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Chapter 11

Was the Rocket "Invented" or "Accidentally Discovered"? Some New Observations on Its Origins*

Frank H. Winter,† Michael Neufeld‡ and Kerrie Dougherty§

Abstract

The history of spaceflight would not have been possible without a single object—the rocket—one of the most complex engineering feats in human history. However, a closer examination of the earliest history of the basic rocket, a gunpowder-propelled device developed in China around 1,000 years ago, suggests that it originated as an accidental discovery rather than as a deliberately planned invention. This chapter will examine the evidence in support of the idea of accidental discovery, including new observations on the earliest concepts of rocket motion, not only in China but also in the West.

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http://www.theatlantic.com/technology/archive/2012/07/the-strange-and-wonderful-origins-of-rocketry/2600237/. In addition, another article based on the paper appeared as "The Little Bang" by Jimmy Stamp in *The Smithsonian Magazine*, Vol. 43, Feb. 2013, p. 28.

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Background

Aerospace and engineering historians, such as Reynolds and Bizony[1] regard modern launch vehicles, including the lately retired Space Shuttle and the earlier Saturn V that took the first men to the Moon, as among the most complex feats of engineering in human history. In the case of the 363 ft (110.6 m) long Saturn V, the vehicle comprised some 5,600,000 separate parts, all of which had to work perfectly to enable the rocket to carry out its mission. However, a large part of the complexity of the Apollo missions was in the extremely precise computerized sequencing of almost every mechanical, electrical, and other technical event throughout each mission in order to achieve near pinpoint planned accuracies of soft landings on the surface of the Moon.[2] The Apollo and Space Shuttle programs thus required *multiple inventions*, along with the modern management tools of systems and human factors engineering, to be successful. Of these multiple inventions, the basic rocket is undoubtedly the oldest: yet, was it really an invention? [Figure 11–1]

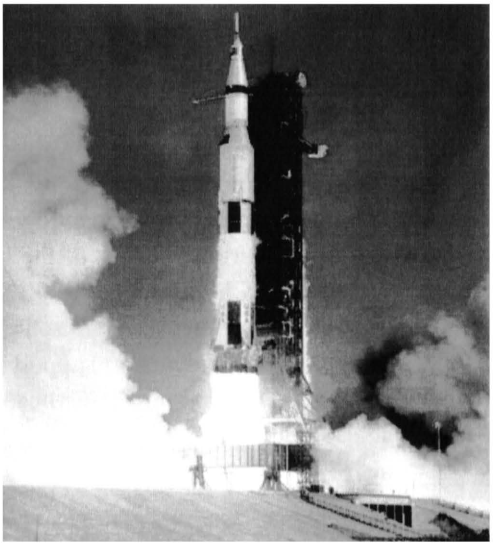


Figure 11–1: The Saturn V rocket. Credit: National Aeronautics and Space Administration.

While it is outside the scope of this chapter to explore the extensive literature on the nature of the term *invention*, we note that the standard Webster's dictionary definition is: "The creation of something not previously in existence" that is the product of "purposeful experimentation leading to the development of a new device or process."[3]

The Earliest Chinese Rockets

The basic rocket has a history extending back about a millennium. Although we still do not know who first made the rocket, nor when nor how it was devised, there has been a long-held and commonly accepted belief that the rocket originated in China. Exhaustive and groundbreaking researches by Dr. Joseph Needham and other scholars studying ancient Chinese manuscripts, principally on alchemy, point to China's Sung Dynasty (AD 960–1279) as the likely period and place of the origin of the rocket.[4]

The first rockets were very primitive and used a weak form of gunpowder (the main ingredients being saltpeter or potassium nitrate, sulfur, and charcoal, although in different and carefully worked out proportions). In these early devices, gunpowder (also termed black powder) was simply tamped into parchment or bamboo tubes, closed at one end to create a chamber, and opened, or partly opened, at the other end so that the gases from the burning gunpowder composition drove the rocket forward. Whether used as weapons or amusement devices, these rockets were evidently stabilized in their short and unsteady flights, by having the cylindrical rocket bodies attached to arrow shafts with feathers at the rear. [Figure 11–2]

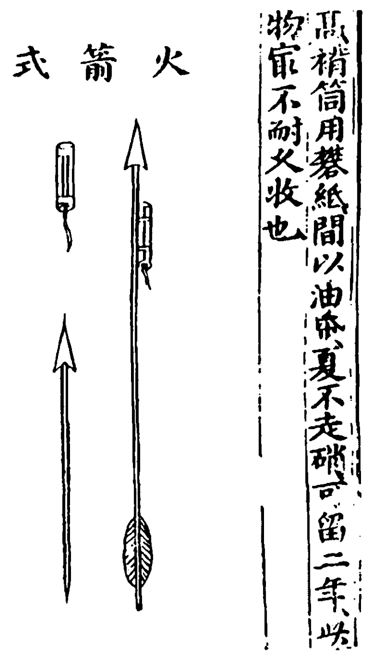


Figure 11–2: Typical early Chinese rocket, as found in the *Wu Pei Chih* (*Treatise on Military Equipment*) by Mao Yüan-i of circa 1621. Credit: *Wu Pei Chih*, circa 1621, chapter 12, p. 44a, from copy in Library of Congress.

Thus, in delving into the origins of the rocket, the most important points we need to focus upon are:

- How gunpowder originated, since the prerequisite appearance of gunpowder was necessary *first*, before the appearance of the rocket;
- How the rocket may have originated;
- How the movement of the rocket—its unique ability for self-propulsion and also the nature of the combustion of gunpowder itself—was perceived by the Chinese.

The Chinese work *Wu Ching Tsung Yao* (*Collection of the Most Important Military Techniques*)[5] is claimed as the first book in history to record written formulas for gunpowder.[6] Undertaken under the imperial order of the Sung Emperor Renzong (ruled AD 1022–1063), the *Wu Ching Tsung Yao* was compiled to improve the knowledge of all the known techniques then used in warfare. It was meant to be kept secret and therefore only limited editions were published. Described under the heading "Method for making the *fire-chemical*" (*huo yao fa*), its gunpowder recipes contained not only saltpeter, sulfur, and charcoal, but added ingredients like oils, vegetable matter, and arsenic compounds. However, these powder recipes only apply to crude bombs and there are no suggestions of any rockets, or rocket-like (that is, reaction-propelled) devices in the *Wu Ching Tsung Yao*. Stronger gunpowder, with no additives and approximating that of more modern recipes, appeared later, by the 13th century.[7]

In determining the earliest reference to, or description of, a rocket device in Chinese (or other) sources, investigators must be cautious in correctly interpreting early Chinese terminology, which can be ambiguous, or refer to changing technologies over time. For instance, the Chinese term *huo chien* (or *fire arrow*) is simply not enough to qualify it as a rocket device since it could also mean an ordinary arrow carrying, or tipped with, an incendiary. Even terms like *fei huo tsiang* (*flying fire lances*) are not sufficient, as such devices may have been no more than hand-thrown lances or spears with burning heads, or handheld devices from which flames shot forth (misleadingly labeled as "flying fire"). It does not help matters that *huo chien* is a term that later did come to mean a true rocket. To identify a *true* rocket-propelled device in the early texts, it must be unequivocally described as operating solely by self-propulsion. The question therefore has to be: Is the device clearly described as flying or moving by itself, either in the air or on the ground, without any assistance from a man or another device (like a bow or throwing stick)? Self-propulsion should be the only rigidly held criteria.

The use of *fei huo tsiang* by the Chinese against the Mongols during the siege of Kai-fung-fu in AD 1232 is often cited in histories of rocketry and spaceflight as the first appearance of the rocket—or, more particularly, the "war rocket." However, the previously mentioned difficulty in interpreting Chinese terminology applies to this and other alleged uses of Chinese rockets from this era. We therefore cannot say for certain that rockets were used at all in the siege of AD 1232. On firmer ground is Needham's description of a simple type of firework found in the *Ch'in yeh-yu* (*Rustic Tales in Eastern Ch'i*) by Chou Mi, dated to AD 1264. Called a "ground rat" (*ti lao shu*) or "earth rat," the device described is a *self-propelled*, ground-crawling firework. It was simply a tube, "probably of bamboo, filled with gunpowder and having a small orifice through which the gases could escape; then when lit, it shot about in all directions on the floor at firework displays."[8] A colorful description of this device is offered in the account of fireworks at the Emperor's court, also during the Southern Sung Dynasty, as reported in the same source, the *Ch'in yeh-yu*:

> During the royal banquet in the palace, the Empress-dowager was entertained by the Emperor (Li Chung [or Li Tsung]) with *yen huo* [fire crackers] fired in the court. Suddenly, a ground rat ran quickly to the Dowager and went beneath her chair. She was so frightened and angered, that the banquet was called off. The responsible eunuchs were put in jail, and the Emperor apologized.[9]

Needham makes the point that the "ground rat" type of firework "may well have been the origin of rocket propulsion."[10] He does not, however, take his explanation further, although he does say that during the second half of the 12th century, there were actually two kinds of fireworks in China: the "ground rat," which was probably "older," and a type known as "meteors" (*liu hsing*), or other names, which was attached to a stick and could therefore fly upward, also by self-propulsion.[11]

According to Sun, the "ground rat" type of firework can still be found in modern China under various other names.[12] It thus appears that this simple specie of firework has a long history and may be just as valid a starting point for the origin (or rather, application) of the rocket as any other. A self-propelled, yet slow-moving, device (using relatively weak powder) would have been ideally suited to be turned into an amusement firework rather than a weapon. The origin of the rocket is still elusive, but the modest "ground rat" is the closest we come to meeting our criteria of self-propulsion. Needham makes the important comment that this simple "ground rat" firework was at first used (by the military) for "scaring troops and upsetting cavalry, then [later] applied, with stick...and balance-weight, to long-distance trajectories," but he cannot precisely date when this happened, nor gives other specifics nor cites his original sources.

The Origins of Gunpowder

In searching for the origins of gunpowder, Needham, Partington, and Sun et al., agree that it was ancient "Taoist alchemists" who discovered saltpeter as well as the explosive effects of this ingredient when mixed with others and ignited. Here, we need to briefly define Taoism, and especially the nature of Taoist alchemists.

Taoism is a philosophy and religion held to be founded by Laozi, an ancient Chinese mystic philosopher also revered as a deity. He was also the author of the *Tao Te Ching* (sometimes translated as *Canon of the Way* or *Canon of the Path*) and variously dated to between the 4th and 6th centuries BC. The *Tao Te Ching* is very complex, but put in its simplest terms it concerns the nature and conduct of life. It advocates "female" (*Yin*) values, emphasizing the passive, solid, and quiescent qualities of nature, that must be complemented by the masculine, "male" (*Yang*) values that are active and energetic. [Figure 11–3]

Figure 11–3: Laozi (fl. 6th century BC), a philosopher of ancient China, credited with founding Taoism. Credit: From author's collection.

Taoist alchemy was a branch of Taoism that focused mainly on the purification of the spirit and body in the hopes of gaining immortality (especially the Emperor's immortality). It included the search for various concoctions known as alchemical medicines or "elixirs," each for a different purpose. Hence, Chinese Taoist alchemy was both a philosophy and an ancient practice focused on finding an "elixir of longevity." Just as in Western alchemy, a secondary goal was to transmute base metals into gold. Many historians view alchemy as a protoscience that evolved into the basics of modern chemistry.[13]

Needham and his colleagues also found early accounts of the haphazard practice of the Taoist alchemists in which they occasionally had their the beards singed, hands and faces burnt, and even the houses where they worked burned down when they ignited certain mixtures. Some of the Taoist alchemical works, like the circa AD 850 *Chen Yuan Miao Tao Yao Lüeh* (*Classified Essentials of the Mysterious Tao of the True Origin of Things*), consequently offered warnings of these experiments. Needham thus concluded: "Gunpowder was not the invention of artisans, farmers, or master masons; it arose from the systematic if obscure investigations of Taoist alchemists." As more emphatically stated by Fang-To Sun, "The eventual invention of the destructive gunpowder began as a by-product of the synthesis of the life-prolonging medicine and the making of artificial gold and silver [and] must [have] be[en] accidental." He sums it up another way: "The primary purposes of such researches [as mixing ingredients together and heating them up] were not aimed at making an explosive mixture, but producing the elixir to prolong man's life, and [secondarily,] converting ordinary materials into...valuable gold and silver." He adds, "Such researches in ancient China were often supported by the Emperor's court." This implies the alchemy research was largely kept secret and few documents exist on the actual research. For the same reasons, we may never know the name of the "discoverer," date, or other details, of the first unexpected instance of the explosive behavior of such mixtures.

From here, we can only speculate that eventually, "reactive" mixtures of this kind—especially weak, slow burning types—were also found by strictly empirical (that is, trial and error) means, to serve as an application for fireworks solely for entertainment rather than as an elixir for longevity. In turn, this led to the chance "discovery" of reaction propulsion that evolved into the self-propelled "ground rat."[14]

Chinese Understanding of Combustion

Another telling piece of evidence for the probable accidental "discovery" of both gunpowder and the rocket is that like their Western counterparts, Chinese alchemists were more philosophers than scientists and lacked an adequate theory of combustion. According to Professor Li Ch'iao-p'ing, the Chinese "did not understand the actual chemical phenomena of fire," or "that air is composed of oxygen and nitrogen."[15] He further states that, "Chemistry in the modern sense did not exist in China before the 19th century." For hundreds of years, and well into the 17th century, the traditional Chinese Taoist alchemical interpretation of the explosive property of gunpowder was regarded as the interaction of *yin* and *yang,* a belief entirely in accord with the principles and practice of Taoism. We find direct evidence of this in the work *T'ien-Kung K'ai-Wu—Chinese Technology in the Seventeenth Century* by Sung Ying-Hsiang, which says, "It is believed [in the 17th century that] saltpeter and sulfur are respectively negative and positive in character. A combination of the positive (*yang*) and the negative (*yin*) forms gunpowder."[16] Based upon this philosophy, it seems highly improbable that the essential ingredients of saltpeter, sulfur, and charcoal were deliberately brought together as a planned invention to form gunpowder since the true chemical reaction of these ingredients upon ignition was hardly predictable. Again, the available evidence points towards "unexpected" results.[17] [Figure 11–4]

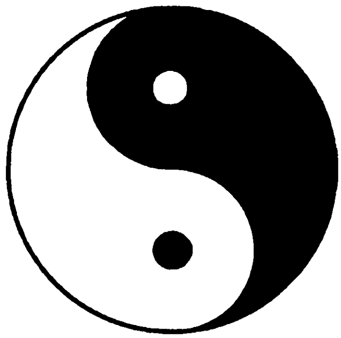


Figure 11–4: Taoist symbol of *Yin* and *Yang*, used to describe how seemingly opposite or contrary forces are interconnected and interdependent in the natural world. Credit: Hampden C. DeBose, *The Dragon, Image, and Demon or the Three Religions of China...* (New York: A. C. Armstrong and Son: 1887), p. 357.

Chinese View of Rocket Motion

Searches have been made, without success, of possible early Chinese explanations of rocket motion. However, given the tenacious and long-standing belief in the *yin* and *yang* theory of combustion, it is very likely a *yin* and *yang* explanation may have been applied to explain the rocket's motion. Dr. Ho Peng Yoke, one of Dr. Needham's former leading collaborators in research on the "gunpowder epoch"—as they phrase it—of the history of early technology in China, informs one of the author's of this paper (Winter) that he, "never encountered any Taoist text concerning the rocket." Nor did he "come across in Chinese literature any reference concerning any Chinese theory on rocket motion." However, for the purpose of this paper, Dr. Ho graciously agreed to postulate how "a medieval Chinese natural philosopher" (that is, a Taoist alchemist) might have interpreted rocket motion in Taoist terms:

"Saltpeter and sulfur are *Yang* substances and belong to the fire agent... Ascension [of the rocket] is the inert nature of fire to rise up. When gunpowder is set alight by fire, the rising *qi* produced would launch the rocket." "The word *qi,*" explains Dr. Ho, "in the modern context can be given as *thrust*, but the ancient Chinese could not have used a more precise term." (But perhaps *exhaust* might have been a more accurate modern definition.)

Qi (also transliterated as *chi* or *ch'i*) is more generally defined as the "energy flow" or "life force" of a living thing (man or animal), while the literal translation is *air* or *breath*. *Qi* is also taken to be the life-process or flow of energy and philosophical conceptions of it in the earliest Chinese records date to the 5th century BC and correspond to Western notions of humors. *Qi* too, played a role in the alchemist search for longevity and in all aspects of health. But *qi* may refer to inanimate things as well, like clouds or wind and indeed, could extend beyond the human body to reach throughout the universe. As another instance, fire and water have *qi,* but do not have life. Essentially, *qi* was used alongside *yin* and *yang* to explain the behavior of almost all phenomena.

As Ho further explains, in his *Li, Qi and Shu—An Introduction to Science and Civilization in China*, "*Qi* can exist in two different states...at rest or motion...and it can contract or expand, giving rise to the two states, *yin* and *yang*...*Yin* conveys...anything feminine...while *yang* conveys anything ... masculine." Furthermore, these two components of *qi*, *yin* and *yang*, each dominate over the other "successively in a wave-like motion...[that] can be best illustrated by the *Taijitu* diagram [Figure 11–1]. Half of the diagram is *yin* and the other half is *yang*...hence, *yin* and *yang* are opposite and complimentary to each other."[18]

Clearly, the employment of this set of Taoist philosophical, quasi-scientific and religious beliefs of the universal polarity of *yin* and *yang,* as well as *qi* to explain most all phenomenon is inadequate, from the point of view of modern science and physics, to understand and scientifically describe both the true nature of combustion and of rocket motion. We therefore theorize that it was highly unlikely that the early Chinese "invented" the rocket from a basis of well-established and proven scientific principles. Again, we contend, from early examples cited above in the history of the development of gunpowder, that the ancient Chinese alchemists (by the 11th century), seeking an elixir for longevity, very likely "witnessed" the accidental discovery of the explosion of a proto-gunpowder—an event that caused singeing of facial hair or other unexpected harmful effects.

After continuous trial-and-error experiments, possibly over centuries, these alchemists arrived at true gunpowder and these empirical experiments may have further led to the accidental discovery of the rocket, perhaps when gunpowder was placed in a container, with one end closed: when accidently lit, the container unexpectedly flew off by itself due to what we would today explain as Newton's Third Law of Motion—"For every action, there is an opposite and equal reaction."

Nonetheless, the Chinese continued their empirical experimentation, once the basic rocket had been "found," and were able to improve upon them, as well as fireworks in general, and the gunpowder weapons that eventually led to guns. As documented by Needham and his colleagues, the "improved" rockets included, more powerful gunpowder fuels, rockets with fins or wings, two-stage rockets, multiple rocket launchers, rockets disguised as animals such as birds, and rockets carrying poisonous smokes or dazzling firework lighting effects.

From the Sung Dynasty, rockets rapidly became commonplace in China and spread to Europe by the late 13th century and elsewhere: they continued to be used by the Chinese in warfare up to the later Opium Wars (1860s), and perhaps later.[19]

Another important example of the empirical nature early Chinese rocket technology, which also pertains to rocket motion, is a sketch and description in the *Wu Pei Chih* (*Treatise on Military Equipment*) by Mao Yüan-i, of about 1621 (but also dated 1628), of a tool for boring out the central cavity of a rocket's gunpowder propelling charge (Figure 11–2).[20] One of the authors (Winter) is indebted to his friend, Lola Wu, for the English translation of the description of this tool as follows: "The crucial point of a rocket arrow flying...relies on the position of its bored hole; if the hole is well-centered, the rocket will fly straight; off-centered, slanting. If the hole is bored too deep, the fire will seep out from the rear gate [that is, exit]; too shallow, the flow would be too feeble." Yet, these descriptions provide no explanation of *why* the cavity works. Significantly, this identical cavity feature is also found in several early (16th–18th century) Western pyrotechnic works and is named as "*the soul*" of the rocket—likewise without explanation. [Figures 11–5 and 11–6]

It would be a mistake, however, to conclude that the Western pyrotechnists believed that the rocket possessed a "soul," or essence or "spirit, within or of the cavity and this soul caused the rocket to fly. Rather, from at least the 16th century Western artillerists called the hollow (bore) of the gun the "soul," and the "soul" in the rocket may therefore simply have been a term borrowed from artillerists although its meaning and origin are still obscure.[21] *

But, just who originated this key feature in the rocket—whether it was in China or in the West—and when, and how it spread between these geographical regions, we may never know. As Dr. Ho notes, the *Wu Pei Chih* is "the most comprehensive compendium [of early Chinese gunpowder weapons]" and "includes much information from earlier works...[but] Some of those earlier works could have been lost since writings on firearms were listed as...classified...[secret] during a certain period in Ming China." Needham also describes the constriction of the rocket's orifice or near-nozzle, as "a way to increase the flow-velocity of the issuing gases," at ca. AD 1300, although does not cite his source.[22]

* Briefly, a modern explanation is that the rocket cavity increases the burning area and hence generates more combustion and greater thrust. However the cavity, which indeed, should be straight and uniform, although is *not the cause* of the rocket's ascent or motion.

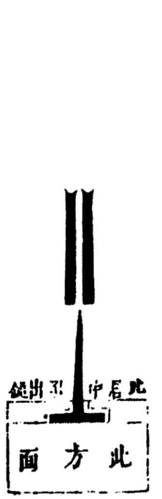


Figure 11–5 (left): Drawing from the *Wu Pei Chih*, showing a spindle used during the manufacture of rockets for making the long internal conical cavity toward the exhaust end of the rocket. Credit: From *Wu Pei Chih*, circa 1621, chapter 126, p. 3a.

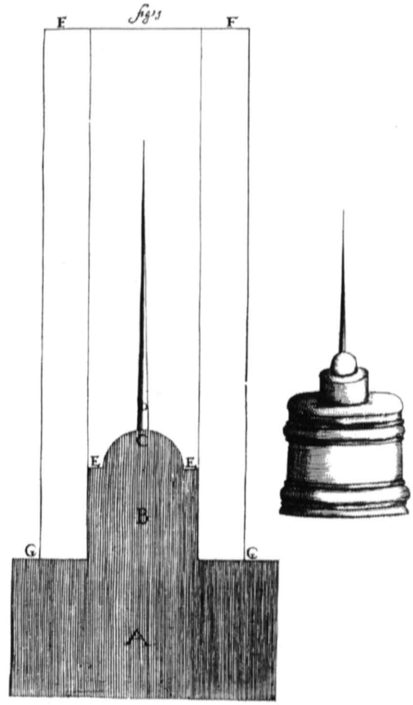


Figure 11–6 (right): A contemporary Western counterpart to this tool, as given in *Pyrotechnia, or Artificiall* [*sic*] *Fire Works* of 1635 by John Babington. Credit: From John Babington, *Pyrotechnia, or Artificiall* [*sic*] *Fire Works* (London: Printed by Thomas Harper. For Ralph Mab, 1635), p. 2.

We need not go into the spread of rocketry from China into the West except to note that it took place by the late 13th century, perhaps by way of trade routes via Arabia. Information about rockets must have spread rapidly as rocket fuel recipes appear in the *Liber Ignium* (the *Fire Book*) of Marcus Graechus, or "Mark the Greek," of the same period. By AD 1280, the German Albertus Magnus (circa 1193–1280) presented similar rocket recipes. By the 16th century, the rocket was firmly established in the West, not so much as a weapon, but primarily in its more popular application as a firework or conveyor of signals. Mentions of lavish firework displays are found from the time of Queen Elizabeth I of England (r. 1558–1603) while the first fireworks books, often detailing the making of rockets, appear from the same period, although the rockets were still small, crude and differed little from those of the *huo chien* of Sung China. If anything, these works reflect the almost stagnant nature of rocket technology in the West at this time. Coupled with this stagnation, understanding of both the nature of combustion and rocket motion was poor and it is therefore interesting to briefly examine these. Specifically, we will look at the *lack of impact* of Newton's Third Law of

Motion in the overall history of the rocket in the West up to the late 19th century.[23]

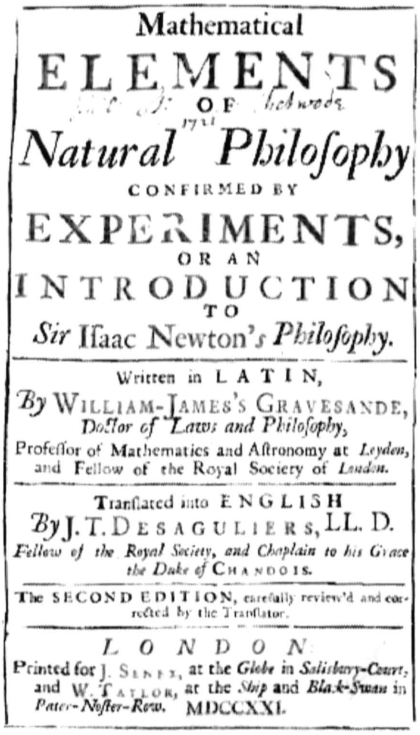
Newton's Third Law

Newton's Third Law of Motion, cited above, was first published in 1687 in his *Philosophiæ Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*), usually abbreviated as *Principia*. Although we now fully accept that the Third Law succinctly describes reaction propulsion, or rocket motion, such was not always true. For centuries the Third Law was difficult to fathom and interpret. According to Cohen: "Newton's third law has often been a source of confusion."[24] Lack of space in this chapter does not permit us to address specific details of the technical problems and Cohen and Whitman's translation should be consulted for this. In addition, apart from its incomprehensibility for many readers, Newton did *not* cite the rocket as an example of the Third Law in *Principia*; nor is the Law included in the early pyrotechnic works or other works that attempt to describe rocket motion. [Figure 11–7]

Figure 11–7: Sir Isaac Newton (1642–1727).
Credit: From the author's collections.

Interestingly, the first English translation of *Principia*, the *Mathematical Elements of Natural Philosophy...or an Introduction to Sir Isaac Newton's Philosophy* published in 1721 by Newton's friend the Dutchman Jacob Willem s'Gravesande, Anglicized as Willam-James s'Gravesande, includes the Third Law, along with four examples of its use plus two experiments to demonstrate how it actually works, but rocket action is *not* among these examples or experiments. Yet, elsewhere in the same work, in a separate section titled "Of the Dilation occassion'd by Heat," s'Gravesande does describe the cause of rocket motion. In this same section he also presents and depicts another experiment, labeled as, an "experiment [that] Shews a more sensible Effect of the Elasticity of Vapours"—with a small steam reaction-propelled car, or "a little light car," as he calls it—that could have very well been used to demonstrate the Third Law.[25] [Figures 11–8, 11–9 and 11–10]

Figure 11–8 (left): Portrait, Willem Jacob s'Gravesande (1688–1742). Credit: From the author's collections.



Mathematical
ELEMENTS
OF
Natural Philofophy
CONFIRMED BY
EXPERIMENTS,
OR AN
INTRODUCTION
TO
Sir Ifaac Newton's *Philofophy*.

Written in LATIN,
By WILLIAM-JAMES's GRAVESANDE,
Doctor of Laws and Philofophy,
Profeffor of Mathematics and Aftronomy at *Leyden*, and Fellow of the Royal Society of *London*.

Tranflated into ENGLISH
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Figure 11–9 (right): Title page of the 1721 English translation of the work by s'Gravesande, also known as William James s'Gravesande. Credit: Title page, *Mathematical Elements of Natural Philosophy, Confirmed by Experiments...* (London: Printed for J. Senex at the Globe, 1721), copy courtesy of the Dibner Library, Smithsonian Institution, Washington, DC.

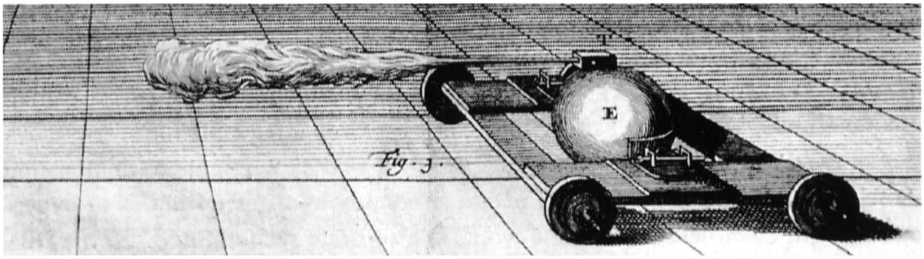
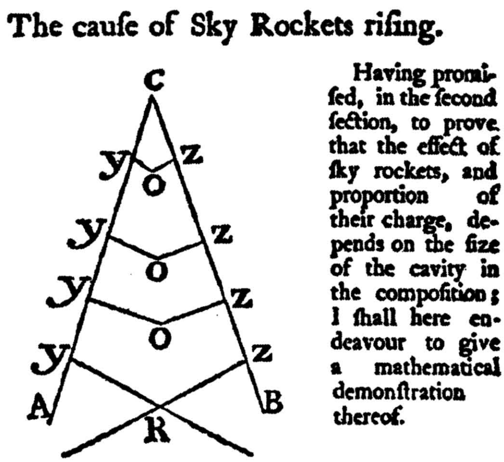


Figure 11–10: Drawing, model of a steam reaction-propelled car described in the work of s'Gravesande. Credit: From William James s'Gravesande, *Mathematical Elements of Natural Philosophy*...1721, plate 3, and in other editions.

Apparently, it did not occur to s'Gravesande that rocket motion and the steam-reaction propelled car were equivalent and ideally could have been used to describe and experimentally demonstrate the Third Law. Rather, the brief rocket motion explanation given by s'Gravesande is as follows: "A Sky Rocket rises into the Air, because the Gunpowder, being set on Fire, acquires an Elasticity, and its Parts endeavor to recede every way: As the Pipe or Case [the rocket body] of it is open at one End, it is less press'd that way, and consequently at the other end, the Pressure, and carries up the Rocket." Thus, even Newton's friend Willem s'Gravesande whose work *Mathematical Elements* was dedicated to explain and prove, whenever possible, Newton's principles (including his Laws of Motion) had failed to grasp the true cause of rocket motion as we now know it.[26] [Figure 11–11]


The caufe of Sky Rockets rifing.

Having promifed, in the fecond fection, to prove that the effect of fky rockets, and proportion of their charge, depends on the fize of the cavity in the compofition; I fhall here endeavour to give a mathematical demonftration thereof.

Figure 11–11: Theory of rocket motion as proposed by Robert Anderson in his *The Making of Rockets...of 1696.* Credit: Robert Anderson, *The Making of Rockets*...(London: Printed for Robert Morden, 1696), p. 18.

Hence, the significance of the Third Law as applying to rocket motion was *missed altogether* and this situation remained so until at least the late 19th century when it was recognized by Konstantin Tsiolkovsky, and later by others, notably Robert H. Goddard, Robert Esnault-Pelterie, and Hermann Oberth (all of whom are considered among the founders of astronautics). They further grasped that the Third Law, or reaction propulsion, can also work in a vacuum (it is not dependent upon air) and therefore reaction motion (as exemplified by the rocket) would be able to serve as a method for achieving and sustaining space flight.[27]

References and Notes

[1] David West Reynolds, *Apollo: The Epic Journey to the Moon* (New York: Harcourt, Inc., 2002), p. 282; Piers Bizony, *One Giant Leap*—Apollo 11 *Remembered* (Minneapolis, Zenith Press, 2009), p. 26.

[2] Michael Collins, *Carrying the Fire* (New York: Farrar, Straus and Giroux, 1974), p. 304.

[3] *Webster's Third New International Dictionary of the English Language* (Springfield, Massachusetts: Merriam-Webster, Inc., 2002), p. 647.

[4] Widely regarded as the best scholarship on early Chinese rockets is: Joseph Needham et al., *Science and Civilization in China. Vol. V—Chemistry and Chemical Technology, Part 7: Military Technology—The Gunpowder Epic* (Cambridge, England: Cambridge University Press, 1986) *passim.* Another excellent work on early gunpowder, that includes some coverage on the early rocket, is J. R. Partington, *A History of Greek Fire and Gunpowder* (Cambridge, England: W. Heffer & Sons, Ltd. 1960), pp. 237–298. For an examination of Indian claims for the origin of gunpowder and the rocket, with the overall finding that Chinese claims for the origin of the rocket are more supportable (mainly due to their documents being dateable, in contrast with early Indian legends of its origins) see Frank H. Winter, "The Rocket in India from 'Ancient Times' to the 19th Century," *Journal of the British Interplanetary Society—History* (London) Vol. 32, No. 12 (December 1979), pp. 467–471.

[5] Compiled from 1040 to 1044 by the scholars Zeng Gongliang (the chief editor), with Ding Du and Yang Weide.

[6] Partington actually terms it "proto-gunpowder."

[7] Joseph Needham (*Science and Civilization in China. Vol. V—Chemistry and Chemical Technology , Part 7: Military Technology—The Gunpowder Epic* (Cambridge, England: Cambridge University Press, 1986), pp. 19–21, 70–71, 73, 80–84, 117–118, 120–124, 252–253, 601; Partington, p. 287.

[8] Needham, pp. 12–13, 135–136.

[9] Needham, pp. 12–13, 135–136.

[10] It should be noted that the ground-rat origin of the rocket is only one of Needham's theories regarding the rocket, but it is his most favored.

[11] Needham, pp. 472–474, et seq.

[12] Fang-Toh Sun, "Rockets and Rocket Propulsion in Ancient China," in *History of Rocketry and Astronautics* (Proceedings of the Twelfth, Thirteenth and Fourteenth History Symposia of the International Academy of Astronautics, Dubrovnik, Yugoslavia, 1978; München, Fed-

eral Republic of Germany, 1979; Tokyo, Japan, 1980), Å. Ingemar Skoog, editor, AAS History Series, Volume 10, IAA History Symposia, Volume 5 (San Diego, California: Published for the American Astronautical Society by Univelt, Inc., 1990), p. 36 (paper IAF/IAA 80-IAA-02 presented at the 14th History Symposium of the International Academy of Astronautics as part of the 31st International Astronautical Federation Congress, Tokyo, Japan, 21–28 September 1980).

[13] Will Durant, *Our Oriental Heritage* (New York: Simon and Schuster, 1954), pp. 655–658, et seq.; Dun J. Li, *The Ageless Chinese* (New York: Charles Scribner's Sons, 1965), pp. 83–89, et. seq.

[14] Needham, pp. 12, 111–115; Needham, *Science in Traditional China* (Hong Kong: The China University Press, 1981), p. 54; Sun, p. 29. For more on early deflagrating and explosive mixtures in China, see, Needham, *Science in Traditional China* pp. 30–31.

[15] Li Chi'iao-p'ing, *The Chemical Arts of Old China* (Easton, Pennsylvania: *Journal of Chemical Education*, 1948), pp. 2–3; Rodney Leon Taylor, *The Illustrated Encyclopedia of Confucianism* (New York: Rosen Publishing Group, 2005), Vol. 2, p. 869.

[16] Sung Ying-Hsing, *T'ien-Kung K'ai-Wu—Chinese Technology in the Seventeenth Century*, translated by E-tu Zen Sun and Shiou-Chuan Sun (University Park, Pa.: State University Press, 1966), p. 268.

[17] In the West, as in China, for centuries there were only philosophical or deductive explanations of the nature of combustion, based on assumptions about the constitution of the natural world. In the West, the earliest known theory of combustion was propounded by the Greek philosopher Heraclitus (circa 540–475 BC) who held that "fire is eternal, being the source of all things." Aristotelian and post-Aristotelian theories of combustion centered around the belief that fire was among the four basic elements—along with earth, air, and water. In the 17th century, there emerged the theory of Phlogiston, which specifically attempted to explain the processes of combustion, but this theory was discredited by the late 18th century by one of the founders of modern chemistry, Antoine Lavoisier, who used experimentation to demonstrate the existence of oxygen and its role in combustion. Consult, Joshua C. Gregory, *Combustion from Heracleitos [sic] to Lavoisier* (London: Edward Arnold & Co., 1934), and J. H. White, *The History of the Phlogiston Theory* (New York: AMS Press, 1973), and similar works.

[18] E-mails, Prof. Ho Peng Yoke to Frank H. Winter, 2 and 3 March 2011, copies in collections of the authors; Ho Peng Yoke, *Li, Qi and Shu—An Introduction to Science and Civilization in China* (Mineoloa, New York: Dover Publications, Inc., 1985), pp. 11–12, 217. The latter work more fully explains *qi* and other early Chinese philosophical terms.

[19] Needham, *Science and Civilisation*, p. 11; Henry Knollys, *Incidents of the China War of 1860* (Edinburgh and London: William Blackwood and Sons, 1865), p. 71.

[20] The illustration of the cavity-making tool appears in Needham, *Science and Civilisation*, p. 482, and earlier, in Tenney L. Davis, "Early Chinese Rockets," *The Technology Review*, Vol. 51, December 1948, p. 101. See also *Journal of Chemical Education*, Vol. 24, Nov. 1947, p. 547. The drawing in the original *Wu Pei Chih* source, is in Vol. 126, p. 3a.

[21] Examples of early Western firework books calling the rocket cavity the "soul" are: P. [Perrinet] d'Orval, *Essay sur les Feux d'Artifice* (Paris: Chez Charles-Antoine Jombert, 1745), pp. 36–27; and Amédée François Frézier, *Traité des Feux d'Artifice pour le Spectacle*... (Paris: Charles-Antoine Jombert, 1747), pp. 196–198. It is also interesting to point out the aphorism on gunpowder by English pyrotechnist John Bate in his *The Mysteries of Nature and Art...Fireworks for Tryumph and Recreation* (London: Ralph Mabb, 1635), that: "The Saltpeter is the Soule, the Sulfur the Life, and the Coales [charcoal] the Body of it."

[22] Needham, *Science and Civilisation,* pp. 111–112, 482–483; Translation by Lola Wu of sections of *Wu Pei Chih,* in author's collections; e-mail, Ho Peng Yoke to Frank H. Winter, 3 March 2011; "Soul," in *The Oxford English Dictionary* (Oxford [England]: Clarendon Press, 1989], Vol. XVI, p. 42.

[23] Consult Alan St. H. Brock, *A History of Fireworks* (London: George G. Harrap & Co. Ltd., 1949) and similar works.

[24] I. Bernard Cohen and Anne Whitman, translators, *Isaac Newton—The Principia…A New Translation* (Berkeley, [California]: University of Chicago Press, 1999), p. 117; William-James [Willem Jacob] s'Gravensande, *Mathematical Elements of Natural Philosophy…or an Introduction to Sir Isaac Newton's Philosophy* (London: J. Senex and W. Taylor, 1721), Vol. I, pp. 21–22, 50–51.

[25] The identical material on the Third Law, as well as his own rocket theory and the "little light car" experiment is repeated verbatim in s'Gravesande's 1747 and other editions of this work.

[26] For centuries before and after Newton, there were actually two schools of thought on rocket motion: one was that the rocket needed air to "push against" to make it fly, while the second belief was that the pressure of the gases in the rocket pushed it upward. Clearly, s'Gravesande espoused the latter belief—not Newton's Third Law of Motion in his *Mathematical Elements.* By far, the "air-pushing" school was the most popular concept and predominated while rocket ballistics, internal and external, were essentially unknown for most of the millennium-old history of the rocket.

As still another early example of the long-history of ignorance of the true cause of rocket motion in the West, the Englishman Robert Anderson in 1696 in his *The Making of Rockets* presented a: "Proposition…Of the cause of the Rockets [*sic*] rising." With an accompanying diagram of "rays of fire…continually agitating" with each other [see Figure 11–11]. Consult Anderson for further details on his theory, Robert Anderson, *The Making of Rockets* (London: Printed for Robert Morden, 1696), p. 18–19. Anderson's proposition was not at all espoused by the pyrotechnical or scientific communities in his day, with one known much later exception, Robert Jones, *Artificial Fireworks* (London: John Miller, 1776), p. 79.

[27] Two other very early reaction-propelled devices are the "Pigeon" of Archytas of Tarentum in ancient Greece (circa 428–circa 350 BC), and the "Aeolipile" of Hero (circa AD 10–70) of Alexandria, during the Roman Imperial period. However, both objects were amusement devices only and had no connection with the development of the gunpowder rocket; nor were they developed further. See, "Archytus of Tarentum," in *Dictionary of Scientific Biography* (New York: Charles Scribner's Sons, 1970), Vol. 1, pp. 231–233; Needham, *Science and Civilisation,* p. 521; and Hero, *Pneumatica,* (London: Taylor and Maberly, 1851), p. 72.

It is important to add that it is not firmly established whether the steam-propelled car designed by s'Gravesande was ever constructed, much less demonstrated. S'Gravensande's models were made by his friend, the Dutch instrument maker Jan van Musschenbroek (1687–1748), but the car is not listed by Claude A. Crommelin in his *Descriptive Catalogue of the Physical Instruments of the 18th Century, Including the Collection s'Gravesande-Musschenbroek…* (Leiden, 1951). Nonetheless, the depiction of s'Gravesande's steam car may have been the origin of the apparently apocryphal story that Newton himself had demonstrated his Third Law with the use of such a model. Examples of a supposed steam car attributed to Newton are found in Alan Sutton, *A Victorian World of Science* (Bristol, United Kingdom: Adam Hilger Ltd., 1986), p. 184; Ron Miller, *The Dream Machines—A Pictorial History of the Spaceship…* (Malabar, Florida: Krieger Publishing Co., 1993), p. 15; and Herbert S. Zim, *Rockets and Jets* (New York: Harcourt, Brace and Co., 1945), p. 34, who attributes the steam car to both s'Gravesande and Newton.