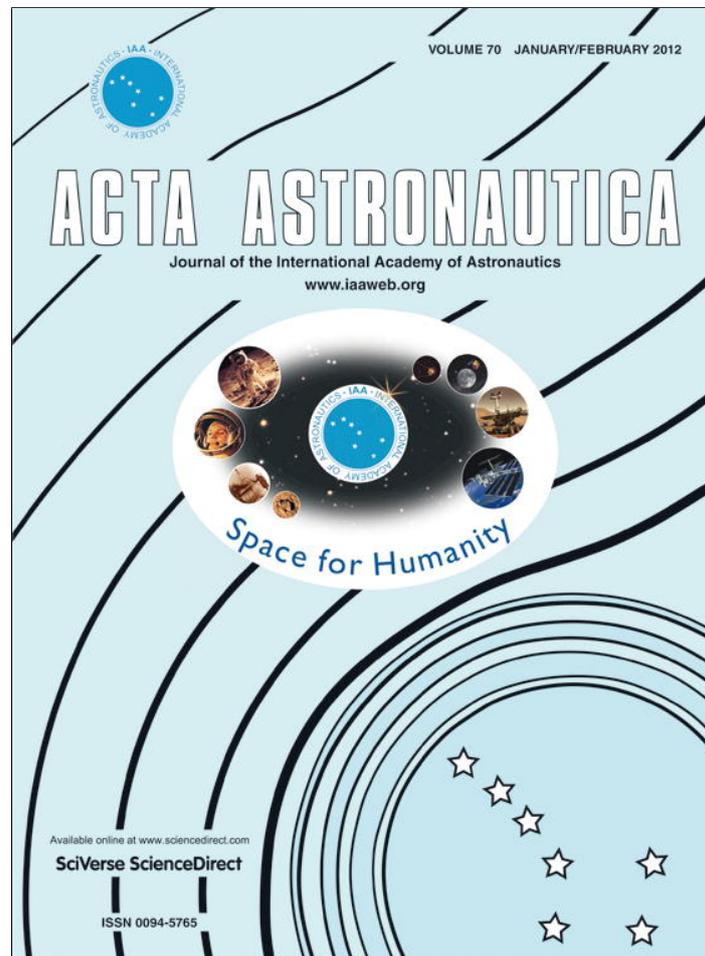


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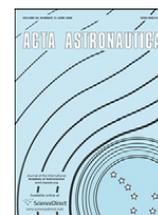
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Was the rocket invented or accidentally discovered? Some new observations on its origins[☆]

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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 900 years ago, suggests that it originated as an accidental discovery rather than as a deliberately planned invention. This paper 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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1. Background

Aerospace historians such as Reynolds and Bizony regard modern launch vehicles, including the recently retired Space Shuttle and the earlier Saturn V that took the first humans to the Moon, as among the most complex feats of engineering in human history [1,2]. 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 events throughout each mission in order to achieve the planned accuracies of soft landings on the surface of the Moon [3]. 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: but was it really an invention? (The standard Webster's dictionary definition of an invention 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')[4].

2. 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 it originated in China. (Claims for India seem less credible for a lack of dateable documentation) [5]. Exhaustive and ground-breaking researches by Dr. Joseph Needham and associated scholars studying ancient Chinese manuscripts, principally on alchemy, point to China's Sung Dynasty

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(960–1279 A.D.) as the likely period and place of the origin of the rocket. Needham's Science & Civilization in China, volume V, part 7, is widely regarded as the best scholarship on the topic [6]. Partington's history of Greek fire and gunpowder is also useful [7].

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 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.

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

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

The Chinese work *Wu Ching Tsung Yao* (Collection of the Most Important Military Techniques), compiled from 1040 to 1044 A.D. by the scholars Zeng Gongliang (the chief editor), with Ding Du and Yang Weide, is apparently the first book in history to record written formulas for gunpowder, or what Partington calls 'proto-gunpowder' [7, p. 287]. Undertaken under the imperial order of the Sung Emperor Renzong (ruled 1022–1063), the *Wu Ching Tsung Yao* was compiled to provide information on all the known techniques then used in warfare. It was secret and therefore only limited editions were published. 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 (i.e., reaction-propelled) devices in the *Wu Ching Tsung Yao*. Stronger gunpowder, with no additives and approximating more modern recipes, appeared later, by the 13th century [6, pp. 19–21, 70, 71, 73, 80–84, 117, 118, 120–124, 252, 253, 601].

In determining the earliest reference to, or a 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* (fire arrow) is simply not enough to qualify a device as a rocket 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 hand-held 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 criterion.

The use of *fei huo tsiang* by the Chinese against the Mongols during the siege of Kai-fung-fu in 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. 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 1264. Called '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' [6, pp. 12, 13, 135, 136].

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' [6, pp. 12, 13, 135, 136].

Needham makes the point that the 'ground rat' type of firework 'may well have been the origin of rocket propulsion'.¹ He does not, however, take his explanation further, except to give examples from the later work, the *Huo Lung Ching* (The-Fire Drake [Artillery] Manual [of Gunpowder Weapons] of circa 1412, of weapons like the 'water-melon bomb' (*hsi kua phao*) containing small multiple 'earth- or ground rats', which he calls 'mini-rockets'. He adds 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 the 'meteor' (*liu hsing*), or other names, which was attached to a stick and could therefore fly upwards, also by self-propulsion [6, pp. 472–474].

According to Fung-Toh Sun, the 'ground rat' type of firework can still be found in modern China under various

¹ It should be noted that the 'ground-rat' origin is only one of Needham's theories regarding the rocket, but it is his most favored.

other names [8]. 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 additional 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' [6, p. 472].

3. The origins of gunpowder

In searching for the origins of gunpowder, Needham, Partington, Fung-Toh 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 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 B.C. 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.

Taoist alchemy was a branch of Taoism that focused mainly upon the purification of the spirit and body in 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 proto-science that evolved into the basics of modern chemistry [9,10].

Needham and his colleagues also found early accounts of the haphazard practice of the Taoist alchemists in which they occasionally had their beards singed, hands and faces burnt, and even the houses where they worked burned down when they ignited certain mixtures. Some Taoist alchemical works, like the circa 850 A.D. *Chen Yuan Miao Tao Yao Lüeh* (Classified Essentials of the Mysterious Tao of the True Origin of Things), consequently offered warnings about these experiments. Needham thus concluded elsewhere that: 'Gunpowder was not the invention of artisans, farmers, or master masons; it arose from the systematic if obscure investigations of Taoist alchemists' [11, p. 54]. As more emphatically stated by Fang-Toh 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 ... [8, p. 29]. 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. (Lai-Chen Chien, et al., also briefly allude to Taoist alchemy experiments leading to the development of the rocket, but they refer to it as 'fairy medicine' and do not explain much about Taoism. Similar articles on early Chinese rocketry and gunpowder also do not get into Taoism) [12, p. 72].

From here, we can only speculate that eventually, 'reactive' mixtures of this kind – especially weak, slow burning types – were also found by strictly empirical (i.e., 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' [6, pp. 12, 111–115], [8, p. 29], [11].

4. 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 [13,14],² Chinese alchemists were more philosophers than scientists and lacked an adequate theory of combustion. According to 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 Chemistry in the modern sense did not exist in China before the 19th century' [15].

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 [16]. We find direct evidence of this in the work of Sung Ying-Hsiang, who says: 'It is believed [in the 17th century that] saltpeter

² In the West, for centuries there were only philosophical or deductive explanations of the nature of combustion, based on assumptions about the constitution of the natural world. The earliest known theory of combustion was by the Greek philosopher Heraclitus (circa 540–475 B.C.) 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 seventeenth century A.D., 'phlogiston' theorists specifically attempted to explain the processes of combustion, but this theory was discredited in 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.

and sulfur are, respectively negative and positive in character. A combination of the positive (*yang*) and the negative (*yin*) forms gunpowder' [17]. 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.

5. 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 that a *yin/yang* explanation may also have been applied to the rocket's motion. Ho Peng Yoke, one of Needham's former leading collaborators in research on the 'gunpowder epoch' (as they phrased it) of the history of early technology in China, informs one of the authors 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 purposes of this paper, Ho graciously agreed to postulate how 'a medieval Chinese natural philosopher' (i.e., 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 innate 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.) [18].

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. Philosophical conceptions of it in the earliest Chinese records date to the 5th century B.C. and correspond to Western notions of 'humors'. *Qi* too, played a role in the alchemist search for longevity and in all aspects of health. However, *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*: '*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

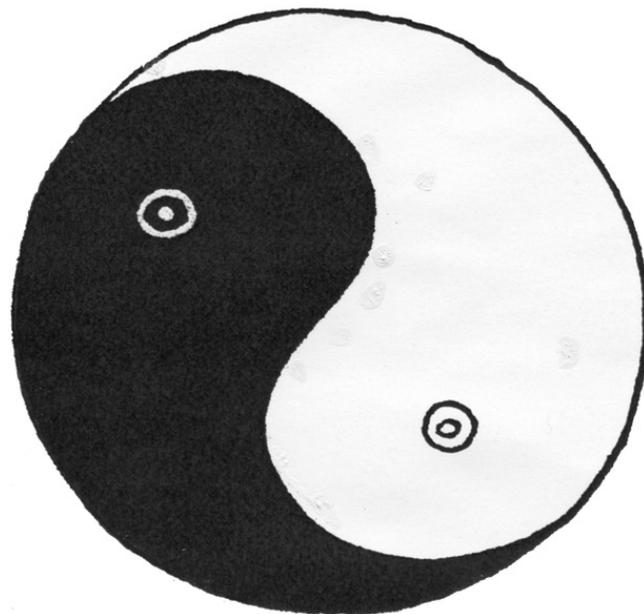


Fig. 1. *Taijitu* diagram, the symbol for the concept of *yin* and *yang* (*Taiji*) of the Taoist religion. From Hampden C. DuBose, *The Dragon, Image, and Demon* (1887).

be best illustrated by the *Taijitu* diagram (Fig. 1). Half of the diagram is *yin* and the other half is *yang* ... hence, *yin* and *yang* are opposite and complimentary to each other' [19].

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 well-founded 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.

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 accidentally 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 upon fireworks and gunpowder weapons that eventually led to guns. As documented by Needham and his colleagues and others, 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 mid-19th century and perhaps later [6, p. 11], [20].

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) compiled by Mao Yüan-i, (circa 1621), of a tool for boring out the central cavity of a rocket's gunpowder propelling charge (Fig. 2) [6, p. 482] [21,22].³ One of the authors (Winter) is indebted to his friend, Lola Wu, for the partial 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 too much from the rear [i.e., exit]; too shallow, the flow would be too feeble.' Yet this description provides no explanation of *why* the cavity works.

Significantly, the cavity is also found in several early modern Western pyrotechnic works and was called "the soul" of the rocket, such as depicted and described in *Pyrotechnia, or Artificial [sic.] Fire Works* by the Englishman John Babington of 1635 (Fig. 3). The term's origin is obscure, but it is obviously based on a Christian metaphor that was not, however, an attempt to explain the cause of the cavity's effectiveness in increasing rocket motion, which we now know to be due to increased surface burning area⁴ [23–25]. The usage probably came from gunnery, as Western artillerymen had already called the hollow (bore) of the gun the 'soul' by the 16th century [26].

Just who originated this key feature of the rocket – whether it was in China or the West – and when, and how it spread between these geographical regions, we may never know. As 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' [17]. Needham describes a second important feature in the rocket, the constriction of the rocket's orifice or near-nozzle, as 'a way to increase the flow-velocity of the issuing gases,' as occurring circa 1300 A.D., although he does not cite his source [6, pp. 111, 112, 482, 483].

³ The original drawing is in the *Wu Pei Chih* compiled by Mao Yüan-i, vol. 126, p. 3a, although The Library of Congress copy, used here, is not the first edition and is most likely an early Qing Dynasty [1644–1912] edition of ca. 1644. The usually ascribed ca. 1621 date of this work comes from the date of the preface, not is the publication date, and took several years to compile.

⁴ English pyrotechnist John Bate in his *The Mysteries of Nature and Art*, 1635 used a parallel set of Christian metaphors: "The Saltpeter is the Soule, the Sulphur the Life, and the Coales [charcoal] the Body of it"



Fig. 2. "Thorn" or tool for making the cavity in the rocket propellant charge in the rocket cylinder, as shown in the *Wu Pei Chih*, ca. 1621. Courtesy of the Library of Congress.

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* (Fire Book) of Marcus Graechus, or 'Mark the Greek,' of the same period. By 1280 A.D., the German Albertus Magnus presented similar rocket recipes. By the 16th century, the rocket was firmly established in the West, not so much as a weapon but primarily 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 in the same period. The rockets were still small and crude and differed little from the *huo chien* of Sung China. If anything, these works reflect the almost stagnant nature of rocket technology in the West at this time [27]. Coupled with this stagnation, the scientific understanding of the nature of combustion and rocket motion were poor. It is therefore interesting to briefly examine these misunderstandings as an aside to the main argument. Specifically, we will look at how Newton's Third Law of Motion had no impact on rocket development in the West up to the late 19th century.

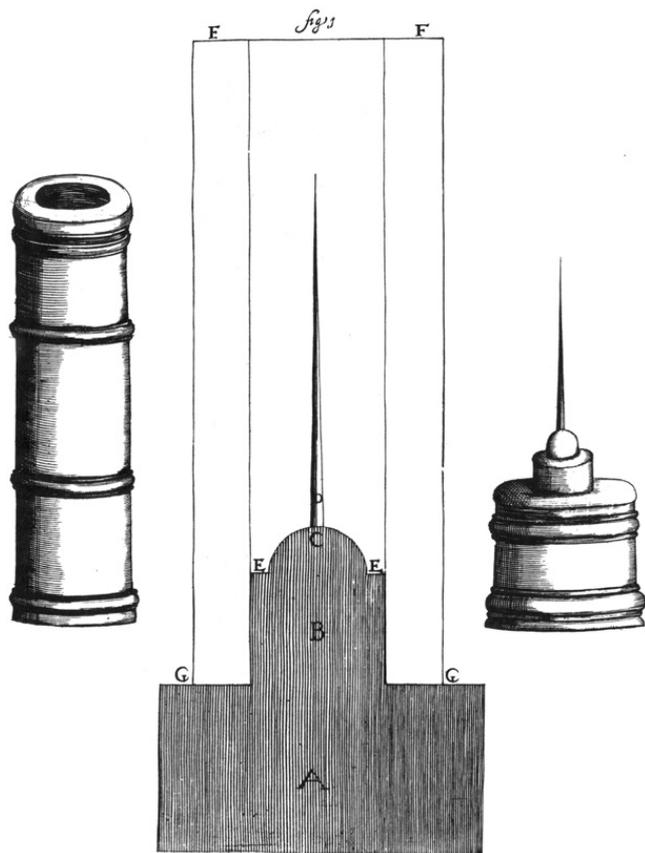


Fig. 3. A Western counterpart to the tool shown above. From John Babington, *Pyrotechnia, or Artificiall [sic.] Fire Works* (1635).

6. Newton's third law of motion

Newton's Third Law was first published in 1687 in his *Philosophiæ Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy), usually abbreviated as the *Principia*. Although we now fully accept that the Third Law succinctly describes reaction propulsion, or rocket motion, that was not always true. For two centuries the Third Law was difficult to fathom and interpret. According to Bernard Cohen: 'Newton's third law has often been a source of confusion' [28]. Apart from its incomprehensibility to many readers, Newton did not use the rocket as an example of the Third Law in the *Principia*. It is therefore unsurprising that the Law is not included in eighteenth and 19th century pyrotechnic works or in works attempting to describe rocket motion.

Interestingly, the first English translation of the *Principia*, published in 1721 by Newton's friend, the Dutchman Willem Jacob s'Gravesande, includes the Third Law, along with four examples of its use plus two experiments to demonstrate how it actually works. Yet rocket action is not among these examples or experiments although elsewhere in the same work, in a separate section, titled 'Of the Dilation occasion'd by Heat,' he does describe the cause of rocket motion: 'A Sky-Rocket rises up into the Air, because the Gun-powder, being set on Fire, acquires an Elasticity, and it is 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 prevails, and carries up the Rocket.' In this same section he also presents and depicts an 'Experiment [that] Shews a more sensible Effect of the Elasticity of Vapors' 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 Law⁵ [29] (Fig. 4). Apparently, it did not occur to s'Gravesande that rocket motion and the steam-reaction propelled car were equivalent and could have been used to describe and experimentally demonstrate the Third Law.

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 other was that the pressure of the gases in the rocket pushed it upward, as per s'Gravesande's explanation. The 'air-pushing' school was far more popular, while rocket ballistics, internal and external, were essentially unknown. The significance of the Third Law as applied to rocket motion was missed altogether until the late 19th century, when it was recognized by Konstantin Tsiolkovskii, and later by Robert H. Goddard, Robert Esnault-Pelterie, and Hermann Oberth, all of whom are considered among the founders of astronautics. They grasped that the Third Law, or reaction propulsion, can also work in a vacuum and therefore reaction motion (as exemplified by the rocket) would be able to serve as a method for achieving and sustaining space flight.

7. Conclusions

While some may believe that the origins of gunpowder and the rocket were instances of 'serendipity,' the situation was more complicated than that. Serendipity has been defined as 'the phenomenon of finding valuable or agreeable things not sought for,' a 'happy accident' or 'pleasant surprise' [30]. We argue that the accidental discovery of gunpowder, and very likely also the rocket, were literally accidents that were hardly pleasant and appear from early Taoist alchemical documents to have caused bodily harm and the destruction of property. These accidents were caused by experiments to find "elixirs" of longevity as a part of Taoist beliefs. In neither China nor the West was there a body of scientific theory adequate to provide the basis for anything more than purely empirical experiments with gunpowder and gunpowder devices. Even when Newton proposed the Third Law of Motion in 1687, none could see how it applied to rocket motion until two hundred years later. Thus the rocket appears not to have been consciously 'invented' through some logical process based on a clear purpose related to propulsion or weapons making, let alone

⁵ The material on the Third Law, his own rocket theory and the "little light car" experiment is repeated verbatim in the 1747 and other editions of this work. The use of steam for propulsion had a long history. In classical antiquity, two devices were the "Pigeon" of Archytus of Tarentum (circa 428–350 B.C.), and the "Aeolipile" of Hero of Alexandria (circa 10–70 A.D.). However, both were amusement devices only, were unconnected to the development of the rocket, and had no impact on scientific theory.

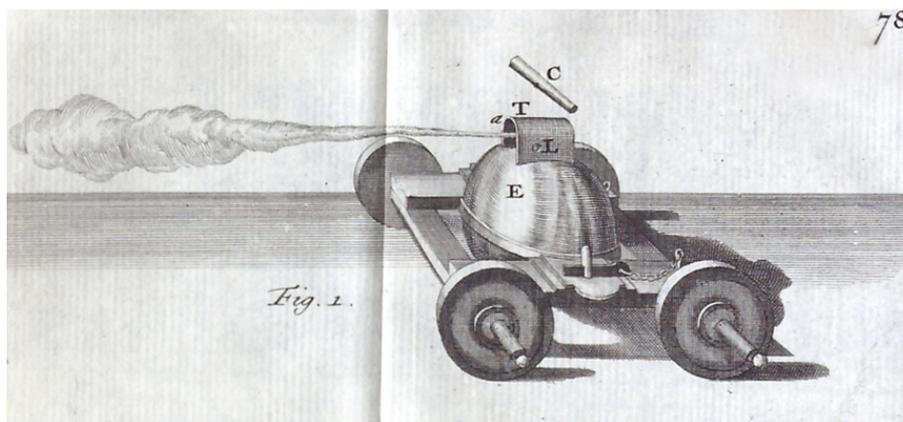


Fig. 4. Steam reaction-propelled car, drawing of a model for demonstrating Newton's physics. From Jacob Wilhelm s'Gravesande, *Mathematical Elements of Natural Philosophy* (1747 edition).

theory, at least in its earliest stages. It was quite literally 'accidentally discovered.' The rocket evolved thereafter in a purely empirical way, as did all virtually technologies before the Scientific Revolution began to produce effective theory that could be applied to the process of invention.

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