

Mieczysław Subotowicz

KAZIMIERZ SIEMIENOWICZ (1650) AND HIS CONTRIBUTION TO THE ROCKET SCIENCE(*)

A long range rocket is an outstanding technical attainment of our age. In realization of cosmic flight of the scientific instruments and of the men (on the first and future artificial satellites and space vehicles) the rocket plays and will undoubtedly play a principal role. It has two basic qualities: it makes possible to attain the greatest speed that man has been able to reach by technical means and it is the only engine which is capable to move by a propulsive flight in an empty space.

The rocket is a device having an old and long history. In the historic development of rocket problems great credit is due to the work of a Pole, Kazimierz Siemienowicz, done by him some 300 years ago.

The present work is intended in the first place to discuss the importance of Siemienowicz ideas on rocket construction. Technological matters dealing with the production of rockets will occupy less space and the work of Siemienowicz as a theoretician and a founder of artillery science shall be discussed but briefly.

THE DEVELOPMENT OF ROCKETS TILL THE MIDDLE OF THE XVII CENTURY

The earliest informations about rockets have come to us from ancient Chinese and Indians. According to some unverified sources rockets have been known to Chinese three thousand years before our era. The powder rocket has been used for fireworks, for religious

(*) The elaboration of this subject was made possible by getting acquainted with a Polish translation of K. Siemienowicz work *Artis Magnae Artilleriae*.

The author takes great pleasure to extend to prof. general St. Okecki his most hearty thanks for making the said translation accessible to him.

celebrations and entertainments. The discovery and the development of a rocket had to be preceded by the discovery of powder and our knowledge is limited to the fact that powder has been known in China at the time of Alexander the Great.

Claudius the Roman poet describes the use of rockets in Milan in the year 199 of our era. Leo the Philosopher is said to be engaged in the fabrication of rockets at the end of the IX century.

The oldest Chinese chronicle where rockets are mentioned tells of the siege of Peking by Mongols in 1232 of our era. It says the Chinese have applied then a new weapon named „arrows of flying fire”. These weapons were just rockets.

For the first time in Europe rockets came to be used probably in the battle of Lignica in Poland in 1241. Eight years after the battle of Peking has been fought an Arabian scientists Ibn-Albaitar already writes of rockets and around 1280 Hassan Alrammah gives an exact instruction for the production of gun powder and for the manufacture of improved rockets. Rockets were used by Arabs on the Iberian Peninsula in 1249. In 1288 Valencia has been bombed by rocket missiles. Rockets have been named “flying fires” or “wild fires”.

Roger Bacon in 1260 and Albertus Magnus in 1265 have been writing about the production of rockets. In 1379 an Italian, Muratori, gives a technical description of a rocket. The first large description of the production of rockets for military purposes that has been written by others than Arabs appeared in Europe in the XV century.

The technology of rocket production was steadily improved and already in 1405 a German military engineer Konrad Keyser von Eichstädt in his work *Bellifortis* tells of three types of rockets. A number of interesting and ambitious rocket designs is contained in sketches of an Italian engineer Joannes de Fontana published in 1420 in his work *Bellicorium instrumentorum liber*. Fontana is also the author of a prototype of a modern jet propelled airplane, that is of a rocket equipped with bearing planes which the contemporaries have named „pigeon”.

At that time the cannon became a competitor of the rocket, an instrument of destruction of a greater precision, and soon the rocket has been driven away by the cannon and disappeared from the battlefields for a couple of centuries.

In the works of the XVI century we may find some information concerning rockets. Such is the book by Vannoccia Biringuccio

Della Pirotechnica (1540), the works of Leonhart Fransperger from Frankfurt a/M. (1557), by Johann Schmidlap from Nürnberg (1591), and Hanzelet (1598). The first Polish author to write about rockets was, it seems, Marcin Bielski (1569). Rockets equipped with a parachute were the subject dealt with in unpublished manuscripts by Reinhard v. Solms in 1547, and rockets exploding under water were described by von Nassau in 1610, the manuscript remaining also unpublished.

The first Russian publication dealing with rockets appeared in the beginning of the XVII century. It is: *Ustav ratnych pushetchnykh i drugich diel, kassayushtchichsia do woyennoy nauki* by Onisim Mikhajloff, from the years 1607—1621.

The author writes of the production of rockets and of the possibility to use them for the transportation of projectiles filled with an explosive.

From the Polish publications dealing with rockets from the time before Siemienowicz, beside Bielski who has been already mentioned we may note here some small notices on rockets by an unknown Polish author from the year 1624, in a manuscript by a Venetian doing his service in Poland, Dell Aqua from the year 1632 and the book of a Spanish author Diego Uffano in a Polish translation (1643).

Kazimierz Siemienowicz is the first Polish author who gave a full account of rocket problems.

THE LIFE STORY OF KAZIMIERZ SIEMIENOWICZ

Kazimierz Siemienowicz was a native of the Grand Duchy of Lithuania. His name may be found in the Heraldry Book of Lithuanian Families by Koyalowitch (Kojalowicz).

Siemienowicz acquired a thorough humanistic education, the knowledge of ancient history and a solid knowledge of the military art. Perfect Latin which Siemienowicz demonstrated in writing his work *Artis Magnae...* and a comprehension of the subject indicate that he was well acquainted with Greek, Roman and later literature, including the contemporary writings dealing with the subject that interested him most.

In order to get better acquainted with all problems of artillery Siemienowicz had to acquire (as he wrote himself) the knowledge of a "number of liberal arts and mechanics" namely: arithmetic,

geometry, statics, hydraulics, pneumatics, civil and military architecture, fortification, graphics, optics and tactics. "I acquired also, writes he, some knowledge of physics and chemistry". Wishing to command not only the theoretical disciplines but also the practical ones he gets acquainted with handicrafts that are necessary for his purpose, namely carving, engraving and the art of casting.

Siemienowicz travelled widely through foreign countries. It is possible that the first voyage he made as a young man as a companion to the prince-heir to the Polish throne Wladyslaw (1624–1625), who at that time visited Belgium, the Rhine Provinces, Austria, Bavaria, Switzerland and Italy. We know for sure though that in later years he went abroad, in the first place to Holland where he specialized in artillery. It was probably connected with the activity of Sigismond the III Vasa and especially of Wladyslaw IV and had in view the modernization of Polish artillery (establishment of a college for gun-smiths and building a foundry). A further step in this process was the establishment by Wladyslaw IV of a Corps of Artillery.

During his stay abroad Siemienowicz became acquainted with the contemporary military literature especially with the one dealing with artillery and undertook extensive studies, theoretical as well as practical, in matters that interested him most. He had in mind to write a monography devoted to artillery.

After his return home his studies and notices made abroad attracted the attention of the chancellor Ossoliński and King Wladyslaw IV. Thanks to their patronage he is going to be able to accomplish the greatest work of his life by making further theoretical studies and experiments home and abroad, mostly in Holland, where he was sent by the king who saw in him a great opportunity to learn the art of artillery.

Siemienowicz took an active part in the Smoleńsk campaign in the years 1632–34 and in the siege of Biała. In later years he is engaged in the organization of Polish artillery in company with some eminent specialists in that matter of such calibre as Paweł Grodzicki, general of artillery, Krzysztof Arciszewski, general of artillery and his nephew Mikołaj Arciszewski, Sebastian Aders and Frederic Getkant. Siemienowicz tells that in 1644 he took part in the battle of Ochmatow against the Tatars. In 1647 his name is mentioned as one of the 106 persons who belonged to the "company of men in the Royal artillery". Siemienowicz is also a member of

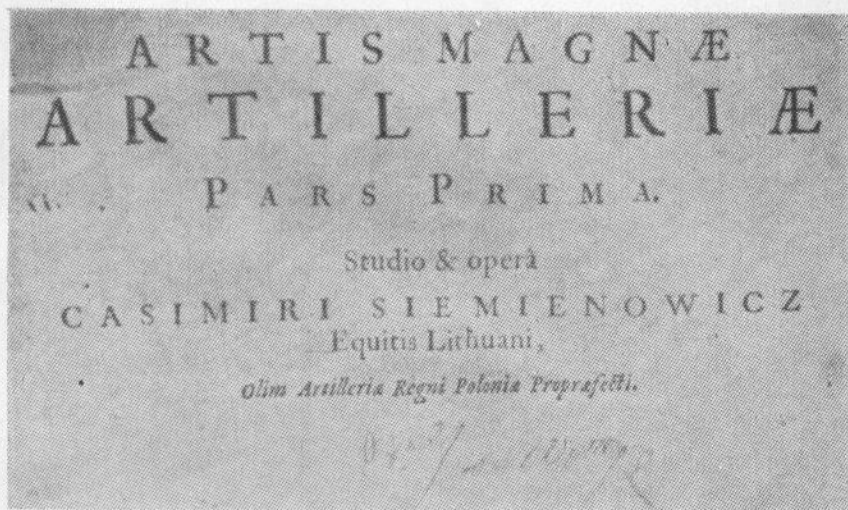



Fig. 2. The full title of the monograph by K. Siemienowicz; a photograph.

ARTIS
MAGNÆ ARTILLERIÆ
PARTIS PRIMÆ
LIBER III.
DE ROCHETIS.

 Mulum artificialium ignium, primum sibi vendicant locum Rochetæ, vel *Pyroboli* ex Græco (tametsi id improprie usurpatur ad nostras Rochetas: cum ~~magis~~ tela ignita denotet; de quibus infra) Italis *Rochette* & *Raggi Fuses*, Germanis *Steigende Kasten*, vel *Rageten*, & *Dracheten*, nobis vero Polonis *Raca* dictæ. Harum constructio perantiqua, & omnibus Pyrobolitis nota satis: quæ licet facilis, laboriosa tamen, & accuratam præparantis requirit sedulitatem. Pyroboliæ vero operam dari ab his totum sumunt; nec incongruè sane, cum omnes recreativi ignes artificiales, omnes Machinæ: ut sunt Tubi, Rotæ ignitæ, Gladii, Semispathæ, Globi, ceteraque his similia Pyrobolica inventa, absque Rochetis, vix esse possint. Igitur hoc tertio libro illarum preparandarum modum, varias formas, figuras, & usum sufficienter proponemus.

CAPVT I.

De Formis seu Modellis, tam Ligneis quam Metallis, ad constituendas Rochetas Parvas, & Mediocres.

Modus. 1.

Formæ, sive Modelli ad constituendas Rochetas, tum ex ære fusili vel aurichalio, tum ex lignis solidioribus: ut sunt Cupressus, Palma, Castanea, Buxus, Nux Italica, Juniperus, Prunus sylvestris, & aliis hisce similibus, immo ex Ebore, & lignis Indiciis, parari, & quam poltissime ab intus, & ab extra tornari solent. Proportio tam altitudinis, quam crassitiæ, & ornamentorum, variat apud artifices; juxta illud, quot capita, tot sentus. Quantum ad formas in quibus Parvæ & Mediocres Rochetæ construuntur, (Parvas Rochetas autem voco, quæ in orificiis aliquot uncialium globorum plumbeorum diametros habent; sed unam libræ non excedunt: Mediocres vero quæ sunt 1 1/2, & 2; trium verò vix concesso: Majores denique à 2 1/2 usque ad 100 1/2 sumi possunt) Istarum duos modos hic exponam: Majorum vero sequenti capite rationes docebo. Primus itaque modus est hic. In Figura N. 20, sinimus diametrum orificii formæ A B, esse 1 1/2 plumbei globi (usu enim apud Pyrobolistas receptum est, ut orificia formarum & Rochetarum mensurentur diametris globorum plumbeorum.) Altitudo formæ ab Y, usque in E, est 7 diametrorum orificii: ab E vero usque in G, est altitudo Stylobatæ, qui subponitur formæ dum Rocheta oneratur 1 diametri cum. Hæc habet in medio Cylindrum, qui erassus est per diametrum C D: Altus verò 1 diametrum orificii. Huic Cylindro, insilist dimidius Globus L O P M, cujus diameter L M est: ejusdem

Fig. 3. Photograph of the first page of the III book of Siemienowicz work; this III book is devoted to the rockets.

the staff of artillery corps, composed of five men whose chief was general Krzysztof Arciszewski.

As an expert in artillery Siemienowicz was highly respected not only in Poland but in Western Europe as well, as many foreign orders conferred on him bear witness.

In 1648 taking with him a much advanced monography on artillery Siemienowicz goes to Holland after being assured of the financial backing of King Wladyslaw IV for the publication of this work and having obtained "an order to have it printed". Unfortunately the king dies the same year. Siemienowicz having finished the first part of his work begins to write the second, but to have it printed must look after another patron. He found such a patron in the person of archduke Leopold-Wilhelm, viceroy of Belgium and Burgundy. To him dedicated Siemienowicz the first part of his work on artillery published in 1650: *Artis Magnae Artilleriae Pars Prima...*

Soon after Siemienowicz dies; he had no time to publish the second part of his work, which according to a paragraph in the first part was "already finished and shall appear soon".

THE WORK OF SIEMIENOWICZ

The full title of the monography by Siemienowicz, published in Latin in Amsterdam in 1650 is: *Artis Magnae Artilleriae Pars Prima. Studio et opera Casimiri Siemienowicz, Equitis Lithuani olim Artilleriae Regni Poloniae Propraefecti, Amsterdami, apud Joannem Janssonium, A° MDCL (fig. 2).*

The first part is divided in five books, has 304 pages and 206 figures on 22 tables and a titlepage, done by Siemienowicz himself (copperplate, fig. 1).

An extensive introduction of 11 pages (*Lectori*) preceeds the five books of the work.

Book N. 1 *De regula calibrae* deals with cannons calibre, its construction and application. The author gives further a number of informations about methods of alloys making, on units of measure and weight and on instruments for weighing.

In book N. 2 *De materis et materialibus in pyrotechnia usurpari solitis* the author discusses the technology of powder and other materials used in artillery.

Book N. 3 *De rochetis* is wholly devoted to the construction, production and to the properties of rockets. The author advances

a number of new ideas: simple and compound rockets, with tail and tailless, aquatic rockets and rockets running on ropes.

In book N. 4 *De globis* Siemienowicz discusses missiles for amusements and entertainment purposes (artificial fires, fireworks) and for military purposes (grenades, bullets a.s.f.).

Book N. 5 deals with arrangements for fireworks and for military purposes. It discusses among others pyrotechnical machines and structures and military equipment (shields, sabres, cutlasses, swords, rods, canes, clubs).

Numerous translations into foreign languages bear witness that the work of Siemienowicz was quite remarkable for its time.

French translation appeared one year after the original Latin edition has been published, that is in 1651. The full title reads: *Grand art d'Artillerie par Sieur Casimir Siemienowicz Chevalier Lituanien, Lieutenant General de l'Artillerie dans le Royaume de Pologne mise de Latin en Francois par Pierre Noiset Marcerien*. The French translation is 410 pages long.

The German translation has been published in 1676, a complementary part by Daniel Elrich being added; the translator was evidently not aware that such a part of Siemienowicz work existed. The full title of this translation reads: *Ausführliche Beschreibung der grossen Feuerwercks — oder Artillerie-Kunst Casimiri Siemienowicz itzo mit dem Zweitetheil vermehrt von Daniel Elrich. Francfurt am Mayn, bey Johann David Zünthern im Jahr 1676*.

The title of the English edition, which was published 79 years after the original edition reads: *The Great Art of Artillery of Casimir Siemienowicz, Formerly Lieutenant-General of the Ordnance to the King of Poland. Translated from the French, by George Shelvocke, Jun. Gent. Illustrated with 23 Copper Plates, London, printed for J. Tonson at Shakespeare's Head in the Strand, 1729, fol. p. 404, Tables 22*.

The translator says that he did his translation from French; the Latin edition being a great rarity and hidden by Poles like a treasure. He tells also that the pyrotechnic art is of a very high standing in Poland.

The Dutch translation has been published in the same year as the English, that is in 1729; the full title of this edition could not be established.

Janocki (*Janociana III*) relates that the manuscript of the second part of Siemienowicz work was in the library of princes Sanguszko

in Lubartow near Lublin, later it has been in the library of Załuski in Warsaw and together with this library was transferred to Petersburg. The author of this paper was in Leningrad (previously Petersburg) in 1957 and could not find there the manuscript of the second part of *Artis Magnae*...

In the introduction to the first part of *Artis Magnae*... Siemienowicz enumerates the titles of the seven books of the second part of his work.

In giving a general characteristic of the first part of Siemienowicz work we shall consider it to be the first serious attempt in the world to create a new science, for such the science of artillery was considered by Siemienowicz. Hitherto it consisted mostly of artisans prescriptions. The work contains many things which have been "discovered by others" but a large part of it is an original work by Siemienowicz.

Siemienowicz is perfectly conscious of the necessity to have his science of artillery founded on a number of basic sciences such as: arithmetic, geometry, mechanics, chemistry, hydraulics, architecture, optics, ballistics a. s. f. He attempts to have empiric prescriptions substituted by scientific prescriptions. Being well aware of the worth of his work he writes it in Latin so it may be of service to everybody. He is not hiding his knowledge but exposes it with the utmost clarity and correctness. Such a stature of a scientist and research-worker makes him distinguishable from pyrobolists-practicians, who take the greatest care, writes he, that "what they obtained from others remains the greatest mystery to everybody". Technological prescriptions hidden most jealously by gun-makers were openly published by Siemienowicz and improved by his own observations and experiments. All prescriptions were thoroughly verified: "Every mixture that I applied in practice was preceded by an exact calculation and has been subject to a geometric verification, till it has been established on the basis of physical laws".

Siemienowicz shows a substantial knowledge of up to-date literature. While elaborating his book on rockets he availed himself of the works of 25 writers dealing with pyrotechnics. He quotes the works of Brechtelius, Uffanus, Hanzelet, Fronsberger, Hieronim Cotaneus and Hieronim Ruscelli. The clarity and the scope of his lecture and of the relevant problems show that he was thoroughly acquainted with all problems of artillery and of the application of artillery to military purposes.

DE ROCHETIS, BOOK N. 3 OF SIEMIENOWICZ WORK
AND HIS PHYSICAL IDEAS

The whole activity of Siemienowicz as an outstanding theoretician of artillery deserves to be analysed in detail, but we are not going to discuss it here. We shall go over and discuss the achievements of Siemienowicz in rocket matters, as his merits from the point of view of modern rocket development are in this respect especially remarkable.

The book *De rochetis* is partly a review of the state of rocket technique in the middle of the XVII century, partly an independent work of Siemienowicz, theoretical as well as experimental.

The theoretical attainments of Siemienowicz, which beside new types of rockets, are especially noteworthy are: the elaboration of new fuel mixtures for rocket propulsion, application and boring of holes in propulsion mixtures (the nozzles), classification of rockets on a new basis (on rockets diameter and not on its length), a new elaboration of such an important constructional parameter of the rocket as the relation of its length to its diameter, depends on the dimension and the weight of the rocket. We shall not discuss these matters any further, they belong to the technology of rockets and may be of interest to an historian of pyroballistics only.

An elucidation of the principle of rockets motion has a general significance, as is said by Siemienowicz in connection with the boring of holes in propulsion parts. These holes play the role of an ejection nozzle enlarging at the same time the combustion surface of a solid fuel (powder). Siemienowicz writes: "...such a shape of the flames outlet ensures a more easy way to the gnawing of the matter, which flowing out returns its power and throws the rocket with great force".

Worth noticing here is the fact that the cause of the rocket motion according to Siemienowicz are the outflowing gases. Siemienowicz tells that they "return the power", today we would speak of a thrust or of the reaction force with which the flowing out from the nozzle gases act upon the rest of the rocket. We see that Siemienowicz did not commit the error, which is made frequently even to-day when explaining the principles of rockets motion, namely that the rocket is pushed back from the surrounding matter (air). We know perfectly well that the rocket may be propelled in an empty space also, and the propulsion occurs from the process

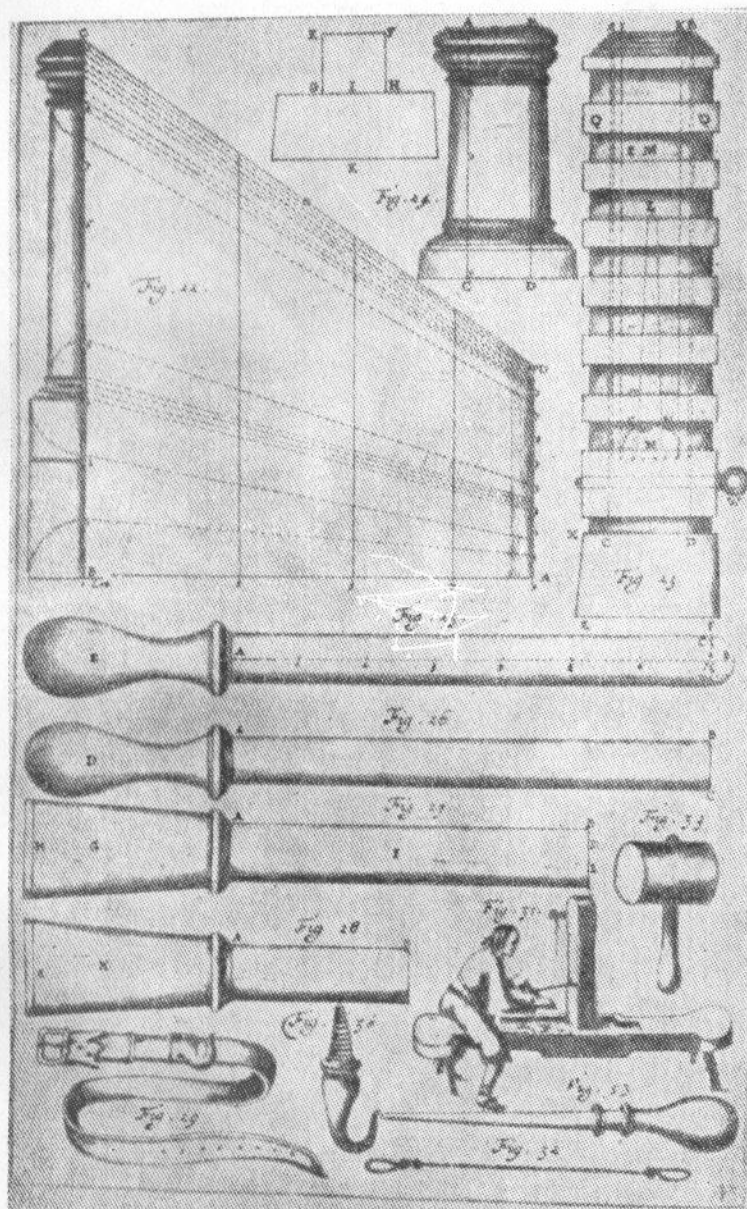


Fig. 4a. The designs and sketches by Siemienowicz of tools consecutive stages of rocket production in the middle of the XVII century as in *Artis Magnae...*, table E.

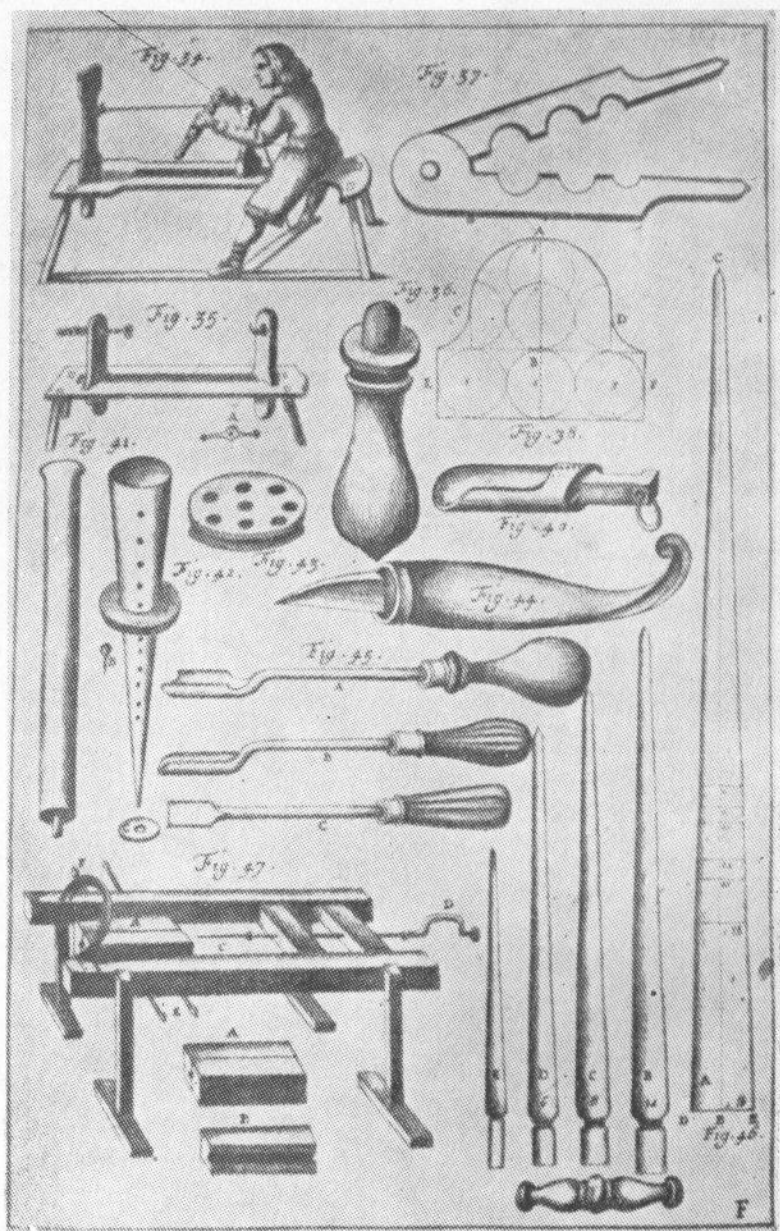


Fig. 4b. The designs and sketches by Siemienowicz of the consecutive stages of rocket production in the middle of the XVII century, according to the *Artis Magnae...*, table F.

of gases ejection out of the nozzle thanks to the reaction of these gases. The explanation of this phenomenon was formulated by Newton in his third principle of dynamics in 1687. It seems that in connection with this special case of rockets motion Siemienowicz understood already the third principle of Newton dynamics, although his explanation lacked clarity.

In Siemienowicz text we can find some formulations relating to the principle of rockets motion which indicate that he was not always capable to get free from the ideas predominating at that time. So for instance discussing the holes in the propulsion mixtures of the rocket and stressing their necessity he writes that otherwise "the fire would not reach the inner parts to set the fuel on fire and the property of its nature is such that everything it controls it carries off returning home, and in this way it lifts the pipe of the rocket together with all accesories and runs through the air as far as the material with which it is filled lasts". We can see in this explanation of rocket motion some signs of Aristotle ideas. Elements tend to their proper sphere. The fire's sphere is above the air's sphere. The fire which is visible when the powder is burning runs to its proper sphere carrying with itself the pipe and the rest of the rocket and lifts it up.

It must be said that considering the motion of the rocket in the air Siemienowicz stresses the importance of the rockets shape due to the resistance of the air. To-day we would say that the shape of a rocket moving in the air should be aerodynamic in order to reduce the resistance of the surroundings.

THE TECHNIQUE OF ROCKETS PRODUCTION ACCORDING TO SIEMIENOWICZ

The designs and sketches by Siemienowicz (fig. 22 to 47) fig. 4a and 4b present in detail the consecutive stages of rocket production. The mould cast in brass presented as fig. 22 had inside a vertical pin located in the centre. A shell inside the mould was filled with powder strongly compressed by beating it by means of pegs of a consecutively reduced length (fig. 26, 27 and 28). The shell was made of paper by wrapping it around a wooden pin (fig. 25). The binding of the shell filled with powder with a special cord (fig. 32) was done on an apparatus shown on fig. 31 and prevented the powder to be poured out of the rocket. Due to the pin in the brass cast the cartridge

had a long conic hole. During the binding this hole was secured by a wooden pin (fig. 36) which was later removed. The fore part of the rocket was closed by a wooden or metallic shield (fig. 43) with many small holes pierced through, due to which in the final stage of the powders burning the flame could set on fire the illuminating or the lighting load lodged in the upper part of the missile. The drill shown on fig. 47 was used to bore holes in the rear part of the powders load in cases when the mould for rocket production had no pin. Drills of various sizes used for this purpose are presented on fig. 46.

Such an equipment for rockets production as represented on the above named designs remained unchanged for over 200 years.

We have already spoken of the application by Siemienowicz of long holes in the propulsion mixtures: these holes played the role of ejection nozzles increasing at the same time the combustion surface of the propulsion mass (gunpowder). Before Siemienowicz no one has written about the boring of holes in the propulsion mixtures, that is about the necessity of nozzles in a rocket. On another place Siemienowicz says that it is hardly possible to suppose no one before him had the idea to bore holes in the propulsion mixtures, but probably such a procedure, being of great importance in the production of rockets, has been strictly concealed.

It is therefore impossible to consider Siemienowicz as the first who designed and built rockets provided with ejection nozzles. Nevertheless he is undoubtedly the first who has made known this idea and published detailed construction and technologic data how such ejection nozzles in rockets should be made. Nozzles spoken of here are of course nozzles in rockets for solid fuels.

SIEMIENOWICZ ATTAINMENTS IN THE CONSTRUCTION OF ROCKETS

The sketches of Siemienowicz presented on figures N. 5 and 6, fig. N. 48 to 75 represent various constructional solutions and many of them are original Siemienowicz devices. At a further place we are going to discuss various types of rockets beginning with the most interesting solution devised by Siemienowicz such as compound rockets and tailless rockets with stabilizations devices by means of wings having the shape of the letter delta.

It must be preceded however by a general discussion on the relation of the parameters of a modern rocket to its range and speed.

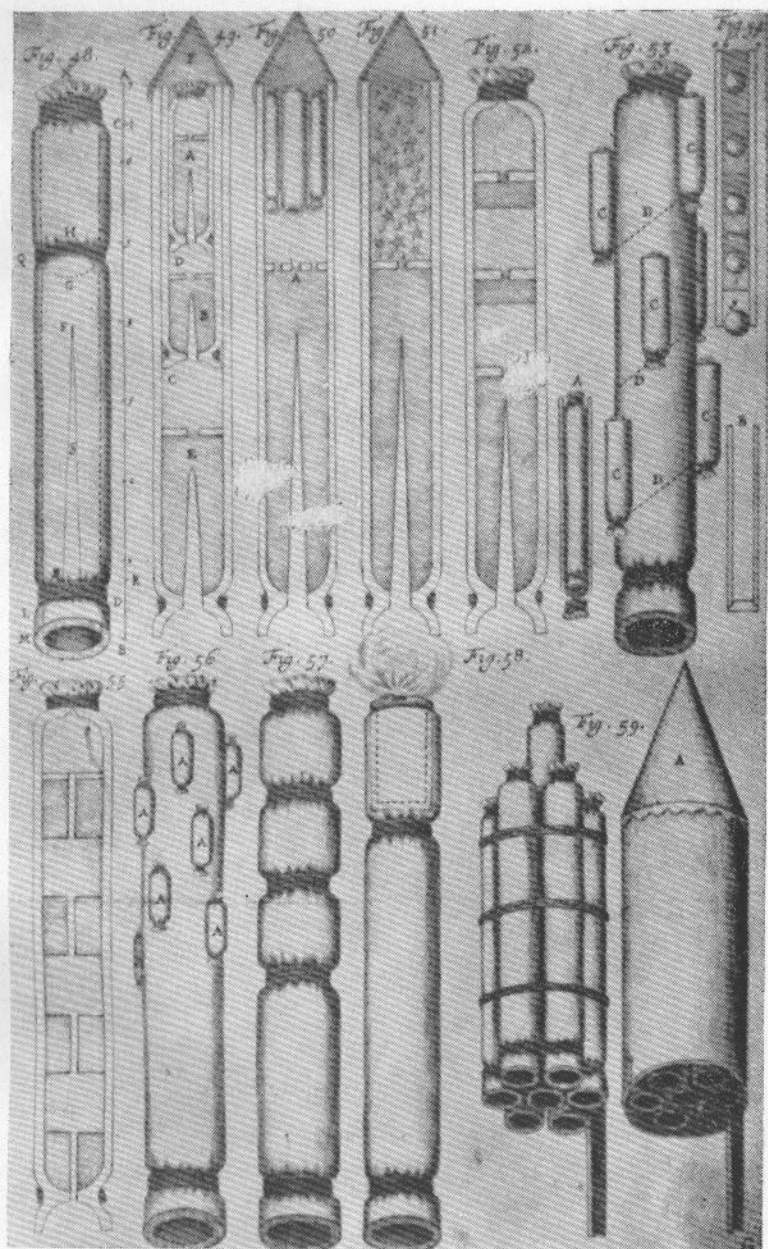


Fig. 5. Table G of Siemienowicz monograph. The sketch bearing the number 49 is the first in history version of a multistage rocket, the sketches bearing the number 59 are a version of a rocket battery, and number 50 is the first version of a combined rocket of a two stage system, the second stage is the rocket battery.

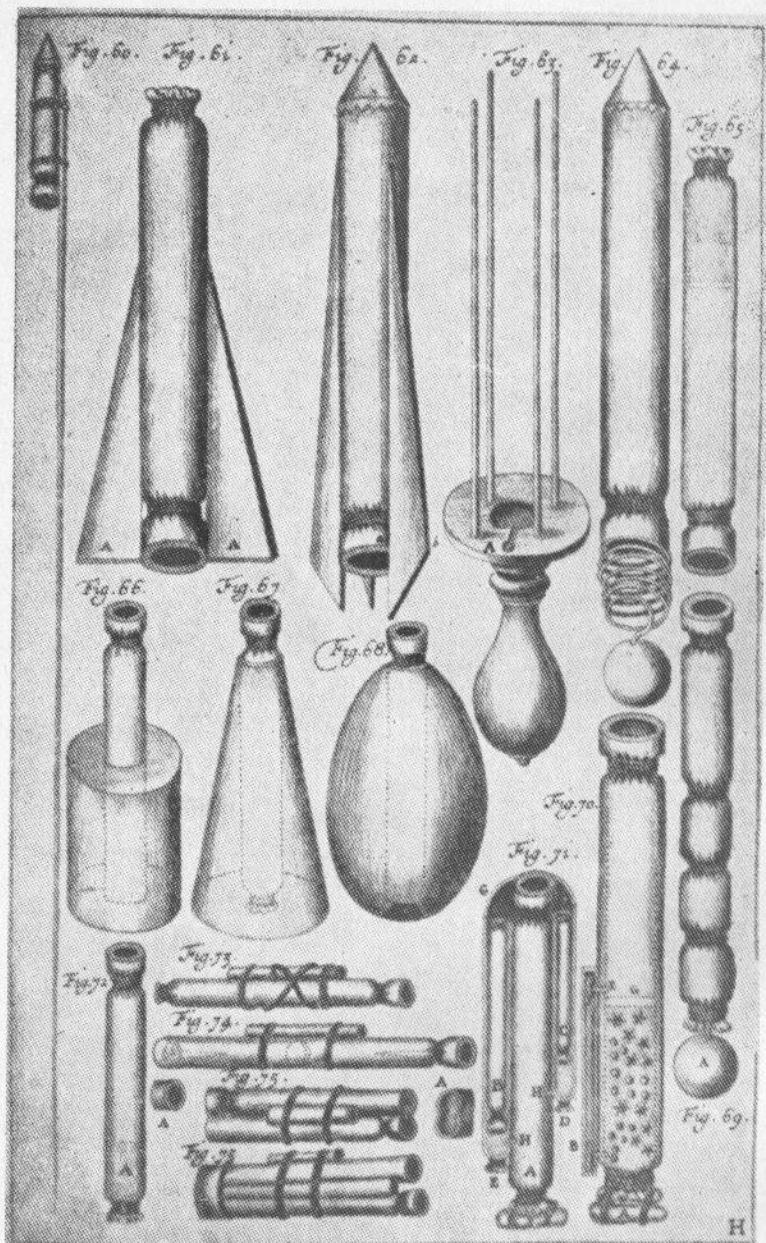


Fig. 6. Table H of Siemienowicz monograph. The sketch No 61 is the delta wing stabilized rocket. The tail pole in No 60 is replaced by two (Fig. 61) or three (Fig. 62) shafts. A different solution of the stability of the rocket flight represent sketches No 64 and 69. The design as in No 60 is named in Suttons (1949) book in connection with Congreve's developments around 1800).

It will help to understand the real importance of Siemienowicz constructional ideas stressing at the same time his profound knowledge of the possibilities of a rocket.

The third principle of Newton's dynamics explains the origin of the reaction force and so also the flight of the rocket. The rockets motion is an example of motion of a body of a variable mass. During a propelled flight (while the engine is running) the mass of the rocket varies; it is getting less by the mass of gases ejected through the nozzle, i. e. the so called jets. The rockets flight does not depend on the surrounding environment and may take place in an empty space also. The rocket has namely on its deck the fuel as well as the oxidizing matter.

Let us suppose the speed of the gases ejected from the nozzle relative to the rocket to be a constant w . Assuming that the rocket is moving in a gravitationless space and no drag, and that at the moment of starting ($t = 0$) the rockets mass is m_0 we obtain for the speed v which will be reached by the rocket after a part of the fuel is burnt, when the mass of the rocket with the remainder of the fuel will amount to m the formula: $[v = w \cdot \lg m_0/m_k]$. In case the whole mass of the empty rocket is m_k and the mass of the fuel is m_p , then: $[m_0 - m_p = m_k]$. The speed the rocket in a gravitationless field may attain with no drag, after the whole fuel has been burnt is named v_p the characteristic or ideal speed $[v_p = w \cdot \lg m_0/m_k]$. This formula has been derived by Ciołkowski (1903).

The relation m_0/m_k is one of the most important parameters characterizing a rocket and is called the mass ratio.

Writing this formula in the shape of: $[\lg m_0/m_k = v_p/w]$ we see that in practice the velocity w of the ejected gases has a much greater effect on the speed of the rocket v_p than their mass. So for example to accelerate a mass of 1 kg. to a speed $v_p = 12$ km/sec. the velocity of the jets being $w = 1$ km/sec. the mass of fuel must amount to 160 000 kg. approximately. It is evident that in practice it is impossible to have the mass of rocket together with the tank and equipment 160 000 times less then the mass of fuel. The mass ratio m_0/m_k is becoming less unfavourable as the velocity of the ejected gases goes up. So when the velocity of gases ejected from the nozzle $w = 12$ km/sec. the final speed of the rocket will reach 12 km/sec. when $m_0/m_k = 2,718$.

The meaning of this example is perfectly obvious: in order to increase the speed of the rocket it is necessary to increase the velocity of gases ejected from the nozzle. It is the more evident as technical considerations do not admit the ratio of the rocket masses to be too big. The mass of the empty rocket together with empty tanks and equipment and with useful load cannot be less than the mass of the transported fuel by more than 7-9 times even with the most optimistic constructions premises. It seems not possible in a one stage rocket the relation of masses m_o/m_k to be more than 10. We see there is a strict limit to the possibilities for an increase in the relation of masses at a one stage rocket. To-day the possibilities to increase the velocity of gases ejected from the nozzle are also limited to 3 or possibly 3.5 km/sec. Taking all together it means that the ultimate speed of a one stage rocket is also limited to a few km/sec.

The speed of an intercontinental rocket must be around 6—7 km/sec. and of a rocket carrying an artificial satellite of the earth near 8 km/sec. A flight to the moon is possible with the flight speed around 12 km/sec. In order to attain such speeds and to reduce the unfavourable mass ratios m_o/m_k the jet velocity has to be substantially increased. But here we meet immediately new difficulties. A higher velocity of gases ejected from the nozzle means a higher pressure. At present we have no such heat resisting materials at our disposal.

In such a way the difficulties in materials and construction put a limit to the application of one stage rockets to high speeds. There is however a solution to this problem, namely the construction of a multistage rocket which is one of the variants of a compound rocket.

There are two types of a compound rocket: a multistage rocket where the particular engines are located one behind the other and are running not simultaneously, and battery rockets (a multinozzle rocket) where separate smaller engines are elements of a bigger aggregate and are located one beside the other and all run simultaneously. There is a possibility of a third kind of a compound rocket, namely a combination of the two above types. It would be a compound combined rocket. In such a case one or more stages of the multistage rocket are composed of rocket batteries.

The problem of compound rockets arose in connection with the possibilities of cosmic flights beyond the atmosphere area and by the construction of missiles of a great vertical and still more of a great horizontal range (intercontinental rockets) and of anti-aircraft rockets. In a multistage rocket the smaller rocket is a load of the bigger rocket and these two rockets form a load of a still bigger rocket. At a certain altitude the big rocket launched from the earth throws off the load it carries—the smaller rocket equipped with all necessary installations and fuel. This rocket continues an independent flight deprived of all its needless ballast — the tanks and equipment of the mother rocket and is starting to this new flight a much greater initial speed. Such a daughter-rocket may carry with itself further up a still smaller rocket, equipped with its own engine and fuel a.s.f. till the desired speed is attained. So for example a three stage rocket may attain about three times greater speed than a one stage rocket.

Let us compare the characteristics of a two stage rocket built in 1949, V-2 + WAC Corporal, named "Bumper". Let it work first as a one stage rocket, and then as a two stage tandem. When the engines of both stages work simultaneously (technically it would be almost impossible to attain, but in this case we wish only to illustrate the principle), then after the fuel has been exhausted the speed of this one stage rocket would theoretically amount to 2,760 m/sec. Then let the same rocket work as a two stage tandem: to begin with let the engine of the rocket V-2 work, then at a certain altitude the fuel being exhausted the shell V-2 drops off and the rocket WAC Corporal, its engine being set to work, continues its flight independently. When its own fuel has been exhausted its speed according to theoretical calculation shall amount to 4,600 m/sec. The advantages of a multistage rocket are evident, the increase in speed is almost twofold.

The author of the idea of a multistage rocket is Kazimierz Siemienowicz.

His sketch presented on fig. 49 is the first in history version of a multistage rocket. The design represents a three-stage rocket. Each of the stages is an independent rocket, equipped with fuel, an ejection nozzle and ignition. The whole is composed of three pipes. The third stage is a load of the second stage and the second — a load of the first stage. The masses of the three rockets as proposed by Siemienowicz are: 820 grams, 307 grams and 128 grams respectively.

the relation of masses being accordingly $(6.4) : (2.4) : 1$, and each stage works successively. The increase in the number of stages should bring an increase in the vertical and horizontal range of the rocket.

Konstanty Ciolkowski* was first to advocate in 1917-18 the idea to use a multistage rocket in cosmic travels. We cannot tell did Siemienowicz only design a multistage powder rocket or did he built it himself as well. Consequently as the first technically realized multistage rocket for solid fuel is to be considered the German guided missile „Rheinbote“ from the period of the second world war. The first multistage rocket for liquid fuel that was built and launched was the already mentioned tandem “Bumper”. In an independent flight each of the component rockets V-2 and WAC Corporal can separately reach an altitude of 183 km. and 70 km. respectively. As a two stage tandem the rocket WAC Corporal attained in 1949 the altitude of 402 km., and in 1954 — 425 km.

With the chemical fuels that are at present at our disposal the flight speed, necessary to launch an artificial satellite was obtained with a three stage rocket.

K. Ciolkowski while considering the means to attain the greatest possible thrust with fuels being at that time at his disposal, with a cosmic flight in his mind, sought a different technical solution, other than a multistage rocket. He found such a solution in a rocket battery where a number of rocket propelled units are located not one behind the other as is the case in a multistage rocket, but one beside the other. Contrary to the multistage rocket all engines work here simultaneously.

A rocket battery is a propelled aggregate capable to attain a very big thrust and consequently very remarkable accelerations being at the same time devoid of the difficulties inherent in a very big combustion chamber. In this case each element of the propelled aggregate is a separate rocket engine of a middle size with a normal combustion chamber and nozzle. The construction of such an aggregate is simpler, the separate engines being a product of a serial production, they are therefore much cheaper than a single gigantic engine, which would be really a prototype.

An idea of Ciolkowski, which he advanced after the first world war, was to have the particular rockets, parts of the rockets battery

* In English transcription Tsiolkovski.

aggregate, move one beside the other and burn the fuel simultaneously. The exterior rockets would be dropped during the ascent having the remainder of the fuel in the tanks pumped over to the other rockets which form the core of the battery. Such a system would enable to attain very considerable acceleration provided the remainder of the fuel will be pumped quickly enough. Identical designs of a rocket battery have been advanced recently by professor G. Crocco and dr. W. v. Braun.

The idea of a rocket battery also originated with Siemienowicz.

The sketch by Siemienowicz bearing the number 59 is his first version of a rocket battery. This battery was composed of seven powder rockets. It is a battery of a signalling type or for the transportation of explosives. Its elements are joined together to form a system of propelling units all working simultaneously. Fig. N. 50 is an example of a combined rocket, such as is recently advocated in connection with the designs of a vehicle to be used for cosmic flights. A combined rocket is a multistage system, whose one or more stages are rocket batteries. In cases when a big thrust is necessary and when a production of a very large single propelling unit presents great technological and technical difficulties, it is especially advisable to apply rockets batteries as the first stage of a multistage rocket. Such a combined multistage rocket was launched to put the American artificial satellites "Explorers" in their orbits.

The combined Siemienowicz rocket is of a two stage system. The second stage consists of a battery composed of two rockets. A wooden cylinder located between the two rockets is filled with shining balls (fig. 54). These balls are dropped consecutively during the flight and present a beautiful luminous sight.

Up to the beginning of Siemienowicz activity and even for a long time after him rockets were supplied with a pole tail (fig. 60) which kept its equilibrium during the flight, neutralizing the disturbances caused by the change in the distribution of the load, the fuel being gradually burnt.

A wooden tail, seven or eight times the length of the rocket made a stable flight of the rocket possible. The launching installation consisted of a big scaffolding. After a number of experiments Siemienowicz came to the conclusion that the problem of a stable flight of the rocket may be solved without the pole tail. He found an excellent solution in the rocket being equipped with shafts or

fins having the shape of the letter delta. He proposed to equip small rockets, their mass being 100—250 grams, with fin-wings placed crosswise in the rear part of the rocket. The tail pole to be replaced by two (fig. 61) or three (fig. 62) shafts. The length of the stabilizer to be $\frac{2}{3}$, the width — $\frac{1}{6}$ of the rocket length and thickness to be $\frac{1}{6}$ to $\frac{1}{8}$ of the diameter of the rockets outlet.

The wing stabilizers applied to the rocket permitted to simplify considerably the launching installation. It consisted now of a small circle with four wooden rods driven in the earth vertically (fig. 63). At the moment of firing the starting rocket had to be in vertical position.

To make the rockets flight stable wing stabilizers were universally adopted in the current century only. The following example may give an idea of advantages offered by the use of wing stabilizers. The rocket V-2 which was used by Germans in the second world war has a horizontal range of about 300 km. After the war when the German rockets were tested, the construction of the rocket V-2 has been changed a little, it has been namely equipped with delta shaped wings. The horizontal range of the rocket has been almost doubled. All supersonic airplanes are now equipped with delta shaped wings. In the time to come rockets which are going to transfer passengers from the cosmic stations (artificial satellites) back to earth will be all equipped with delta shaped wings. The idea of Siemienowicz to have the problem of flight stabilization solved without the aid of a tail pole was indeed of first class importance.

The same problem Siemienowicz sought to solve in a different way. The stability of a rocket's flight had to be secured by means of an iron ball attached to the rear of the rocket on a metal rope coiled in the shape of a spiral (fig. 64).

Some of the other Siemienowicz sketches are interesting too. The most simple types of rockets are represented on fig. 48 and 51. Their rear part is filled with a propelling load and the fore part with a substance giving luminous effects. Fig. 52 represents a rocket with slackened combustion. The rocket represented on fig. 53 has on its hull smaller rockets along a spiral line; they make the rocket rotate along its axis during the flight.

Rockets represented on fig. 66, 67, 68, 70 71, 72 are adapted to move in water and to start from water, and rockets fig. 73, 74 and 75 may glide on a string running through a pipe attached to the

rocket. Two rockets tied together, with their nozzles turned in opposite directions, the fuel of the one being burnt the other one begins to move the rocket in the opposite direction. Such rockets were used for entertainment only.

The accomplishments of Siemienowicz in the domain of rockets technique is equally imposing. It seems that only in the beginning of the XIX century the activity of an Englishman Congreve may be considered, and only to a certain degree, as a step further to the work of Siemienowicz, unsurpassed for at least 150 years. The tool outfit used by Józef Bem (1820) in the Polish army of the Congress Kingdom in the production of rockets is almost identical with the one projected by Siemienowicz. Constructional ideas of Siemienowicz may be considered as classic models.

The form of modern rockets brought no basic changes, no new fundamental solutions have been since introduced. In recent times some real progress consists chiefly in the application of liquid fuels instead of solid (powder) fuel which has been applied by Siemienowicz. A further novelty in the time to come shall be probably the ion and photon rockets but so far they are still in a sphere of hypothetical projects, especially the photon rocket.

Constructional solutions similar to those of Siemienowicz may be found in the works of Ciołkowski, the founder of modern astronautics, they came but 280 years later.

It must be however strictly understood that Siemienowicz constructional solutions were conceived with regard to small powder rockets used for military or entertainment purposes. The ideas advanced by Ciołkowski and by other later authors had to do either with astronautic problems or with a broad application of rockets to military purposes. Here however we are not concerned with the destination of rockets for such or other purposes but merely with the formulation of constructional solutions.

From this point of view it must be considered strange that such a remarkable work as that of Siemienowicz was almost entirely ignored by contemporary historians of rocket technology at a time when rockets such as have been designed by Siemienowicz are built for military purposes and for future cosmic flights.

In foreign literature men who lived much later than Siemienowicz are considered to be the authors of multistage rocket. In Soviet literature K. E. Ciołkowski (1857—1935) is regarded as the author of a multistage rocket. The idea of a multistage rocket is

advanced by Ciolkowski in his fantastic novel *Beyond the Earth* written in 1917 and printed in the publication "Nature and men" in 1918 (in Russian).

A mathematical analysis of "cosmic rocket train" (multistage rocket) has been published by Ciolkowski in 1929.

In order to give an idea of the importance attached to the multistage rocket we may quote some remarks taken from the work by Gilzin, bachelor of technical sciences: *Poutieshestvia k dalekim miram* (Moscow 1956) (considering the difficulties to attain the flight speed by means of a onestage rocket) ... "Ciolkowski's genius prompted him an excellent solution. The idea of a multistage rocket advanced for the first time in the world by Ciolkowski... consists in getting rid of these parts of the rocket that are becoming superfluous. As each outstanding idea the Ciolkowski's conception combines a remarkable simplicity with an extraordinary efficiency".

These words should have been rightly applied to Siemienowicz.

Willy Ley in his book *Rockets and space travel* (1948) discussing broadly rocket problems puts Siemienowicz work in bibliography only, omitting his name in the text, whereas he quotes the names and includes the designs of other less prominent authors some of whom lived before and some after Siemienowicz. According to Ley an American rocket research worker, R. Goddard, who lived from the end of the last century till the middle of the present century, and Oberth, a still living German specialist of rockets and astronautics, have devised the principles of a multistage rocket already in the beginning of their theoretical studies. Ley adds however that the "Belgian patent, granted to dr. André Bing in 1911 described that invention". Ley writes further that "you can find pictures and descriptions of step rockets in books on fireworks dating back 1700 and earlier".

In an article published in 1954 in the "Journal of the British Interplanetary Society" H. E. Ross wrote: "both V-2 and the A9/A10 combination are realizations of ideas advanced by Oberth as far back as 1922. However the principle of the step rocket itself is attributed by one cutting to a French officer, Montgéry, in 1827".

Examples of such formulation are numberless.

It should be emphasized that the professional literature published in foreign languages is almost completely devoid of any mention about Siemienowicz works. It may be that the difficulty to find a monography on Siemienowicz is the cause.

Siemienowicz as the author of the idea of a multistage rocket is mentioned by merely one sentence by the following: Shershevsky in his book *Die Rakete für Fahrt und Flug* (Berlin 1929) and A. Szternfeld in his monography: *Wwiedienie w Cosmonawtiku* (Moscow 1937). Three illustrations taken from Siemienowicz book given rather as a sort of curiosity and not spoken of in the text, appeared in an article by professor T. v. Kármán in a monthly "Inter Avia", 1953.

And that is all. The rest of the rich contemporary literature on rockets in foreign languages omits the name of Siemienowicz, does not say a single word of his merits and his ideas are credited to authors of a much later period.

G. P. Sutton for instance in his book *Rocket Propulsion Elements* (London 1949) writes about an early stage of the rockets technology development and connects it with Congreve. On page 23 of his book he inserts a design of a powder rocket equipped with a pole tail and gives the following explanation: "Early rocket projectile (around 1800)". This design is identical with the one presented by Siemienowicz as fig. 60 of his sketch of a rocket with a tail.

Gilzin (1956) attributes the idea to equip a rocket with wings to a Soviet constructor Zander (in the twenties of our century). This idea in reality has been advanced as early as 1420 by an Italian constructor J. Fontana who supplied his rocket with the "traditional" wings and made his ship resemble an airplane in its early stages of development. The idea of wings in the shape of the letter delta as a stabilizing element has originated with Siemienowicz.

It may be said further that the merits of Siemienowicz and his conceptions on rockets have been stressed by the author of this here article in a notice in the British publication of the British Interplanetary Society, 1955.

It may be said in conclusion that the foregoing remarks have established the priority of Siemienowicz conceptions of the three varieties of a compound rocket namely: of multistage rocket, a battery rocket and a combined rocket, and in addition the conception to equip the rocket with delta wings.

The author of this here article does not know of anyone in world literature who prior to 1650 has conceived the ideas discussed above, that is before it has been done by Siemienowicz.

BIBLIOGRAPHY

1. Bem: *Doświadczenia nad zapalającymi raketami Congreve'a zebrane w Królewskiej Polskiej Artylerii do roku 1819*. Weimar 1820.
2. F. Bentkowski: *Historia literatury polskiej*, vol. II, page 361, Warszawa 1814.
3. I. Chodynicki: *Dykcyonarz Uczonych Polaków*, 1833, vol. III, p. 106.
4. K. Ciołkowski: *Sobranie sotchinienii*, v. I-1951, v. II-1954, Moscow.
5. K. Ciołkowski: *Wnie Ziemi*, 1918, in the publication „*Priroda i Liudi*“.
6. *Encyklopedia Orgelbranda* v. 23, 420.
7. *Encyklopedia Powszechna Gutenberga* v. 16, p. 37.
8. *Encyklopedia Wojskowa*, Warszawa 1933.
9. *Enciclopedia ditcheskij slowar*, 1900, v. 57, 431.
10. Estreicher: *Bibliografia Polska*, v. 28, p. 24.
11. K. A. Gilzin: *Putieshestvie k dalekim miram*, Moscow 1956.
12. R. Goddard: *Methods of reaching extreme altitudes*, 1919.
13. K. Górski: *Historia artylerii polskiej*, Warszawa 1902, 148.
14. Janocki: (*Janociana*) vol. III, 299.
15. M. Jahns: *Geschichte des Krieges von der Urzeit bis Renaissance*, Leipzig 1880.
16. T. v. Kármán: „*Inter Avia*“, nr 11, 628, 1953.
17. Korzon: *Dzieje wojen* vol. III, 50—51.
18. W. Ley: *Rockets and space travel*, London 1948.
19. Łukaszewicz: *Historia szkół* vol. I, 441.
20. T. Nowak: *Polska sztuka wojenna w czasach Odrodzenia*, Warszawa, 1955, 126—133.
21. H. Oberth: *Wege zur Raumschiffarth*, Munich 1929.
22. St. Probulski: „*Technika Lotnicza*“ vol. 10, nr 3, 66, 1955.
23. St. Probulski: „*Problemy*“ nr 9, 1955.
24. „*Roczniki Towarzystwa Warszawskiego*“ PNT, IX—218, XVIII—150.
25. H. E. Ross: „*Journ. Brit. Int. Soc.*“ vol. 13, 245, 1954.
26. A. B. Shershevsky: *Die Rakete für Fahrt und Flug*, Berlin 1929.
27. K. Siemienowicz: *Artis Magnae Artilleriae Pars Prima*, Amsterdam 1650.
28. M. Subotowicz: „*Journ. Brit. Int. Soc.*“ vol. 14, 245, 1955.
29. M. Subotowicz: „*Problemy*“ nr 9, 1955.
30. M. Subotowicz: *Loty międzyplanetarne*, Warszawa 1955.
31. M. Subotowicz: *Silniki odrzutowe i loty międzyplanetarne*, Warszawa 1950.
32. M. Subotowicz: *Astronautyka*, PWN, Warszawa in print.
33. G. P. Sutton: *Rocket propulsion elements*, London 1949.
34. A. J. Szternfeld: *Wwiedienie w cosmonawtiku*, Moscow, 1937.
35. T. Zebrawski: *Bibliografia mat. i fiz.* Cracow 1873, p. 294-296.