) energy enables any amount of energy to be supplied, producing gases having extremely high temperature and velocity. If one designed a device with directional ejection of the gases, one could obtain more efficient exhaust velocities than rocket engines burning a chemical propellant. Thus, in 1929 he suggested the electrothermal rocket engine. Electrical energy from power stations was to be used in the preliminary experiments. For space flight he proposed to transform solar thermal energy into electrical energy by placing a large number of thermoelements on an annular surface about the craft, in the center of which would be the rocket.

Later,¹⁶⁻¹⁹ Glushko calculated the gas temperature in the electrical explosion of various metals, the exhaust velocity and gas formation for the various metals, and confirmed the high efficiency of metals. Experiments that he conducted agreed closely

with these calculations. In reference 20, Glushko described an electrothermal rocket engine; he calculated exhaust velocity as a function of the amount of electrical energy expended per gram of metal. Of course, this electrothermal rocket engine can generate a small, but constant thrust; however, as we know, the efficiency of thermoelements is low. In 1931, Glushko was granted an author's certificate [patent] for an electrothermal rocket engine.

M. K. Tikhonravov also dealt with the methods of using solar energy to propel spacecraft.²¹ He maintained that solar energy could be converted into electrical energy most efficiently with thermoelements or photoelements [photocells]. Using electrical energy, hydrogen molecules would be split into atoms, and the union of the latter into molecules would produce large amounts of energy. This rocket was called an "electrohydrogen" rocket. The originality of the idea notwithstanding, its realization could scarcely be hoped for.

CONCLUSION

1. Even in the early stage of the study of space flight, the pioneers of rocket technology found the most efficient chemical propellants and concluded that more efficient and longer-lived energy sources for propulsion of interplanetary craft had to be sought.

2. They specified the following as these sources:

- a) Nuclear energy (in modern terminology)
- b) Solar energy.

Though nuclear energy appeared then to be inaccessible, the example of radium showed the importance of such a long-lived energy source for interplanetary voyages (K. E. Tsiolkovsky, R. Esnault-Pelterie and R. H. Goddard).

3. Solar energy was proposed in three forms:

- a) action of solarlight pressure on extended surfaces--"solar sail" (R. H. Goddard, F. A. Tsander and K. E. Tsiolkovsky);
- b) direct use of the thermal energy of sunlight (Yu. V. Kondratyuk, the solar rocket engine, and H. Oberth);
- c) direct conversion of thermal energy of sunlight to electrical energy with thermoelements (A. F. Ulinsky, V. P. Glushko and M. K. Tikhonravov), of photoelements (M. K. Tikhonravov).

4. The use of electrical energy on board the space craft was proposed to:

- a) increase the velocity of particles ejected from the jet apparatus (K. E. Tsiolkovsky);
- b) accelerate charged particles in an electrostatic field (Yu. V. Kondratyuk, K. E. Tsiolkovsky, R. H. Goddard, and A. F. Ulinsky);

- c) direct electrical explosion of metals (V. P. Glushko--electro-thermal rocket engine);
 - d) decompose hydrogen molecules into atoms, then organizing the hydrogen molecules with the release of heat--the electrohydrogen rocket (M. K. Tikhonravov).
5. The pioneers in rocket technology realized that all variants of solar energy use were capable of yielding small, long-lived thrust, and thus were suitable only in interplanetary space where the effect of gravitation forces was small or negligibly small.
6. Present-day research on low-thrust engines is founded on transforming the Sun's thermal energy or the energy of a nuclear reactor into electrical energy, either directly or by Brighton and Rankine cycles. Electrical energy is used in ion and plasma electrorocket engines. In the case of engines with large, but short-lived thrusts, use is made of a nuclear reactor with fission of heavy nuclei serving to directly heat the rocket engine reaction mass.

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THE SILVER BIRD STORY: A MEMOIR⁺Irene Sanger-Bredt (German Federal Republic)⁺⁺

On March 23, 1935, a self-willed young Viennese engineer wrote in his diary: ". . . Nevertheless, my silver birds will fly!" (Figure 1) He penned these words despite having received two months before notice to quit his post as an assistant at the Technische Hochschule, Vienna, where he had successfully completed two years of tests with new liquid-propellant rocket combustion chambers. Moreover, with debts in the amount of RM 2000 to publish the first textbook on spaceflight technology, he faced ruin.

On January 23, 1964, a tired and weary man in Brussels, just 18 days before his premature death, supported for the last time his favorite project, the space transporter--known today as the space shuttle. Before the assembled delegates of the European aerospace industries he observed:

. . . An efficient, economical system of space transportation will become topical at a time when the problems of rendezvous technique have been solved in Earth orbit; furthermore, when the first successful manned landings on the moon have taken place, the construction of large manned permanent lunar bases has to be started. For undertakings like these, which may be realized, presumably during the next decade--an economic system of space flight becomes an absolute prerequisite

If such developments are not yet fully underway in the USA and USSR, it is because the total intellectual and material resources of these countries, at present, are occupied with actual pioneering efforts, especially with the race to the moon. As soon as this strain is over, they will devote all their efforts to the next phase of practical spaceflight--the preparatory work of the American aerospace industry shows this already quite clearly.

Hence, there exists for Europe a unique but transient opportunity to become fully active, both intellectually and materially, in a branch of spaceflight where the great powers have not yet gained an unassailable lead; a branch of spaceflight which promises high material profit, and may even make these countries customers of the European aerospace industries.

⁺Presented at the Fourth History Symposium of the International Academy of Astronautics, Constance, German Federal Republic, October 1970.

⁺⁺A physicist who worked with Eugen Sanger on the Antipodal Rocket Aircraft, and later became his wife. Founding member of the International Academy of Astronautics.



Fig. 1
Eugen Sänger (1905-1964) Demonstrating
Skip Flight Trajectories at a Model
Globe of the Earth

Between these two dates mentioned above, and representing nearly 30 years of a man's life work, there took place the story of a technical development project named "Silbervogel" (silver bird) in the dreams of its creator, and known also by several other names--such as "Flugboot" (flying boat), and in Sänger's earliest computations and project notes, simply "Raketenflugzeug" (rocket plane) in the first relevant publication of its advocate in 1933, later on as "Bügeleisen" (flat iron) in the jargon of the technicians at test stands and wind tunnels, thereafter camouflaged as "Raketenbomber" (rocket bomber) during the storms of the second World War, and finally "Raumtransporter" (space transporter) in the dry language of aerospace experts at the beginning of the astronomical age. All these names refer to a manned, recoverable flying machine that operates both in air and space, especially to be used as the first stage of booster rockets, or respectively, to ferry, supply, and furnish rescue equipment for manned space stations. Depending on the region of its flight domain and the type of mission, the craft would be able to follow either ballistic or aerodynamic trajectories, and would combine the properties of a powered booster rocket with those of an aerodynamic glider. The realization of such an aerospace transporter would eliminate a strange gap in astronomical development until

now--the historical background of which will be briefly examined first. Of course, it may appear surprising to an unaffected observer that manned spaceflight did not evolve gradually and consistently from aviation within the past 50 years; furthermore, that for ascent into the cosmic regions one should renounce the benefits of an atmosphere delivering oxygen and lift, as well as the benefits of a concept enabling recovery of the hardware. Instead, men have been launched into space with high accelerations tolerable only to a select few, and on projectiles that consume more fuel than is absolutely essential and of which only a small re-entry capsule can be returned--rather inelegantly--to Earth, fit only for display in a museum at last.

Would the first steps into space have been different if the astronomical pioneers, especially Hermann Oberth as the spiritual father of Western Europe spaceflight, been inspired by aerodynamic methods of flight, such as the Icarus legend or Bishop Goodwin's journey, rather than by Jules Verne's novel "De la Terre à la Lune," with the moon traveler setting off in a cannon ball? Was it the war, disastrous promoter of many inventions, that made the ballistic solution (in the form of intercontinental missiles) appear more interesting, and offered it to astronautic purposes as a cheap by-product? Or was the realization of the Silver Bird delayed in fact by the high development costs of aerodynamic carrier vehicles, and by doubts about a sufficiently high operating frequency of reusable boosters?

In his last lecture Sänger expressed his own opinion:

When a quarter of a century ago, spaceflight first became a technical reality, two fundamentally different avenues of development existed. On the one hand, we could develop the ballistic, missile-like spacecraft, essentially similar to the proposals of Tsiolkovsky, Goddard, Oberth and Esnault-Pelterie; whilst on the other hand lay the further development of aircraft engineering towards space vehicles capable of cosmic flight, the so-called aerodynamic way to space, as advocated by a group of Viennese scientists, including von Hoeffft, Valier and Sänger.

More exhaustive work on definite projects very soon showed that, considering the contemporary state-of-the-art, fewer problems would need solving by using the ballistic method, and that the transport of defined payloads would be more economical in the ballistic mode (because the saving of dry weight, enabled by the omission of wings, undercarriages, high bending loads and so on, gave a better payload to gross weight ratio), as long as the operating frequency remained low. The high construction costs of such ballistic and non reusable transporters were overshadowed first by the still higher development costs of reusable transporters. Thus, the benefit of repeated availability of aerospace planes could show no economical effect as long as operating frequencies and consequently mass production rates remained low. Of course, trial flights of individual specimen before their proper application are not possible with ballistic aircraft, because each can be used only once. Nevertheless, a low reliability in flight resulting from this fact seemed acceptable for military and even for unmanned civil missions.

Conclusively, it was the development of ballistic spaceflight which proceeded during the last few decades. This way has led to the well known spectacular first successes in orbit followed by commercial applications of great promise,

such as communication satellites, and will attain its zenith with the first landing of human beings on the surface of neighboring planets. This latter application lies near the limit of technical feasibility, because of the aforementioned restrictions of reliability. This first pioneering phase of experimental space flight is supposed to be finished within the next few years by the landing of men on the moon.

The demand for large, and probably in a rapid manner far more growing, transport-volumes which is to be expected within the near future will result from the following tasks in particular:

- . transportation in earth orbit of numerous scientific or commercial satellites and recovering them after their mission is over;
- . construction of large manned space stations in earth orbit for scientific or commercial use, and especially qualified as transit stations for the traffic between Earth and the Moon;
- . supply of these stations with all the goods necessary for their operation, moreover periodical exchange of the working crew and occasional transportation of visitors;
- . transportation of all men and goods needed for the construction and the current management of permanent Moon stations, from Earth to the Moon and back;
- . transport missions between mutual space stations in orbit and between such stations and unmanned satellites, for purposes such as supervision, recovering, rescue or repair work, change of orbital elements and so on. . . .

How did Sänger come to advocate so resolutely and so contrary to general opinion, a solution other than a pure ballistic one, more than forty years before the Moon landing? Thirteen days before his death, when he was asked by a radio interviewer of Berlin RIAS, how he had become involved in space research, Sänger answered:

Contact with spaceflight occurred for the first time at grammar school, when my physics teacher whose special favorite I was, gave me as a Christmas present a novel by Kurt Lasswitz, Aufzwei Planeten (On two planets). At that time I was about 16 years old. Naturally I read this novel with glowing cheeks, and thereafter dreamed of doing something like this in my own lifetime. I started to occupy myself seriously with spaceflight when—I think in 1924—the first publication on the subject by Hermann Oberth came into my hands. At that time I was studying at the Technische Hochschule in Vienna. I had to pass my examination on mechanics, and therefore, made a particular study of this and related subjects. Then I also started to check and recalculate in detail everything in the book of Oberth, and I became convinced that here was something that one could take up seriously. From that moment onwards I devoted myself more and more to these things, but there was the added difficulty that at the Technische Hochschule I was studying construction engineering, especially over and underground workings, bridge building, railway construction and so on. Thus I had to change the emphasis of my studies in the direction of aeronautics and the field of science that would favor aeronautic engineering.

Thus, Sänger really was led to his life's work through the influence of Hermann Oberth, as were so many of the second generation spaceflight engineers. However, right from the start he kept himself independent of Oberth's concrete program of realization. Was this because his ideas were formed by his studies of construction techniques (particularly those of the aviation industry) when he began systematically to occupy himself with spaceflight? How far was he influenced by the 'Viennese School' of space

research, represented by Valier or von Hoefft? Did Sänger's distinctive inclination towards systematic and complete study, his aversion to discontinuity of thought and unfounded principles of any kind--did these play any part in choosing his way? Maybe even he too was never quite sure about this. Perhaps all three factors motivated his way of project realization. However, there is no doubt that the force of his personal character must have been primarily responsible.

The idea of performing the first step into space using the atmosphere, with the aid of aerodynamically-dependent carrier equipment, is at least as old as the designs that use a purely ballistic method. During the 19th century ballistic rockets received considerable attention as weapons of war, with the experiments of the British Colonel Congreve, and in the publications of the French engineer, Montgery. At the same time, the French pyrotechnician, Ruggieri, demonstrated with animals the modern techniques of parachute landings from ballistic rockets on the "Champs de Mars," and in 1841 the first patent for an aircraft with hot water rocket propulsion was obtained by the Englishman Golightly.[†] A German project of 1847, in which a rocket plane would be driven by burning nitro-cellulose, is attributed to Werner von Siemens. In 1873 the Russian General Ivanin proposed to power aircraft with war rockets. Toward the end of the 19th century, Ganswindt in Berlin promulgated the idea of a "Weltenfahrzeug" (space-vehicle) driven by dynamite cartridges, after being carried to the upper limit of the atmosphere by a "Spezialflugzeug" (specially-designed aircraft). Further proposals for aircraft with reaction propulsion systems were known by the beginning of the 20th century--for instance those of Christopher Antonovitch in Petersburg (1910), René Lorin in Paris (1911), and Alexander Gorochoff in Moscow (1911). Auguste Picard, the later stratospheric and deep-sea research scientist, started his experiments in 1912 with a rocket-driven model aircraft, because originally he intended to realize his push into the stratosphere by means of rocket propulsion.

Sänger had heard about some of these attempts in 1924, but at this time it is not known if he was aware of the work of his compatriots Max Valier and Franz Edler von Hoeff, who were born one or two decades before him--even though he seems never to have had any personal contact with Valier.

During his studies at Innsbruck in 1914, Valier had driven a model plane by means of firework rockets--just as Picard did two years before. However, Valier was seriously engaged in problems of spaceflight again only after he had accomplished war service and studies of astronomy. In January 1924 he bought Oberth's book, Die Rakete zu den Planetenrauman. Immediately afterwards he contacted Oberth. This led to an extensive, still extant correspondence between these two pioneers of astronautics--a correspondence

[†]The Patent of Golightly is unrelated to an early caricature of a man flying a steam-rocket, published in most Western European countries--Ed.

soon joined by von Hoeffft and Hohmann. From these letters it is clear that the views of Oberth soon differed with those of Valier and von Hoeffft on the most suitable vehicle for the first steps to conquer space.

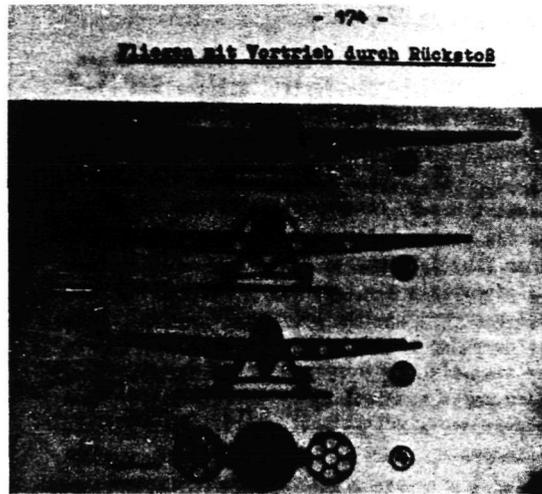
Oberth insisted upon a purely ballistic, multi-stage, liquid-propellant rocket, as proposed in his book. On the other hand, Valier resolutely supported the idea of an airplane with jet propulsion for the atmospheric phase of flight; however, he mistakenly called it a "rocket plane," not considering the difference between jet propulsion and true rocket propulsion operating too in empty space. He commented in 1925:

Consider, please, my idea of developing the spaceship from the JUNKERS aircraft. I imagine such aircraft initially provided with Blicharski's wing propeller and completely hermetically sealed, with normal air pressure inside. Then, there would be a way of developing an "intermediate type" between aircraft and spacecraft. Such vehicles would take off like aircraft. Thereafter at an altitude, where propeller engines fail to work, they would boost themselves with a single rocket impulse. Like the projectile of a long-distance cannon they would thereupon follow a very smooth ballistic trajectory over most of the flightpath, where the characteristics of a free flight trajectory are only slightly influenced by the effect of the airfoils. During the descent path, from reentry altitudes of 12,000 to 10,000 m, they would again proceed to the normal gliding flight of the aircraft. Their attainment of half orbital velocity together with the lifting effect of the airfoils would greatly increase their gliding path. Finally they would land just like ordinary aircraft. I cannot depart from the concept of a spaceship with wings, especially not from the "intermediate type," a rocket plane which daily appears to me to have greater chances of realization. A rocket plane using gasoline as fuel and precompressed air as oxidizer could operate with the oxygen of the atmosphere still in altitudes of 15 to 20 km and attain burnout velocities of 1400 to 1500 m/s, in my opinion. In this way one could eliminate the difficulties associated with liquid oxygen carried on board, but had to deal on the whole with technical matters already rather well known.

In the spring of 1927, during a lecture to the "Wissenschaftliche Gesellschaft für Luftfahrt" (WGL) in Berlin, Valier described a program for gradually transforming a three-engined JUNKERS G-23 aircraft into a spacecraft. (Figure 2) He commented on this:

At first the JUNKERS G-23 will be equipped with two rocket engines in the airfoils. If jet propulsion proves to be successful within the first tests in flight, a true rocket plane with an auxiliary reciprocating engine retained for safety could represent the next transfer stage of development. First there will be four, and later on six rocket engines in the wings. When sufficient experience has been gained, the pure rocket plane, with small wings and pressure cabin suitable for intercontinental flights in the stratosphere, can be built. The final stage is to develop a rocket ship which will ascend vertically from a launching tower, and which will be developed into the spaceship at last.

Dr. Franz von Hoeffft's projects were still different from those of Oberth and Valier. He commented on this during a lecture given to the "Verein deutschösterreichischer Ingenieure" in Vienna on 9 February 1928: "I contemplated every possibility, from the exhaust of compressed air to that of ether atoms and electrons accelerated by zero-point energy of ether, or by the energy of nuclear fission, until in 1924, I read Oberth's



(1)
Die 2 seitl. Moto-
ren sind durch 2
Raketentoren +)
ersetzt.

(2)
4 Raketentoren
und kleinere Flü-
gel

(3)
6 Rak.-Motoren,
noch kleinere
Flügel und Druck-
kabine

(4)
Raketenschiff

Fig. 2

Valier's Concept of a Space Aircraft developed from a Junkers G-23

- (1. The two side engines are replaced by "rocket" motors;
- (2. Plane with four "rocket" motors and smaller wing-span;
- (3. With six "rocket" motors, even smaller wings and a pressure-cabin;
- (4. Definite spaceship.)

book . . . and realized the possibility of achieving the necessary cosmic velocities by using as fuel liquid hydrocarbons presently available."

He then proposed on the staging principle to join jet planes, which were shaped like winged lifting bodies, so that each upper stage became the payload of the lower ones, using a vertical ascent. In this way, with standardized units, he combined different models for different missions. From his designs he first described the RH 3 carrier system, a two-stage combination of three tons gross weight, with which the payload, a camera, should be put into an orbit around the Moon, and after taking photographs of the far side, complete the orbital ellipse and land by parachute on the Earth. A further system (RH 5) (Figure 3) with a gross weight of 30 tons, would take off and land like a hydroplane and was intended as a manned earth-orbiting craft, or as the upper stage of a manned multi-stage spacecraft. But strangely, von Hoefft had apparently overlooked in his space travel plans the establishment of the "orbiting space station," which was claimed by his friend Guido von Pirquet according to his perception of the "cosmonautic paradox."

From present points of view, it seems they had not such bad ideas, all these representatives of the second generation of space pioneers and their predecessors. They overlooked only the fact that they could not proceed in the way of lone wolves with hobby tool and casual work if they wanted to achieve a task that to be realized in a later period demanded a well organized effort involving billions of working hours. Nevertheless,

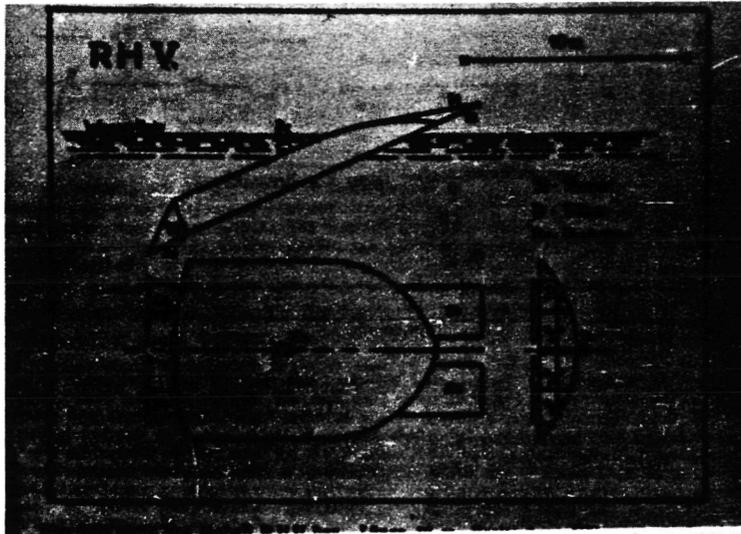


Fig. 3

Franz von Hoeffft's scheme for a rocket-powered lifting body of 30 tons weight, capable of taking off and landing like an hydroplane--the upper stage was to have orbital capability.

their creative imagination and their untroubled optimism provided almost all those minute construction elements which only had to be assembled correctly.

One year before , von Hoeffft and Sänger made personal contact. Forty years later, von Pirquet wrote about this meeting to Irene Sänger-Bredt:

In the year 1927 Hoeffft had the idea of testing a model rocket in the wind tunnel at the Aerodynamic Institute of the Technische Hochschule in Vienna. This model based on ideas of von Hoeffft was designed in detail by me. Of course, the measurements produced satisfactory results, but had no immediate practicable application at that time. However, we heard that a young assistant at the Institute was ardently interested in rocket problems, and so I learned for the first time of Eugen Sänger.

In a letter dated March 24, 1928 and still saved by Guido von Pirquet, Sänger applied for admission to the "Wissenschaftliche Gesellschaft für Höhenforschung" (Scientific Society for High Altitude Research) (von Hoeffft was the secretary of this society at that time):

Honorable Mr. Engineer:

With reference to the detailed consultation with Dr. von Hoeffft, I should like to beg the favor of accepting my application as a full member of the Wissenschaftliche Gesellschaft für Höhenforschung and, as far as possible, of informing me of arrangements, lectures, etc. of your society. Especially I shall be at your disposal for the preliminary tests planned at the Aerodynamic Institute, as already discussed with Dr. Hoeffft.

This letter shows a note handwritten by von Pirquet, and answered on March 28, together with an invitation to the lecture of Dr. von Hoeffft on April 4. However, real cooperation between Hoeffft, von Pirquet, and Sänger did not occur, as von Pirquet mentioned. Sänger was very much absorbed by his studies and duties as scientific assistant at the college. Moreover, he probably realized quite early that the most difficult stage on the way of realizing spaceflight did not concern the aerodynamics of the airframe, but its propulsion device. Therefore, he devoted most of his life-work to this problem.⁺

Among the documents left by Sänger were found several notes, written at different times and entitled "Lebensprogramm" (Life program). In these he formulated the aims of each of his diverse interests, and carefully noted points in the program already reached. One of the earliest of these programs probably originated between 1929 and 1931. Beneath the caption "Constructions" he detailed the following developments: "Stratosphere plane--spacecraft--space station--interplanetary spaceship--interstellar spaceship." Below the heading "writings, main works" appears: "Stratosphere flight, cosmic-technique--bio-technique."

From these notes it can clearly be seen how Sanger progressed systematically both as an engineer and a research scientist. He never disregarded the overall interdependence and the final aim, even when he apparently dealt only with detail. From the beginning he understood spaceflight as a manned enterprise. Therefore, he considered the realization of his first project, the stratosphere plane, only as a very first step on the way to realize space flight. Nevertheless, he did not want to omit this stage as in fact it happened during the subsequent development. Among the fragments of the scripts mentioned in Sänger's first "Lebensprogramm" was a draft on "Rocketflight technique." The front page bears the supplementary title: "Dissertation zur Erlangung der Würde eines Doktors der Technischen, Wissenschaften, vorgelest der Technischen Hochschule in Wien in Sommer 1929 von Eugene Sanger."⁺⁺ (Investigation of energetic problems in connection with high altitude flights with rocket planes.) The draft was divided into four chapters: General considerations; Ascent; Free flight; Descent. In the introduction, Sänger observed:

The purpose of this work is to give a synopsis of all theoretical and practical knowledge to date in the field of high altitude aviation and cosmonautics. This knowledge will be presented in a practicable way appropriate to technical working and research methods, and will be supplemented by my own investigations.

⁺However, in this "Silver Bird Story" the report on Sänger's activities and successes in developing liquid rocket engines will be excluded, because they are treated already in other proceedings.

⁺⁺Dissertation for taking the degree of a doctor of technical sciences, submitted to the Technical Highschool in Vienna by Eugen Sänger, in the summer of 1928.

The investigation consists of a critical, purely theoretical comparison of the different ways of advancing into space; it calculates the most economical and safest method (aerospace transporter - space station - space ship) and supplies a complete theory of this method. As far as possible, the concept has been arranged in a manner that allows an alternate use of chemical or electrical rocket engines; complete, general solutions of problems shall be given first, followed by calculations using specific data . . . The conquest of space with minimum energy display will proceed according to the following principles:

1. Transport to the altitude of a space station by means of the special aerospace-plane; further advances into space will use modified spacecraft.
2. Ascent of the aerospace-plane according to the principle of minimum energy expenditure.
3. Descent of the craft as a glider, without energy expenditure. (Already here, Sänger explicitly provided for the application of Einstein's theory of relativity to the phase of flight in outer space.)

In his last RIAS radio interview, Sänger reported on the fate of this draft for his doctoral dissertation, which he wrote immediately after passing his second state-examination (Staatsprüfung) on June 29, 1929: "I wished to obtain my doctoral degree some years later in the field of spaceflight. But then my good old teacher Katzmayr, with whom I studied aviation, told me: 'It is much more practical to prepare for your doctoral examination in a classical field--the event will then pass silently across the stage. If you try today to take your doctor degree in spaceflight, you will most probably be an old man with a long beard before you have succeeded in obtaining your doctorate.'" So Sänger took his doctor degree on July 5, 1929--not on the "aerospace plane," but with a paper entitled: "Die Statik des Vielholmig-Parallel-stegisen, ganz und halbfreitragenden, Mittelbar und Unmittelbar Belasteten Fachwerk flugels." (On the statistics of multi-sparred parallel ridged, total-or-half-cantilever, indirectly or directly loaded panelled wings.)

Sänger mentioned his project for a semi-ballistic rocketplane for flight at very great altitudes in public only at the beginning of February 1933, in an essay "On Construction Principles and Performances of Rocket-Planes." This essay appeared in the Deutschosterreichische Tages-Zeitung.⁺ Sänger proposed here an aircraft of a relatively conventional construction type (Figure 4), with liquid rocket-propulsion (Petrol + LOX) to reach velocities even up to 10,000 km/h (about Mach 10), and flight altitudes between 60 and 70 km. More than 23 years later, and 28 months before Sänger's death on October 11, 1961, Robert M. White reached a ceiling of 65.9 km in the American rocket research plane NAA X-15, and thus the altitude imagined by Sänger. The realization of the visionary velocity limit of Mach 10 for rocket-planes has not been attained to date. The highest flight velocity was reached by a redesigned and improved X-15 on October 4, 1967 and came to Mach 6.7.

⁺German-Austrian Daily Paper.

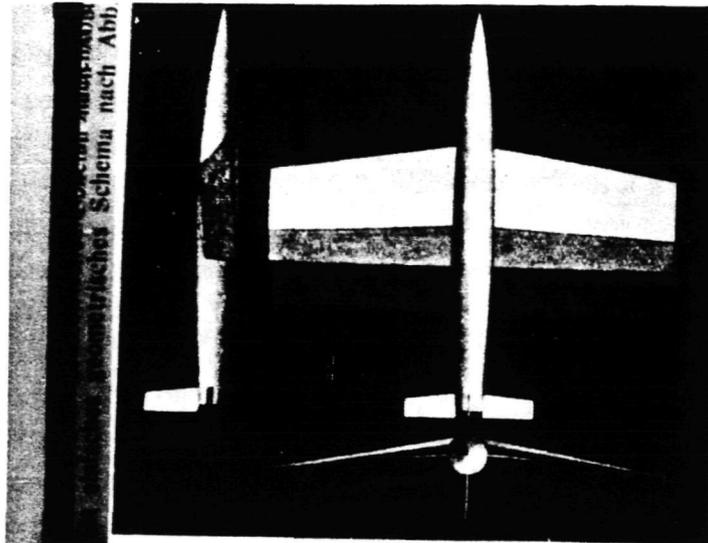


Fig. 4
 First Concept of a Space Plane Published
 by Eugen Sänger in 1933

In 1933, Sänger wrote in detail about the shape of the airframe of his planned rocket-plane: "One will choose for the body the shape of a projectile, pointed in front and blunt at the back-end to give room for the exhaust velocity. The profile of the wings has to be as thin as possible, with sharp leading edges. The wing span can then be kept low because of the negligible resistance of the wing-edges." Regarding flight performance, he observed: "At first sight their limit is given merely by the possible fuel load. It is this restricted fuel load which prevents these planes from increasing their flight velocity up to the orbital velocity of about 29,000 km per hour when the centrifugal force of the curved trajectory is equal to the weight of the plane; the wings then don't need to provide lift anymore, and the plane circles the Earth continuously, like a moon in a free inertial orbit without needing any driving power."

In the preface to his book Raketenflugtechnik, Sänger discussed his project still more clearly and methodically:

In a more limited sense the project deals with that of rocket-flight in the upper layers of the stratosphere, with such velocity that the forces of inertia of the orbit contribute to the lifting effect. This kind of rocket flight is the following fundamental step in the phase of development from the troposphere-flight established during the last thirty years. It is the preliminary stage of space flight, the most powerful technical problem of our time. This preliminary stage, and the development to the construction of an orbiting space station of the Earth, is the most noble aim of rocket flight, though its realization still lies in the future."

However, Sänger's Raketenflugtechnik, regarded today as the first real textbook on this subject in the history of rocket flight engineering, was nearly not published at

all. In the course of the summer of 1932, eleven publishers, among them Springer, Kroner and VOT edition, rejected the manuscript; a small publishing house in Berlin imposed limited financial conditions. Finally Oldenbourg in Munich; which had also published Oberth's Hohmann's, and Valier's books, agreed to print it if Sänger contributed RM 2000 towards the printing costs and purchased the first 50 copies of the book. In those days, Sänger could raise the money only through great personal sacrifices, and he could only completely pay off his debts in 1936 after he had been engaged by the "Deutsche Versuchsanstalt für Luftfahrt" (DVL, German Research Institute for Aviation) as technical director of their rocket projects.

Still, during the summer of 1933, Sänger outlined the development and testing program of his rocket plane project in the journal Flug. One year later, in a special edition of the same journal, he calculated the possible flight performance and flight trajectories assuming concrete technical data for a fuselage with circular cone-shaped nose, flat, extremely thin wings, a mean lift-drag ratio of 5, and an effective exhaust velocity of 3700 m/s. For a mass ratio G/G_0 of 0.16, for example, he calculated a burnout velocity of about Mach 13, a steady flight velocity of Mach 3.5 at an altitude of 40 to 60 km, and a flight range of 5000 km. He commented: "Accordingly, the most important task of the constructor has to be the achievement of an adequate range by severe decreases of empty weight, by the most sophisticated aerodynamic shapes, and by the highest possible exhaust velocity of the engine. But even with the not unrealistic assumptions so far used, a rocket plane with a non-stop range of 4000 to 5000 km can be confidently expected."

During the years that followed, however, Sänger was not able to devote much time to his project. He started from the principle of developing first the propulsion system before concerning himself with the construction and testing of the airframe. Experiments which he carried out as assistant at the Technische Hochschule in Vienna up to the end of 1934, on his own responsibility in the so-called "Bauhof" of the Institute für Baustoffkunde (Institute for research into building materials), served exclusively to spur development of a liquid propellant rocket combustion chamber with regenerative cooling. With his model engines he realized exhaust velocities up to 3000 m/s as is well known. The year 1935 passed with laborious and unloved work as a temporary engineer at a Viennese Construction Company, while he applied for employment at rocket research institutes all over the world. On February 1, 1936, Sänger entered a contract with the Deutsch Versuchsanstalt für Luftfahrt (DVL, German Research Establishment for Aviation) in Berlin-Adlershof. This committed him to prepare a design for a Research Institute for rocket techniques and to elaborate a research program for liquid propellant rocket engines. The building of this institute started in February 1937, at Trauen on the Lüneburg Heath.

Even these large scale research facilities, however, subordinate to the Luftfahrtforschungsanstalt (Research Institute for Aviation), Hermann Göring (LFA), designed by Sänger and especially built for him, were exclusively determined for research

and testing of propulsion engines. Sänger worked here from August 1937 to August 1942. Nevertheless, besides his development work on a 100 ton liquid propellant rocket engine, Sänger still found time for theoretical studies on his aerospace transporter. In May 1938 his paper on the "Gaskinetik Schrgro Ber Fluggeschlindigkelten" (Gas Kinetics of Very High Flight Velocities) appeared as a research report of the "Zentrale für Wissenschaftliches Berichtswesen" (Central Office for Scientific Reports) in Berlin-Adlershof (ZWB). In this study he determined for the first time the formula and numerical values for aerodynamic forces affecting vehicles at altitudes where the atmosphere can no longer be regarded as a continuous medium. At the California Institute of Technology, H.S. Tsien referred to this study already at the end of 1946 in his report "Superaerodynamics, Mechanics of Rarefied Gases" (Journ. Sci. XIII, No. 12, page 653, 1946); Sänger's study had influenced subsequent American work in the field of aerodynamics of rarefied gaseous media. It was translated into English by NACA in May 1950, and published as Technical Memorandum No. 1270. Incidentally, the study "Gaskinetik sehr hoher Fluggeschwindigkeiten" which began in the Autumn of 1937, also signified the start of Sänger's collaboration with Irene Bredt, a collaboration lasting over 26 years, up to Sänger's death.

In October 1938, according to Sänger's outlines, the construction of a steel model (scale 1:20) of a plano-convex supersonic glider plane (Figure 5) was set about. Its optimal lift-drag-ratio with an assumed landing velocity of Mach 0.12, and with a

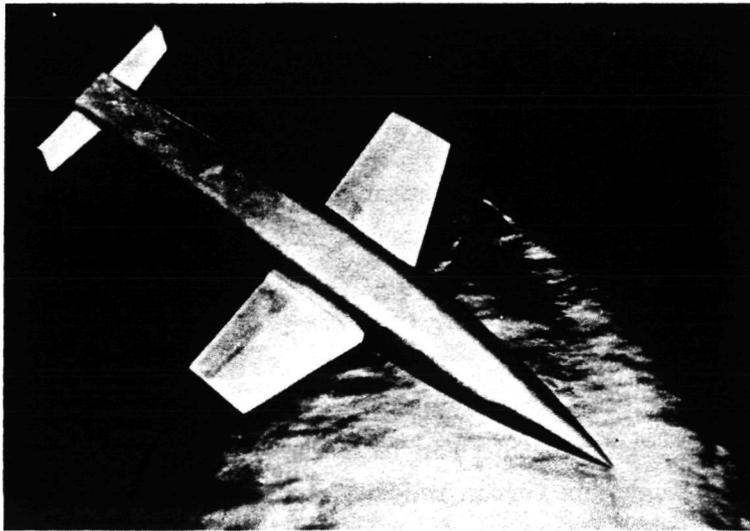


Fig. 5
Wind Tunnel Model of Sänger's Supersonic Glider,
Tested in 1938

5° angle of incidence, was measured as 7.75 in the subsonic wind tunnel. In comparison, the optimal inverse glide ratio of the American glider M-2 was measured as 3.2, with a 12° angle of incidence and a landing velocity of 133 km/h (Mach 0.11). In the supersonic flow region at low flight altitudes the optimal lift-drag ratio was calculated as 6.4 according to Newtons' Theory of Inelastic Collisions. In comparison, the best reciprocal glide ratios realized until now lie between 2 and 3 in the supersonic region, and at 4 in the hypersonic region. To be sure, the reciprocal glide ratios of Sänger's model calculated, assuming free molecule flow (i.e., very great altitudes), proved to be considerably less favorable than those in the region of continuous flow at lower altitudes, but on account of the low absolute values of lift and drag compared with the other forces acting on the craft in this region, they were of no practical importance for computing the flight-path. On the basis of these research results Sänger applied for a patent for his proposed airframe type with half ogival-shaped fuselage, nose, and wedged-shaped wing-profile. Because of its dome-shaped body profile and flat bottom, his assistants nicknamed it "flat-iron." Later on, the German Reichspatent No. 411/42 concerning "Gliding bodies for flight velocities above Mach 5" was granted on June 3, 1942, effective from April 22, 1939.

To save fuel weight, Sänger proposed accelerating his "Silver Bird" before lift-off to a velocity of about 500 m/s by means of a rocket driven launching sled sliding on a straight, horizontal, steel rail several kilometers in length. Thus, it became necessary to obtain knowledge about the amount of dynamical friction between the sliding surface and the upper face of the rail, considering the very high sliding velocities and the subsequent high negative accelerations of braking, for he had to ensure a reliable dynamic floatation of the sliding surfaces by choosing a suitable geometry of the lubricating gap, and a qualified lubricant. For the assumed extreme operating conditions there were no reference data in the literature at that time. Some even feared that it would be impossible to control the frictional heat and consequently the realization of the whole catapult arrangement became questionable. Therefore, Sänger asked his assistant, Irene Bredt, to collect proven values for dynamical friction and lubricating-procedures from qualified experts, and to study adequate research plants everywhere. But even Föttinger and Vogelpohl were not yet engaged in the investigation of sliding velocities of several hundred meters per second, although they worked as professors at the "Institut für Technische Strömungsforschung" (Institute for Technical Flow Research) at the "TH Berlin," at that time the most important German research institution in this specific field. On their test stands, consisting only of rotating elements, the highest sliding velocity obtainable was limited to a fraction of the required values, by the highest tolerable peripheral velocity, i.e., the highest practicable speed of rotation. Again Sänger had a resourceful thought. He suggested a stainless steel bullet ("German ss-Geschob") to be fired with a velocity of about 800 m/s, from a military carbine rifle into the spirally

curved entrance of a circular, closed, and lubricated steel groove with a U-shaped cross section. During this experiment the bullet would pass through all velocity-ranges down to complete rest (Fig. 6). These high velocity sliding-friction experiments began on June 2, 1939, and demonstrated that the construction of sliding faces for velocities up to 500 m/s was possible on a carefully finished and lubricated rail.

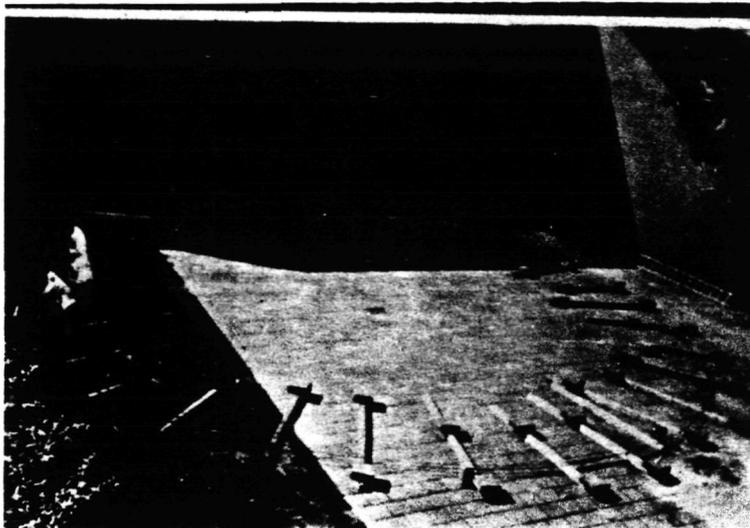


Fig. 6
Dynamical Friction Test Bed at Trauen .
The installation consists of a military carbine and a closed circular sliding track.

A rocket-sled constructed according to Sänger's plan was used 15 years later by the American air medicine officer, Dr. John P. Stapp, in experiments on the effects of short, very high accelerations on the human body. These experiments in the course of which Dr. Stapp endured accelerations up to 25 g, met a basic condition for the feasibility of manned space flight.

World War II burst out a few weeks after the successful sliding-friction experiments on the Trauen test ground. For the small staff of the rocket-research establishment on the quiet Lüneburg Heath, September 1, 1939, meant a sudden awakening from bold, romantic dreams. Sänger, with his own shy charm and his glowing persuasive power, had succeeded in inspiring all his team with great enthusiasm for himself and for his plans-- from the head of the testing stand, (a typical representative of the Austrian aristocracy) down to the youngest canteen-helper (a pretty North German peasant girl). This small crew, spending together working hours as well as free time in the remote Oertze valley, and living rather isolated from other people and the general events of Germany at that time, had created their own separate dream world. Recognizing no differences of social origin

they spent their free time together walking along the traces of the popular heath through the fen-country in dreaming twilight, listening to wood-pigeons and heath cocks, gathering mushrooms, devouring science fiction stories of Hans Dominik, and tasting red wine in tin cups, if they did not prefer to work voluntary overtime in order to accelerate the development of the silver bird. Everyone was happy to contribute his own personal effort to a work considered the realization of a dream of mankind. Even the driver of our service car earnestly hoped to pass his pilot examination and be able one day to navigate the first spaceship.

Now, suddenly, there existed "priority schedules," mobilization, calling up orders and, soon, a general shortage of material. The continuation of the research work and experiments at the "Flugzeugprufstelle," the camouflage name for the rocket testing stands at Trauen, appeared to be in danger for these projects were unsuitable for immediate military use. To be allowed to continue work at all, the military importance of the current work had to be demonstrated and auxiliary projects had to be worked out--projects that promised military application within a reasonable short time. One such project concerned a fighter plane with ram jet propulsion, that claimed more and more priority during the course of the war. Further, the results of the research work on Sanger's silver bird project, which had just been summarized in a report with the heading "Rocket Spaceplane," had now to appear in a new dress if the project wished to survive. Thus, they had to serve as a rocket bomber project. The good old "Flat Iron" became "Rabo" (anacronym for Raketenbomber) in the talks and thoughts of the people working on it.

This "Rabo" report subsequently had a somewhat adventurous fate. "Enriched" with some chapters on the trajectories of bombs, impact ballistics, and offense measures, the elaboration of the original project report could for the time be continued. This project was mainly concerned with an Earth-orbiting, single-stage rocket plane with a launch weight of 100 tons (90 tons of propellant and payload) as well as a propulsion engine for the combustion of highly efficient fuels with liquid oxygen in a combustion chamber at a pressure of 100 atm. and 100 tons thrust (Figure 7). The maximum flight performance of this plane, (with the assumption of semiballistic trajectories and of a specific impulse of 400 sec.) was calculated as follows:

1. flight velocities at the end of the power flight phase of about 8000 m/s, corresponding to the necessary thrust for reaching orbital velocity with a one ton payload;
2. flight altitudes in the ballistic section of the flight path up to 300 km;
3. loading capacities for a transport to the antipodal point of the Earth (20,000 km) up to 8 tons;
4. flight distances up to a single Earth orbit with a payload of 4 tons, or up to two and a half orbits with a one ton payload.

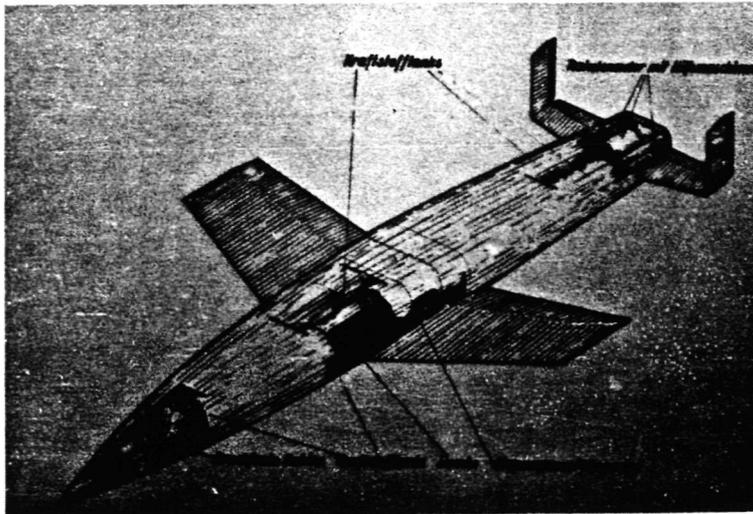


Fig. 7
 Concept of Sänger's Orbiting Rocket Plane
 with 100 Tons Gross Weight

These flight performance data became possible by the application of a semi-ballistic flight technique proposed by Sänger. This technique was later on known as "Rikoschettier" or "Hupf" (skipping) flight, where the aeroplane ricocheted from the denser layers of the atmosphere like a stone flung at a flat angle across the surface of water. In this way gliding flight paths could be obtained which were several times the range obtained with mere aerodynamic descent (Figure 8).

The manuscript with a new heading: "On a rocket propulsion engine for long distance bombers, ("Ubereinen Raketenantrieb für Fernbomber") was completed in 1941 and submitted for approval on December 3, 1941. But it by no means received the same enthusiastic approval from the authorities in the Reichsluftfahrtministerium (State Ministry for Aviation) as it later received from Eastern and Western countries. On March 17, 1942, the printing of the report was rejected outright by the Luftfahrtforschungsanstalt (Research Institute for Aviation) Hermann Goring (LFA), in the first instance. Sänger, who in his private life was one of the most peace loving of persons, was unprepared for compromise in his technical projects. With that refusal therefore, a period of bitter argument ensued. Because of a fuel shortage, as well as objective and personal differences between Sänger and his immediate superior in the LFA, Sänger and his team had to stop their work on the development of the 100-ton rocket motor in the autumn of 1942. However, Sänger and his closest colleagues were allowed to continue their series of tests on ram jet propulsion that had just started at the Deutsch Forschungsanstalt für Segelflug (German Research Institute for Gliding Flight) (DFS) at Ainring.

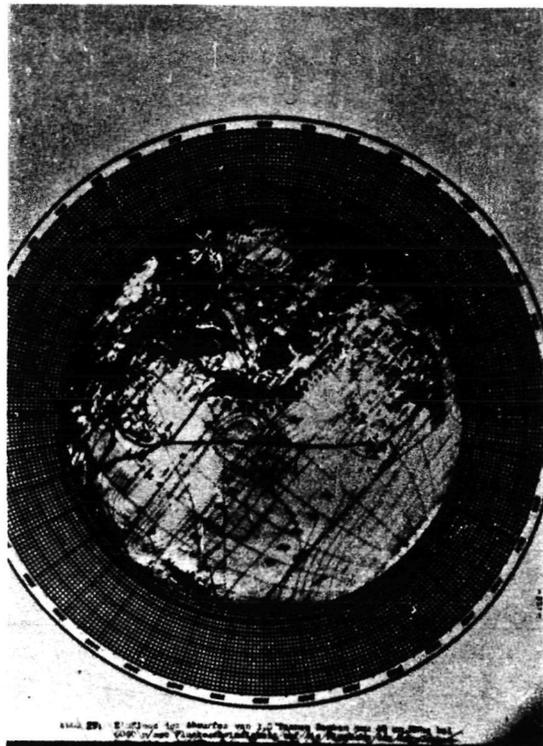


Fig. 8
 Skip Flight Trajectory of Sänger's Aerospace Transporter,
 Assuming 7000 m/s Burnout Velocity, 400 s Specific
 Impulse and 3.8 Tons Payload

Works on projects adapted to the immediate requirements of war-time, such as the development of a ram jet fighter, an auxiliary ram jet propulsion engine for thrust increase of the ME 262, and related projects, as well as the external conditions of life, became more and more unbearable, and did not allow any detailed engagement with the problems of the space transporter during the last years of the war. However, with the support of Professor Walter Georglii, Sänger succeeded at least in publishing the report on a rocket propulsion engine for long distance bombers--even though shortened to half of its original size--as UM 3538, "secret command report" of German Aviation Research. The official approval for printing reached Sänger on his 39th birthday, September 22, 1944.

Events followed with great rapidity: total war, shifting of the work teams into emergency accommodations in the surrounding villages, collapse of the German Reich, marching in of the Allied Forces, operation "Paperclip," and the emigration of Eugen Sänger and Irene Bredt to Paris as consulting engineers of the Arsenal de l'Aeronautique. Subsequent collaboration with French officials, engineers, and workers Sänger found agreeable in both technical and human relationships: one reason being an

early and generous grant of freedom of publishing for Sänger and his collaborators. However, the strenuous reconstruction of the French aviation industry during the first year after the war naturally allowed no scope for far-reaching and expensive projects such as an orbiting aerospace vehicle. Besides, the frequent changes of Government prior to the accession to power of General de Gaulle by no means encouraged continuity of current projects. For example, one evening we would convince Government representatives by a successful experiment of the suitability of a launching rocket with an alcohol-water mixture as fuel, only to be told next morning that a new government had again cancelled all liquid rocket projects.

So the project of the aerospace transporter rested in the refrigerator of world politics. Meantime, there were small encouragements such as the collaboration on the design of the French ram jet research plane GRIFFON, or even the news of the successful first flight of the American rocket research plane BELL-XS-1, that brought new confidence to Sänger after years of frustration. Moreover, with the resumption of international contacts which became feasible again, Sänger was pleasantly surprised to find that his early Viennese work had not been forgotten by the world, and that he had won most of his new friends with the very project that had so far caused him the most annoyance in his home country.

Of course, some of the 70 distributed copies of the secret report on rocket propulsion for long distance bombers had fallen intact into the hands of the Allies, with the conquest of Berlin and Dessau. They had been brought to the notice of rocket research scientists and engineers in the various nations. Some of these experts, like Alexandre Ananoff, Theodore von Kármán, Frank Malina, and Joseph Stemmer, were already in contact with Sänger before the war; others, like Val Cleaver, Arthur Clarke, Fred Durant, Andrew Haley, Leslie Shepherd, and Teofilo Tabanera, were congenial with Sänger and recognized at once in the rocket bomber project the first phase of the realization of spaceflight.

Immediately after the end of the war in most of the highly industrialized countries, private and national societies had been formed for the furtherance of space flight ideas. Some of these national societies met in Paris in the Autumn of 1950, and decided on the foundation of an international organization for the advancement of peaceful space flight. They selected Sänger as chairman of preliminary commission and, in September 1951, in London, as first president of the newly founded International Astronautical Federation (IAF).

Meantime, Sänger had been able to publish some of the chapters which had been deleted from his report, such as, in 1949, the "Kinematics of Spaceflight" in Interavia, and in 1951 a 95 page "Atlas of Selected Trajectories of Rocket Planes to the Spacestation and Back," in the Research Series of the Northwest German Society for Space Research.

On April 19, 1952, Lt. Gen. Walter Dornberger, the former Commander of the Experimental Station for Rocket Weapons at Peenemünde,⁺ called on Sänger in Paris. He came as a representative of the American Bell Aircraft Company to invite Sänger and his collaborator, who in the meantime had become his wife, to contribute to a rocket plane project for which Bell Aircraft hoped to get an order for development by the American government following Bell's success with the research plane X-1. In spite of the tempting prospects, Sänger and his wife chose not to accept this offer, partly for family reasons, and partly because most Sänger's French friends dissuaded him from his purpose, for they feared that Sänger would not feel happy for long in the rough, impersonal climate of American industries—especially as the receipt of a U.S. government order to Bell was only an indecisive promise in the first instance, something to be decided only after Sänger had joined the firm. Whether Sänger's decision to stay in Europe then was right or wrong, whether moving to the United States of America could have changed anything in the destiny of the space transporter, must remain unanswered. The friendship between Walter Dornberger and Eugen Sänger, however was not tarnished by this refusal. The day in Spring 1961 when Dornberger invited him to the Bell Aerosystems Company at Buffalo to show him proudly the regeneratively cooled liquid hydrogen-oxygen rocket motors with bell-shaped short nozzles (Figure 9) developed according to the Sänger-patents, was certainly for Sänger one of the happiest days of his life.

⁺"Versuchsanstalt für Raketenwaffen".

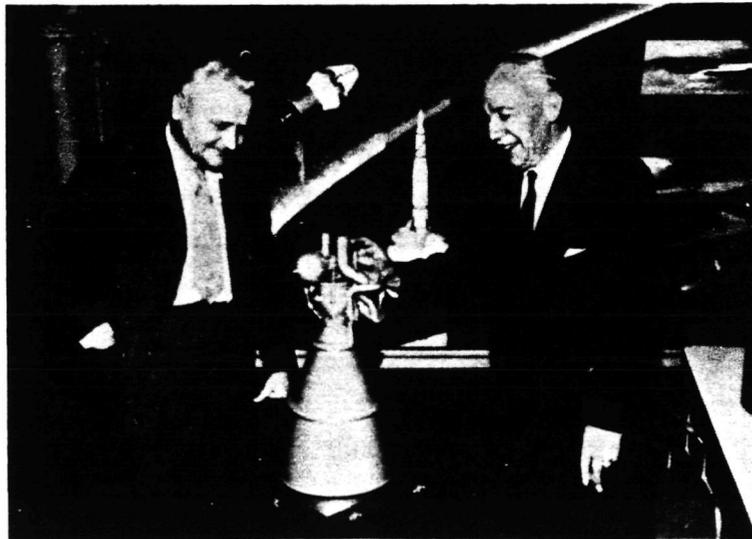


Fig. 9
Eugen Sänger and Walter Dornberger with a Model of LO_2/LH_2 Rocket Engine
Built According to Sänger's Patents by Bell Aerosystems Company

After the war, not only the West but also the East held offers of employment ready for Sänger, even if they appeared to be somewhat more adventurous than the sober offer of American industry. Sänger and his wife heard about this only through French Boulevard papers and discrete warnings by the French Security Service in September 1948, when the whole action was long over. It seems that at least one copy of the captured secret report on rocket propulsion engine for long distance bombers had reached the USSR, and had been submitted to Stalin. This copy gave rise to the following note from the Russian Chief of Government:

The Council of Ministers of the USSR decrees that a government commission shall be formed for the purpose of directing and coordinating scientific research in the field of aviation problems, with special relation to manned rocket planes and to the Sänger project.

The Commission shall be composed of the following persons:

Colonel General Comradé Serov (Chairman)
Engineer Lieutenant-Colonel Comrade Tokayev (Deputy head)
Member of the Academy Comrade Keldisch (Member)
Professor Comrade Kischkin (Member)

The Commission shall depart immediately for Germany and undertake preparations for work. A complete report of its activities and achievements shall be submitted to the Council of Ministers on August 1, 1947.

Marshal of the Soviet-Union Comrade Sokolovsky is hereby asked to support the Commission in every respect.

Moscow, the Kremlin, April 17, 1947, Stalin.

After having searched for Sänger and Irene Bredt in vain for several months throughout Germany and Austria, Colonel Tokayev and Stalin's son Vassilij, who accompanied Tokayev, learned that both of the wanted persons were in France. However, before attempting to make contact, Tokayev took the opportunity to escape and ask for political assylum in the West in September 1948. He settled in England where he published a book Stalin Means War. From a copy of his book, the Sängers eventually learned the details of this venture. In connection with these events, the fact seems impressive that the Russians obviously adhered faithfully to their original plans in manned space flight and pursued projects which were influenced by the ideas of Valier and Sänger, namely:

- . conquest of the Moon and the planets next to Earth by recoverable single stage or at most, two stage space vehicles which started from Earth orbital space stations and returned to them;
- . construction and current supply of the orbital space stations by aerospace transporters.

It was obvious that Sänger, who had remained a sensible realist despite his ambitious technical plans, started now to worry about whether his projects, despite their technical feasibility, might after all be realized, considering the existing

political-economical situation. He asked himself how large working capacities could be made available in favor of a concrete technical development program in order that its realization was guaranteed as far as scientific and technological aspects allowed. This led, in 1951, to Sänger's study, "What are the costs of Spaceflight?" in which he tried to extrapolate from experience at that time, the probable costs of development of representative spaceflight projects such as those of the first moonshot, an antipodal rocket-plane, a manned space station, or a manned orbital flight around Mars. A diagram from this first investigation (Figure 10), subsequently extended, shows the consumption of working hours for development as a function of the necessary engine exhaust velocity for different missions according to the technical level of development. The diagram shows clearly for the first time that, while the discussed projects were within the capacity of great nations, they surpass by far the capabilities of single smaller nations or even private industries. Six years before the successful launch of a first artificial Earth satellite, Sänger knew that spaceflight, even in the neighborhood of the Earth, belonged to modern large scale techniques, where decisions, because of the high expenditure of development, must move more or less completely from the economic sphere of private



Fig. 10
 Estimation of development costs for different space flight projects published by Eugen Sänger. The graph shows the expense in working hours as a function of the effective exhaust velocity attained by the appertaining rocket engines.

enterprise into the region of political power. Subsequently, he tried from that time to interest international societies in the project of the aerospace transporter, and decided to confine his own immediate research work to smaller, separate parts of the general project. He did so because he recognized not only the necessity of international cooperation, but also that the partners in such a community of work would need to contribute, besides money, sufficient technical "knowhow" to effectively participate in the development.

His appointment to Stuttgart from the summer of 1954, with the task of building and directing an Institute for Research in the Boundary Region Between Aeronautics and Spaceflight, allowed Sänger to restart again some modest practical work of his own. He concentrated on preliminary work for the development of suitable auxiliary launching equipment and the main propulsion engines for the aerospace transporter. Thus he began with a project for a ground fixed launching sled propelled by a steam rocket (Figure 11), following this with a liquid rocket engine mixing air in the exhaust jet according to ramjet principles. He also worked on an alternative solution for the first stage of a multiple stage transporter, namely the project of a supersonic ram jet engine. Apart from this he encouraged systematic basic research into different fields which might contribute to further development of the whole project. He commented on this: "Though design, construction, and use of aerospace vehicles in the end will crown all aerospace research, they in themselves represent rather secondary problems within the scientific research

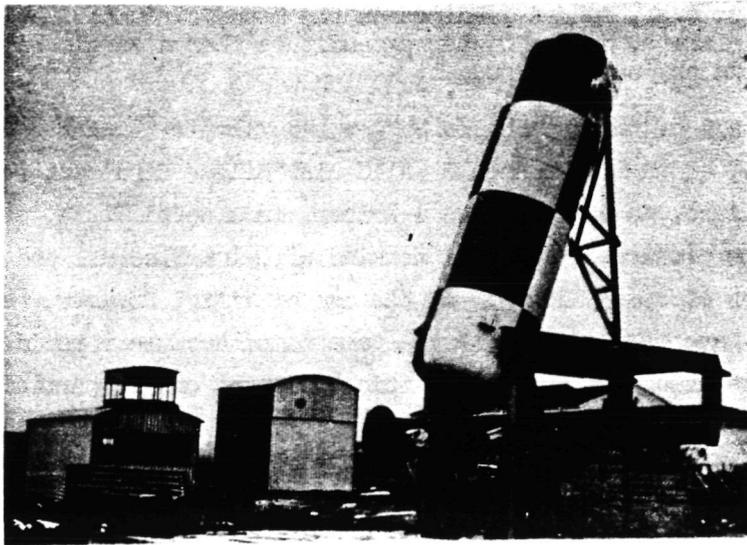


Fig. 11
Steam Rocket Test Stand of the German "Research Institute for the Physics
of Jet Propulsion" (FPS) at Echterdingen-Stuttgart

work, since clarification of basic problems must precede these dominant routine engineering tasks."

Sänger also recognized that the necessity for international cooperation in the development of large scale technical projects was not dictated only by economic factors. In a paper published in 1954, "Research work within the field between Aeronautics and Astronautics," he explained:

The basic idea of the International Astronautical Federation, and its most noble vocation is to let spaceflight become an aim for all mankind.

The innermost motives for this aspiration might be primarily ethical or might be founded in human enthusiasm for a scientific technical problem with the fascinating power of space flight that allows one to forget all insignificant daily worries and oppositions beyond this immense task of mankind. But there are also a number of very sober, objective reasons for spaceflight to be realized only on an international basis.

One compelling reason for international cooperation in spaceflight activities appears clearly in space research, because a single nation may have insufficient intellectual capacity to meet the wide ranging scope of scientific and technical problems involved. . . . If we are obliged to internationalize space research in consequence of our limited intellectual capacities, then this argument applies just as much to the field of space technology, because of our limited national resources. It has been pointed out several times that space flight with characteristic flight velocities up to about 13 km/s, such as missions with long-distance rocket planes, ballistic Moon rockets, space stations, and Moon orbiting satellites, still fall into the region of the budget of the greatest nations as to their real expenses. . . .

Further plans, with characteristic flight velocities above 8 km/h, for the whole mission, e.g., manned landings on the Moon, circumnavigation or landings on planets, demand higher expenditure than a single nation can tolerate and are beyond any national budget.

At the age of thirty, Eugene Sänger had, in his thoughts and diaries, fought the conflict as if he, as engineer, should build his "Silver Bird" and realize the first phase of space flight, or as if he, as a writer, in a novel Thule, should draw for his contemporaries the picture of an ideal mankind with intellectual and cultural maturity equal to his plans of space flight. At the age of fifty, however, he was aware that in fact he ought to have created both at the same time; because a rapid realization of his technical projects assumed moral and political insight on the part of nations and their individual representatives that simply did not exist. Up to that time, he had always believed as a matter of course in the reason of men and their decency. Now, as the desire for the realization of his technical plans forced him to come to terms with just these men, he was mocked because of such naivete and, furthermore, was attacked out of ignorance. For the first time in his life he really began to despair. In the summer of 1957 he suffered his first heart attack. Still in his sick bed, he wrote a paper about the stage of development of missiles, unmanned supersonic flight devices, and space vehicles in the

East and West. The news of the successful development of the American rocket plane X-15, which was to serve for research into manned high-velocity and mesosphere flights, encouraged once more his confidence.

During his recuperation on the Ostersee in Upper-Bavaria, on October 4, 1957, he heard the news of the first successful launch of an artificial Earth satellite orbited by means of a multiple stage ballistic rocket from the USSR. This event brought space flight overnight respectability. The crowd of reporters who flooded the quiet Lauterbacker Mühle, Sänger's refuge, already foreshadowed the fact that from now a preoccupation with space flight would become a political preoccupation too, and attract profiteers among the professionals as light attracts moths. Furthermore, it would become an instrument of the "cold war" between nations thenceforth, and last but not least, a stimulant for the whole industrial technological development on Earth, and thus represent a considerable factor in economy and power.

In many smaller countries, especially in Europe, there suddenly appeared the prospect of national budget funds for space research. The time had dawned when spaceflight became an object of state subsidies--including all its advantages and disadvantages. Silent disregard of all astronautical endeavors practised by the official representatives of science, technology, and government until then was now replaced by a keen struggle for the best starting places for collaboration, and it was not by chance that the center of gravity in projects immediately shifted from astronautics technology towards general space research, where more people felt themselves competent. Already in 1958 the International Council of Scientific Unions (ICSU), in which the national Academies of the Sciences of about 40 countries were united, founded a special committee for questions of space research, COSPAR (Committee for Space Research). An "ad hoc" committee for furthering the peaceful use of space was likewise formed in 1958 by a resolution of the U.N. plenary session. On December 11, 1959, this was converted into a standing U.N. Committee with at first 24 member states.

In the Western European sphere the "Groupe d'Etudes European pour les Recherches Spatiales," active after June 1960, developed into the European Space Research Organization ESRO, the foundation of which was signed in Paris in 1962. Parallel to these activities, nearly all civilized states formed national Space Authorities or agencies. However, all these newly-formed organizations limited their range of work to new possibilities for space research and space exploitation opened up by satellites and space probes. In the technological field they engaged only in the development of scientific instruments and containers like probes or satellites, i.e., the so-called "payloads." They cared little about the technical feasibilities of launching equipment or men in space. Especially, they were unconcerned about the development of carrier-rockets and manned space vehicles.

The political doubtfulness of such an attitude was not difficult to recognize. So, following recommendation of the British government, on September 2, 1960, Australia, Belgium, the Federal Republic of Germany, France, Great Britain, Italy, and the Netherlands, joined in the task to develop a European satellite transporter. A European Launcher Development Organization (ELDO) began work in Paris on September 15, 1962; the agreement was signed successfully by the member states and at last ratified on May 5, 1964—three months after Sänger's death. Although the first successes with the trials of the American X-15 rocketplane were obvious from 1959, and although it was known with reasonable certainty that in the USSR work on the development of recoverable aeroballistic carrier equipment was proceeding—especially theoretical and experimental studies concerning skip flight—the work of ELDO concentrated only on the development of a 3-stage ballistic rocket of classical construction. Its single parts were separately developed in the different member countries or modified there from existing hardware in order to adapt them to their use within the total project.

Sänger (who attended the preliminary discussions for the foundation of ELDO in January 1961 as a German delegate at the first expert conference in London) early had recognized two essential weaknesses of this organization:

1. When the project began it was already technically surpassed. Therefore, the ballistic carrier rocket EUROPA could only be of some use in case that new qualified working teams had to be established after a long period of technical abstinence and, nevertheless, should be brought to effective cooperation with optimal efficiency in large-scale technical projects.
2. An international body of the character of ELDO, where political interests claim priority over technical necessities, where the different interests of the member states have to be reconciled by conference partners with no real authority, and where no long-term commitments can be concluded, where besides all this technical decisions are made by political functionaries, where each decision is preceded by time-consuming bureaucratic measures, and where the real experts of the technical developments at best, are only briefly heard. . . such an apparatus cannot conceivably effect the realization of true technical progress, especially if there exist competitors in its neighborhood with less heavy organizations.

The subsequent fate of ELSO unfortunately confirmed Sänger's gloomy prognosis.

He tried in the following period to act according to his perception—on the one hand by public education work, on the other hand by attracting to those organizations others who seemed to be suitable to carry on the developments. In this way he had, so to speak, to struggle on two fronts; first for his project of an aeroballistic space transporter serving as a ferryboat between Earth and space stations, and second, against the chronic aversion to manned spaceflight, especially by the Federal German officials.

So in 1962 and 1963 he wrote the following publications: "Which Gaps in the Spaceflight Technology can be Filled by Europe?" "Space flight—Yesterday, Today, and Tomorrow," "From Ballistic to Aerodynamic Spaceflight," "Now or Never—Eleventh Hour for

European Spaceflight," and last, a 21-page Memorandum dedicated to the President of the German Federal Republic in which Sanger--following an introduction on the consequences of space flight and the necessary expenditure for its realization--drew up a detailed program of basic research in astronautics and of the best ways to organize space flight in the German Federal Republic.

He indicated again the propositions presented by him concerning the formation of centers of main effort in the European aerospace industry:

- (1) Small satellite carriers and Earth satellites on the basis of the existing English Blue Streak and French Veronique rockets, in the framework of the European Satellite Program - mainly for the introduction of the European industry and research institutions into the technique of space flight.
- (2) Manned aerodynamic Earth-Orbit-Earth-ferryboats in order to supplement the corresponding U.S. developments, which worked only with limited resources, and to produce economical and reliable supersonic planes for the fastest possible air travel as well as conveyor vehicles to reach Earth satellites and Earth space stations.
- (3) Fast manned interplanetary space vehicles based on the development of nuclear energy rocket engines of high thrust, and of high specific impulse.

Propositions (2) and (3) made in 1961 by Sanger, correspond exactly to the latest U.S. official general conception with the following key elements: "Space-station," "Space-shuttle," and "Nuclear Propulsion" (Project Rover), as made known by President Nixon in September 1969. About a possible starting date for such a development, Sanger wrote in 1959 in a contribution, "The Future of Space Flight," to the collective report of the Select Committee on Astronautics and Space Exploration, on The Next Ten Years in Space, 1959-1969, for the American Congress: "With the beginning of the first interplanetary phase of manned spaceflight--probably around 1970--mankind will step into its cosmic age. The proper spacecraft will presumably never enter the atmosphere of the Earth or of other planets, but will only move in empty cosmic space between the space stations of the planets."

The time-table for the successive phases of development, namely research, development, testing, production, and actual use between 1960 and 2000, was described by Sanger in a graph (Figure 12) for the following spaceflight-projects: Pioneer landing on the Moon, Installation of a near-Earth space service-system (aerospace transporter), Construction of permanent Earth-orbital space stations and moon stations, High efficiency nuclear propulsion engines, Installation of a fast interplanetary transport system, Pioneer flights in interstellar space.

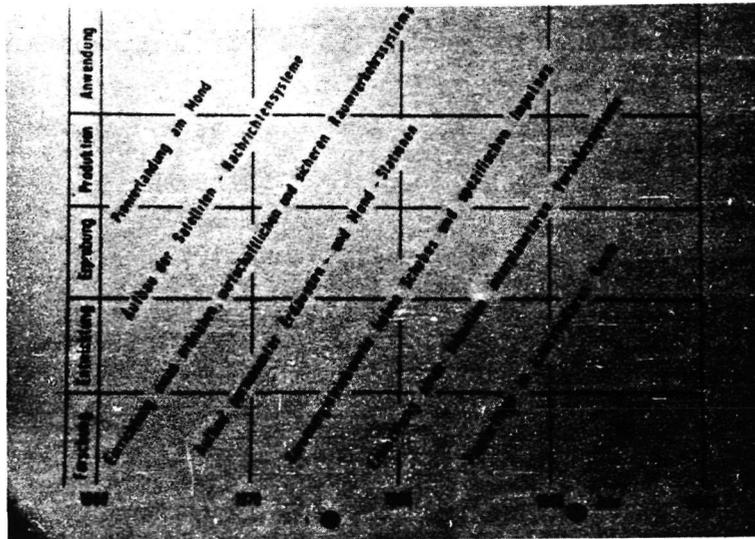


Fig. 12
 Estimated Development of Space Flight According
 To A Sängner Study in 1959

Sängner explained his ideas about the future progress of the development of space flight in more detail during an address on the occasion of his appointment to the newly-created chair for Space Flight Technique at the Technical University Berlin, early in 1963:

The first pioneer phase of practical space flight will probably be terminated during the next few years with the landing of men on the Moon. With this event practical space flight in the neighborhood of the Earth will enter into its next phase, that of big, regular transportation problems such as the organization of a hypersonic air traffic over long distances on Earth, of building manned space stations circling the Earth, and furthermore of the construction of permanent habitable stations on the Moon.

The demands for large and presumably rapidly growing transportation volumes in space, expected within the next few years, arises with a number of tasks:

- (i) Establishment of a hypersonic air traffic system between different points on the surface of the Earth over distances from 800 km to 20,000 km, with flight times below two hours, that is, with the highest physically possible velocities within the Earth's atmosphere;
- (ii) Launch of numerous scientific and commercial satellites into Earth orbit, and returning them after they have concluded their mission;
- (iii) Building of large, manned, space stations in Earth orbit for scientific and economic purposes, and especially as transit stations for space transport between Earth and the Moon;
- (iv) Provision of these manned space stations with the materials necessary for their maintenance, change of crews, and transport of visitors;

- (v) Transport of the necessary equipment and men to the Moon and back to Earth, required for the building and continuous management of permanent Moon stations;
- (vi) Transport between different Earth orbiting space stations, and between these and unmanned satellites for the purpose of control, salvage, rescue work, repairs, change of orbiting planes, etc.;
- (vii) Military political services.

This increase in missions and in transport-volume which requires a regular transportation system within the near space, introduces a whole range of new and greater demands on the spacecraft. In the first place, the average of only 50% reliability of the ballistic space vehicles of today is much too low for these tasks, especially in view of the fact that the spacecraft in this second phase of practical space flight have to carry not only crews, but also passengers.

At the end of May 1961, a few days before the constitution of a pooling agreement among aviation firms, namely the "Association Internationale des Constructeurs de Material Aérospatial" (AICMA), industrial managers met at Konstanz for one of the Drielanders-Congresses of the Federal German, Austrian, and Swiss Space Flight Societies organized by Sänger under the Motto "Space Flight and Europe." Sänger was searching for a suitable European Society to support his Space Transporter Project; the European space flight industrialists on their part were looking for promising projects toward which to orientate their common work and aims. Thus both partners consulted together.

On September 21, 1961, an association of 86 European firms for common industrial development in the field of the spaceflight techniques, called EUROSPACE, was founded in Paris as a sub-organization of the AICMA. On October 4, 1961, Sänger and his wife were nominated associate members of EUROSPACE by the executive committee of the newly-founded association, and on April 30, 1963, the management of the EUROSPACE project group "Aerospace transporter" was assigned to Sänger.

On July 1, 1961, Sänger had already concluded an agreement with JUNKERS about "consultation on the selection of and work on spaceflight developments." Following his advice, all activities were concentrated on preliminary studies for a smaller, manned space transporter (Figure 13) for antipodal flights or transport missions in a 300 km Earth orbit; the assumptions of these studies were: 180 tons launching weight; 2.5 tons payload in orbit; horizontal catapult launching by means of hot water rocket-propulsion; also, for the first phase of development, a two-stage device, each stage with liquid hydrogen-oxygen rocket propulsion of known characteristics ($I_{sp} = 430s$). Following development Phase One, a single stage with increased specific impulse (up to 540s) was specified.

Sänger's endeavors met with approval in the German Federal Republic. The Commission for "Space Flight Technique" responsible for aerospace project planning since July 1961 recommended for the first time in their 1963 Research program for German

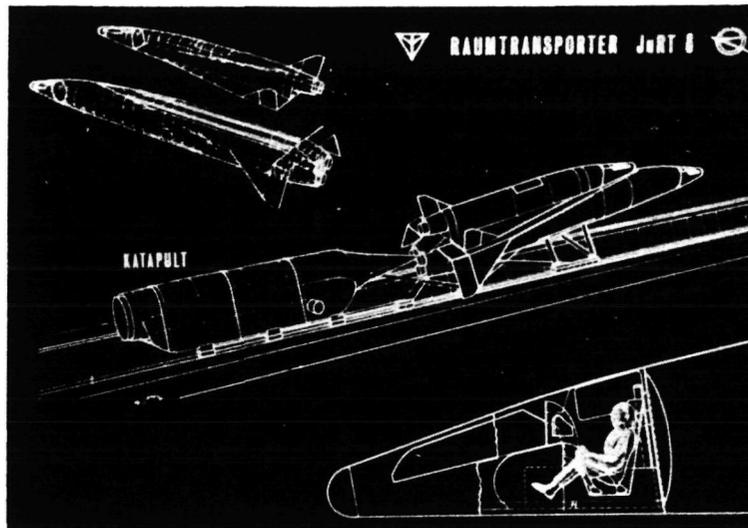


Fig. 13

Two-stage aerospace transporter studied by Junkers Flugzeug- und Motorenwerke (now part of Messerschmitt-Boelkow-Blom) in the early 1960's. Eugen Sänger was consultant on this project which incorporated many of his original ideas.

industry a "Study Project 623" for the determination of the design parameters for a space transporter. For this project a yearly budget of 6.6 mill. D.M. was recommended as well as work in collaboration with EUROSPACE.

Sänger summarized his experience and knowledge in the field of recoverable space transporters since August 1961 in a comprehensive House Report of JUNKERS, "Preliminary Proposals for the Development of a European Space Vehicle." (He supplemented this report up to date and completed its Chapter 32 in the morning of February 10, 1964-- only a few hours before his sudden death from another heart attack.) That report, in which Sänger dealt with the scientific, technical, economical, and political aspects of the project, also contained a summary of the possible variations and alternatives of the following space transporter and space glider projects, which were known at that time:

- (1) X-15, a research plane for manned hypersonic flight, launching from a carrier airplane (North American Aviation Inc./USA);
- (2) X-20 (Dyna-Soar I), a research soaring plane for re-entry tests, launching vertically by ballistic carrier rockets (Boeing Comp./USA);
- (3) ASTRO-A2, a 2-stage aerospace transporter, launching vertically (Douglas Aircraft Comp./USA);
- (4) M-2, a manned soaring space plane with auxiliary propulsion device by solid rockets, launching from a carrier airplane (NASA/USA);

- (5) ASP (Aerospace Plane), aerospace glider for preliminary studies in view of manned aerospace transporter with liquid-hydrogen-ramjet propulsion for operation in lower flight altitudes and devices for liquefaction of air to extract oxygen from the atmosphere for operation in upper flight altitudes (USAF-Aeronautical Systems Division/USA);
- (6) T-4A, an unmanned, 3-stage antipodal airplane with horizontal launching by catapult (manufacturer unknown/USSR);
- (7) Orbital Fighter; manned, 2-stage aerospace transporter with ramjet propulsion during the first stage (Royal Aircraft Establishment/GB);
- (8) MUSTARD, a 3-stage aerospace transporter with parallel-arranged cluster, vertical launching (British Aircraft Comp./GB);
- (9) Lane Project, preliminary design in view of a 3-stage aerospace transporter with horizontal launching, airbreathing first stage, and rocket propulsion during the following stages (Bristol Siddeley Ltd./GB);
- (10) EUROSPACE space glider model, a reduced variation of X-20 (Nord-Aviation/EUROPE).

After critically balancing all these projects Sänger drew the following conclusions from his investigation: "It is my firm opinion, that for civil use of the aerospace transporter the catapult start by means of steam rockets and the main propulsion by liquid-hydrogen liquid-oxygen high pressure rocket engines, is the best initial approach. Later on the main stage may be powered by thermal nuclear fission rocket engines. The total launching weight should initially be chosen between 100 and 1000 tons, and the use of single stage vehicles may be justified if catapults are applied for launching." In opposition to the trend towards a vertical takeoff with a modest lift-to-drag ratio between 2 and 3 in the hypersonic flight range -- a technique which needs less development effort in the beginning -- Sänger always insisted upon developing aircraft with high reciprocal gliding ratios and the application of horizontal launching devices.

Only a few weeks after Sänger's death an American newspaper article confirmed Sänger's daring expectations, always somewhat doubted in Western Europe. It is reported there:

According to studies of the United Aircraft Corporation which were carried out for a commission of NASA, outward and return flights to the Moon with a single stage space transporter system lie in the region of feasibility. The firm is now working on studies for a one stage space transporter which shall be equipped with a gaseous core nuclear rocket propulsion device. Such nuclear propulsion engines would make feasible loading capacities up to 30% of the launching weight and would also offer the economical advantages of a recoverable aerospace transporter system. . . .

In 1965, the "Deutsche Gesellschaft für Raketentechnik und Raumfahrt" (German Society for Rocket Technology and Astronautics) founded a "Eugen Sänger Medal for special merits in the field of recoverable space vehicles" in honour of Sänger who acted as a

president of this society during 8 years before his death. On October 6, 1966, this medal was awarded to Dr. Walter Dornberger for his working on the project of A-10 in Peenemünde; on December 5, 1968, the medal was awarded to John V. Becker leading project engineer of the X-15 team.⁺

Eugen Sänger did not live long enough to see the realization of his dream of the "Silver Bird". However, 3 years before his death, on April 12, 1961, he learned that the Russian Yuri Gagarin had first succeeded in a manned orbital flight around the Earth. More than 5 years after his death, on July 21, 1969, the American Neil Armstrong, was the first man to set foot on the surface of the Moon.

With this event began the "interplanetary phase of manned space flight" predicted by Sänger in 1959 for some time in the early 1970s. With the development of the American "Space Shuttle" a first step has been made towards the realization of Sänger's aerospace transporter. May the defiant motto of Eugen Sänger's youth become true: "Nevertheless, my Silver Birds will fly!"

⁺ It was awarded on October 8, 1970 to George S. Mueller, leading project engineer of the Space Shuttle development. In 1970, the International Astronomical Union approved Sänger's contributions to rocketry and space flight by giving his name to one of the newly discovered craters on the Moon.

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BASIC STAGES IN THE DEVELOPMENT OF THE THEORY OF
RAM JET ENGINES (RJE)⁺

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HISTORICAL PERIODIZATION OF THE DEVELOPMENT OF THE
THEORY OF THE RJE

In the history of the development of the theory of the ram jet engine (RJE), it is possible to distinguish the following basic periods:

1. Development of the basic ideas of the theory of the RJE. This period can be dated between the years 1929-1939. During this decade the general theory and methods of making calculations for the RJE were propounded and procedures for determining the estimated characteristic flight path at subsonic and slightly supersonic speeds were established.

2. The first experimental tests of the RJE by simulation and in flight. This period began in 1932, but it did not really end until the first half of the 1940s (1942-44). The first experiments allowed testing the basic premises of the theory of the RJE, establishing the basic problems for further research on these engines, and evaluating the possibility of the practical utilization of engines of this new type, according to their current stage of development.

3. Investigation of the processes used in the RJE (1929-1960). The main task of developing the ram jet engine at this time was to scientifically explore the processes of combustion, with the objective of perfecting the RJE combustion chamber. Great attention was also given to questions of cooling the combustion chamber and the nozzle. At this time also, much theoretical and practical research was underway on the air inlet

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of air-breathing jet engines. To the extent that the air inlet could be applied not only in engines of the ram type but also in gas-turbine engines (TJE), work on the air inlet led to a separate field and to specialized gas-dynamic laboratories. The results of these investigations, part of the complex of work on the RJE, were used in developing the theory of the ram jet engine.

4. Development of the theory of the hypersonic RJE. At the end of the 1950s several countries began theoretical investigations of the ram jet engine with a supersonic jet of gas flowing into the combustion chamber. The investigations proved that such engines were capable of working at hypersonic speeds. From the beginning of the 1960s, theoretical and practical investigations of the processes used in engines of this type were extended. The most intensive theory of the hypersonic RJE was developed in the mid-60s, and at the end of the decade the basic premises were established.

5. Theoretical development of the cosmic RJE. The development of the basic premises of the theory of the cosmic RJE took place in the period from 1965-1970. At this time, the possibility of using the RJE to achieve orbital and Earth escape velocities was theoretically proven, and methods were defined for realizing this possibility; also, the propelling characteristics of the ideal RJE at cosmic velocities were calculated.

Subsequent decisions regarding the capabilities of this engine in ever higher ranges of velocity mark the periodization of the development of the theory of this engine, and, naturally, this opens up the possibility of dividing the history of the development of the theory of ram jet engines into the following periods: subsonic (RJE) supersonic (SRJE), hypersonic (HRJE), and cosmic (CRJE) engines. However, such a scheme would be, in our opinion, unreliable. In the first place, the theory of the RJE was developed in the 1920s and 1930s by B. S. Stechkin and other scientists not only for subsonic, but also for supersonic speeds, and the basic premises of this theory were true also for hypersonic and cosmic speeds according to the work of A. G. Crocco, published in 1931, where theoretical tests of devices with the RJE achieved speeds of approximately Mach 3. But the first experimental RJE, constructed according to plans made by Yu. A. Pobedonostsev, were tested in flight in 1933-1935 at approximately Mach 2. In the second place, and no less important, the development of the theory of the RJE with the possibility of its effective utilization at ever increasing speeds, is not simply a quantitative change of the engine's parameters, e.g., increasing the coefficient of the pressure of the air inlet, the coefficient of combustion efficiency, the permissible temperature of gas in the chamber, etc. It is rather a development that, following the quantitative increase in the parameters of the RJE, made possible substantial qualitative leaps.

These leaps were characterized by the solution of principally new problems and the discovery of new laws in the physical mechanics of the ram jet engine. The explan-

ation of these new laws also opened a path leading to greater speeds at which the RJE could work effectively. These newly discovered laws did not offer merely a theory for the engine to work at new speeds, and were not just related to one or another range of speed; these new laws applied to any speed. And their relation to the new range of speed amounted to this: without utilizing the new laws, it would be impossible for the RJE to work at any higher speed. It follows that the newly revealed laws were applicable to different speeds of the ram jet.

At the same time, it is necessary to note the influence of this "battle to increase speed" on the development of the theory of the ram jet engine. Increasing speeds was a task paralleling every step in the development of aviation, rocket, and cosmic technology before the theory of the ram jet engine. And in response to this technical demand, the theory of the RJE developed.

THE THEORETICAL FOUNDATIONS OF THE RJE

The idea of the ram jet engine, as we know, was suggested in 1907-1913 by the French engineer René-Loren.¹ The idea of using an air-breathing jet engine for propelling a space ship was first proposed by K. E. Tsiolkovsky in the article "The Space Ship"², written in 1924.⁺

The story of the air-breathing jet engine was developed in 1928 by the Soviet scientist B. S. Stechkin. His work, published in 1929, became the theoretical base for the development of jet propelled craft and the creation of the air-breathing jet engine (JE) for propelling rockets.³ In this work Professor Stechkin investigated the thermodynamic cycle of the JE, gave an analysis of the principles of its operation, and for the first time deduced the level of propulsion and the efficiency factor (k.p.d.) of this new type of engine. "The force R , which we call the free propulsion of the jet engine," wrote the scientist, "will be the resultant force of air pressure on the external and on the internal surface of the jet engine."

To increase propulsion, he gave the following equation:

where

$$R = m(V - V_0) + f(p - p_0)$$

V_0 - velocity of the missile; V - velocity of gas flow from the JE; m - mass expenditure of air; f - the surface of the outlet portion of the nozzle; p - the static pressure in the outlet portion of the nozzle; p_0 - atmospheric pressure.

The thermal efficiency factor of the ram engine was expressed as follows:

$$\eta_e = A \frac{RV_0}{Q_0} - \frac{2V_0}{V + V_0} \eta_t$$

⁺Archive of the USSR Academy of Sciences, I:47.

where: Q_0 - quantity of heat supplied to the air; η_e - thermal efficiency of the cycle; A - thermal equivalent of the work.

"Thus," he noted in the work, "the efficiency of the jet engine is equal to the production of two efficiency cycles of which one is a thermal efficiency cycle complete with air, and the other is equal to a propeller efficiency cycle having a velocity of V_0 and trailing behind it a stream of air with a maximum velocity of $V - V_0$."

Starting from the fact that the magnitude of thermal efficiency is dependent upon the velocity of the outflow of gas, Stechkin gave a second equation for the efficiency factor:

$$\eta_e = \frac{RV_0 2\eta_t}{1 + \sqrt{1 + 2g \frac{Q_0}{AV_0^2} \eta_t}}$$

As already noted above, Stechkin investigated the workings of the RJE at subsonic and supersonic speeds. He calculated the significance of the efficiency of this engine at speeds from 50 to 600 m/sec. It should be noted that he was developing the theory not only of the ram but also of the compressor JE; thus, his work provides the theoretical basis for contemporary turbojet engines. Soon after the publication of the theory of the RJE, Stechkin also developed a method of calculating the heat of these engines.

The work of the Italian scientist A. G. Crocco, published in 1931,⁵ is an interesting report on the theory of the RJE. He expanded the theory of the RJE and explored its application to supersonic craft. Crocco noted that the theory of air-breathing engines was proposed by the Moscow Professor B. S. Stechkin. Of particular value, Crocco showed the effectiveness of applying the RJE at supersonic speeds. The results of his investigations were of interest to aviation specialists in air-breathing jet engines, and considerably helped developments in this field.

In 1930 the basic work of the French scientist Moris Rue came to light. It was dedicated to investigating efficiency factors and the conditions for applying various types of jet engines. In this work a great deal of attention was given to the air-breathing jet engine. Rue's work is a valuable document in the development of the theory of the jet engine.

F. A. Tsander deserves the greatest credit for developing the ideas used in designing the RJE. In his book he advanced the theoretical investigations of thermodynamic cycles and the search for new schemes of air-breathing jet engines and the means for increasing their effectiveness.⁷ These researches led him to the idea of the so-called "inverse cone" that expanded, then compressed moving gas while simultaneously cooling the gas. In this action—first expansion then compression of gas in a channel coupled with intense cooling during compression—the gas completes a cycle. The period of the cycle corresponds to the increase in air pressure. Along with the idea of the "inverse cone," Tsander used in his schematics a stream injector for injecting air into

the chamber of the JE. He also proposed applying the "inverse cone" in the nozzles of jet engines for increasing the kinetic energy of the escaping gases. The idea of the inverse cone in some instances showed promise, as was shown later⁸; in the course of its development, it made possible several tens of percent increases in the propulsion of the engine.

Tsander also showed the effectiveness of applying RJE to rockets. In the chapter devoted to flights of "long-distance rockets," he investigated rockets with various power capabilities and came to the conclusion that for flights at distances of approximately 7,000 km the application of the RJE instead of the LPRE (liquid propellant rocket engine) would require three times less fuel. He described how hydrogen could be applied effectively as a fuel for the RJE, which not a single scientist had considered before him.

Interesting investigations of the ram jet engine were carried out in the mid-1930s by U. Ville and R. Ledyuk. But the most complete theory of the RJE at the end of the 1930s was communicated in Professor V. I. Dadakov's book.¹² In it he presented the classical theory of B. S. Stechkin, the methods of calculating the processes utilized in the engine, and its propulsion characteristics; many calculations of the parameters of the RJE under various programs and conditions were also presented.

Toward the end of the 1930s, the basic ideas of the theory, the methods of calculating parameters, and the definition of propulsion characteristics of the RJE had been completed. The work of a great number of scientists in many countries contributed to this task. As a result, a stable theory of the ram jet engine was established. In the next years the theory of the RJE was presented in several books. Most complete and detailed with regard to later work in the theory of the RJE was the basic work of M. M. Bondaryuk and S. M. Ill'yashenko.¹³

THE FIRST PRACTICAL INVESTIGATIONS

The theory, developed by Stechkin, made possible the invention of the air-breathing jet engine and the practical investigation of this engine. The first experiments on the RJE were conducted in the USSR,¹³⁻²⁰ beginning in the Group For the Study of Jet Propulsion (GIRD) under the direction of Yu. A. Pobedonostsev in 1933. After simulated experiments, actual test flights were conducted.

The ram jet engine proposed by Yu. A. Pobedonostsev had the external appearance of a long-distance projectile of a 76 mm cannon. Internally, the RJE was composed of an entrance canal, the combustion chamber, and the nozzle. A fuel pot of white phosphorous was placed directly in the combustion chamber. The chasis of the fuel pot served to support the phosphorous during ignition of the projectile, and afterwards it was used as fuel material. Thus, the ram jet engine of Yu. A. Pobedonostsev was the

first jet engine in the world which used metal fuel while in flight. The first test flights of Pobedonostsev's engine took place in September 1933. In 1934 and 1935 two more series of test flights were conducted.

In engines of the third series, the specific impulse increased to 423 seconds, and the efficiency factor reached 16%. From the moment the craft left the launching pad until the engine began to operate at a speed of 630 m/sec, the missile experienced a frontal resistance of 42 kg. Switched on, the engine generated a thrust of 23 kg, at which time the frontal resistance decreased to 19 kg.

The most important outcome of these experiments lay in proving that the RJE, based on the theories of B. S. Stechkin, was capable of being used in flight and of developing propulsive force. The first test flights proved that the RJE could develop a comparatively small thrust. Therefore, the question arose of the possibility of developing a RJE with a thrust greater than the frontal resistance with the body of the engine aerodynamically streamlined.

The "Ts. S. Osoaviakhim Jet Propulsion Research Section, USSR," under the direction of the author, conducted research on the thermal cycles of the RJE and determined the optimum parameters for the engine under which it could develop propulsion significantly surpassing its frontal resistance. On the basis of these theoretical investigations, experimental models of the RJE were designed.

The first experiments were conducted on rockets.¹⁷ We used a solid propellant rocket as the first stage, and in the body of the second stage we placed the RJE. Fuel pots of compressed powder--aluminum, magnesium and several other elements--served as fuel. Sixteen rockets were prepared for the test flights. The technical data of the rockets with RJE's (of the first series) were: weight of the powder rocket--3.8 kg; weight of the powder--1.4 kg; total impulse--260 kg/sec; maximum thrust--450 kg; average thrust--118 kg; combustion time--2.24 sec; weight of the rocket with the RJE--4.5 kg; diameter of the rocket with the RJE--121 mm; total weight of the two-stage rocket--8.3 kg. The rockets of the second and third series were somewhat lighter in construction.

In February 1939, test flights of the RJE began at the aerodrome near the Planernaya Station. The launch of the rockets was accomplished with a vertical launching stand. The first launches tested the lift-off of the rockets and evaluated the stages and fuel combustion. The first successful rocket was launched on March 5, 1939, at which time the increase in speed due to the RJE was definitely established.

During ignition of the first stage of the rocket, a speed of 200 m/sec and a height of 250 m was attained. After combustion of all the powder of the first stage, air braking equipment separated it from the second stage. From the moment the powder ceased to burn until the air-breathing jet engine switched on took approximately 2.5 sec while the rocket covered 375 m and attained a height of 625 m. The speed of the rocket

at this moment approached 105 m/sec. At this speed the RJE was engaged and worked 5.12 sec. At the end of this time the rocket had risen to 1,317 m and achieved a speed of 224 m/sec. After the rocket fuel had burned up, the rocket continued to rise for 6.06 sec due to inertia, and attained a height of 1,808 m. When the engine finished working the magnitude of surplus propulsion, i.e., the difference between the propulsion or thrust and the frontal resistance, was 20 kg, the coefficient of thrust thus was 0.7. During the entire flight the average speed with the RJE working was 23 m/sec².

The rocket tests completely demonstrated that the speed of vertical flight could be increased with the ram jet engine. They also gave practical proof of the possibility of inventing a RJE capable of increasing thrust that surpassed the frontal resistance and even the sum of the force of the frontal resistance and weight.¹⁷

The successful tests of rockets with RJE's served as the base for future development work on these engines. In 1939 the aviation RJE (DM-2) was designed by the author. This engine, after much research, was tested in planes designed by N. N. Polikarpov ("I-152" and "I-153": "Chayka," 'The Seagull').¹⁸ The DM-2 engines had a diameter of 400 mm, a length of 1,500 mm, and a weight of 12 kg. They were hung under the lower surface of the plane as auxiliary motors.

Preliminary test flights began in December 1939, but on January 25, 1940, the official tests were conducted over the Central Aerodrome of Moscow. Research on the RJE in flight continued during the year. Taking part in this research were pilots P. E. Loginov, A. V. Davydov, A. I. Zhukov, N. A. Sonotsko. The DM-2 engines switched on at "I-152" speeds of 320-340 km/hr and increased the speed 18-22 km/hr. On the "I-153," the engines increased the average speed 30 km/hr.

In August 1940, the DM-4 engines were built with a mid ship section diameter of 500 mm. They were tested on the "I-153" plane. When these engines were turned on, the flight speed rose 42-51 km/hr. At least seventy-four test flights of the "I-152" and the "I-153" with ram jet engines DM-2 and DM-4 were conducted without a single accident. Thus, the USSR had created the necessary working model of an aircraft-type ram jet engine and successfully tested it in 1940.

In May 1941, the DM-4 engine was tested further in the wind tunnel at the Zhukovskiy Central Institute of Aerohydrodynamics (TsAGI). During the engine tests, which took place in three twenty-four hour periods, one of the engine firings ran continuously for sixteen hours. A month later, in June, the DM-4 engine was placed on the "I-207" plane and a test pilot made several successful flights. Soon after this, test flights of the ram jet engine designed by M. M. Bondaryuk, with an engine designed by E. S. Shchetinkov, took place.

In 1942 in Germany, test flights of the ram jet engine designed by Professor E. S"anger were conducted on the plane "Dorn." In 1942-43, at the Moscow Aviation Institute

under the direction of Professor K. A. Putilov, tests of the ram jet engine DM-4 were conducted after which they were placed on a plane designed by A. S. Yakovlev, the "Yak-76." Test flights of the "Yak-76" followed in 1944.¹⁹

Thus after numerous test flights conducted in the first half of the 1940s, the success of the first aircraft-type RJE was confirmed. After this, a whole series of countries began to work on the practical applications of the RJE. We offer a description of one of these, exactly as it was recorded by the author:

"In 1948 the subsonic, single circuit starting motor for accelerating the LA-9 aircraft was designed. Two ram jet engines were hung under the wings of the plane and could be switched on by the pilot. Each engine operated in the range of Mach 0.4 to 0.85, and developed 320 kg of thrust at a calculated height. The specific thrust of the engines at various heights was

$$520 - 650 \frac{\text{kg}}{\text{kg/sec}}$$

The ram jet engine guaranteed a maximum relative increase in speed of the LA-9 of 110 km/hr. The engine could be switched on more than once. The weight of the powder engine was 40 kg."²

CONCLUSIONS

This work is a first attempt to describe the history of the development of the theory of the RJE. There is no doubt that further investigations of this question will give a more complete picture of the theoretical basis of this very long-range engine. To the extent that the ram engine finds applications in rocket and space technology, interest in the history of its development will grow. We may expect that the history of the RJE will follow the general rule--with the development of science comes a growth in the investigation of its history. As the theory of the RJE gains newer and higher levels of understanding, we will be forced to change our critical evaluations of earlier statements. Therefore, the author has assumed the task of suggesting the scheme of the history of the theory of the RJE and to note the results achieved in early tests--those results, incidentally, are the more easily understood within the contemporary level of scientific understanding of the ram jet engine--and thus illuminate the first two stages in the development of RJE theory which were completed a quarter of a century ago.

The first twenty years of development of RJE theory were dedicated to research in the internal processes of this engine. Also, new supplements to the theory which opened up the possibilities of using RJE's at hypersonic and cosmic speeds were refined, and areas of research, which the author hopes to complete in the future, pinpointed. If the task undertaken by the author to illuminate the path of RJE theory brings forth additional and more specific factual material, descriptions, and evaluations in the

analysis of the historical development of the theory, then the author will consider his task completed.

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