ΠΡΑΚΤΙΚΑ | PROCEEDINGS

3ο Διεθνές Συνέδριο Αρχαίας Ελληνικής και Βυζαντινής Τεχνολογίας

3rd International Conference Ancient Greek and Byzantine Technology

19-21 Νοεμβρίου 2024

ΜΕΓΑΡΟΝ ΜΟΥΣΙΚΗΣ ΑΘΗΝΩΝ

19-21 November 2024

MEGARON THE ATHENS CONCERT HALL

ΟΡΓΑΝΩΣΗ

ΕΤΑΙΡΕΙΑΣ ΔΙΕΡΕΥΝΗΣΗΣ ΤΗΣ ΑΡΧΑΙΟΕΛΛΗΝΙΚΗΣ ΚΑΙ ΒΥΖΑΝΤΙΝΗΣ ΤΕΧΝΟΛΟΓΙΑΣ

NOESIS ΚΕΝΤΡΟ ΔΙΑΔΟΣΗΣ ΕΠΙΣΤΗΜΩΝ & ΜΟΥΣΕΙΟ ΤΕΧΝΟΛΟΓΙΑΣ

THE GREEK TRADITION OF ENGINEERING IN AL-JAZARĪ'S WORK KITĀB FĪ MAʻRIFAT AL-ḤIYAL AL-HANDASIYYA (THE BOOK OF KNOWLEDGE OF INGENIOUS MECHANICAL DEVICES)

Theodora Zampaki
Dr Graeco-Arabic Studies, Hellenic Open University
email: dzampaki@yahoo.gr

Abstract. This paper aims at presenting some Greek ideas about mechanical devices in al-Jazarī's work Kitāb fī maʻrifat al-ḥiyal al-handasiyya (The Book of Knowledge of Ingenious Mechanical Devices). Al-Jazarī was an engineer and completed his book in AD 1206. Al-Jazarī's treatise confirms the cultivation of the Greek and especially the Hellenistic mechanical engineering in the Islamic world, as is shown by his references to the works of his predecessors. Other writings are also mentioned whose authors were unknown to him. Al-Jazarī's work has detailed descriptions about the construction and operation of various devices and also improves upon earlier works. From the Arab bibliographers we know that Greek mechanical works were translated into Arabic during the Graeco-Arabic translation movement (8th-10th centuries). Lost Greek works are extant only in Arabic translation. Among them is the Mechanics of Heron of Alexandria (fl. c. AD 62) translated into Arabic by the great translator, physician and scholar Qusṭā ibn Lūqā (d. 912), a Melkite Christian from Baalbek in Lebanon born of Greek parents. Also, Philon's (fl. c. 200 BC) Pneumatics has come down to us in Arabic, although we have no knowledge of the date or the author of this translation. Al-Kindī (d. shortly after 256/870) says that Philon was skilled in the construction of water-wheels, mills, and ingenious devices (ḥiyal). Even without this evidence there could be little doubt, from an examination of the devices in the works of the three sons of Mūsā (the Banū Mūsā) (3rd/9th century) that they were derived directly from the works of Heron and Philon. Al-Jazarī refers to the Banū Mūsa as one of his sources. Also, al-Jazarī refers to the machine of the flute player and names its inventor as "Apollonius the carpenter, the Indian". Furthermore, al-Jazarī refers to Archimedes (c. 287 to 212 or 211 BC) many times in his work about clocks as well as to Ctesibius (fl. 270 BC) whose works were translated into Arabic. Such examples suffice to show the continuation of the Greek tradition of mechanical engineering in the Arabic language.

Keywords: al-Jazarī, Archimedes, Ctesibius, Philon, Apollonius, Heron

1 Introduction

Badīʻ al-Zamān Abū 'l-ʻIzz Ismāʻīl b. al-Razzāz al-Jazarī, commonly referred to as al-Jazarī, is renowned for being a top engineer in the medieval Islamic world. His detailed book, Kitāb fī maʿrifat al-ḥiyal al-handasiyya (The Book of Knowledge of Ingenious Mechanical Devices), covers a variety of mechanical creations, including water clocks, fountains, automata, and water-raising machines.

2 Al-Jazarī

2.1 Historical context and biography of al-Jazarī

The sole details known about his life come from the introduction of his book, where he mentions working for the ruling family of a Turkish dynasty, the so-called Artuqids for twenty-five years at the time of writing (Hill 2004, 266-267). The Artuqid dynasty, ruled al-Jazīra between the twelfth and fifteenth centuries, became famous for their patronage activities in the field of ancient sciences (Özsoy 2023). The Ayyubid dynasty, under the leadership of rulers like Ṣalāḥ al-Dīn (Saladin), was renowned for supporting intellectual and cultural endeavors. This motivation also extended to various fields like engineering, inspiring scholars like al-Jazarī to innovate and develop fresh concepts. According to Saliba (2007, 238) "his devices were examples of natural physical principles in action". In this timeframe, the political stability and economic prosperity of the region also contributed to the advancement of science and technology.

2.2 Kitāb fī maʿrifat al-ḥiyal al-handasiyya: An overview

Al-Jazarī's Book on Knowledge of Ingenious Mechanical Devices, completed in 1206 under the command of his mentor Nāṣir al-Dīn Maḥmūd, a prince from the Artuqid dynasty of Diyār Bakr, is a groundbreaking contribution to the field of engineering. The book contains 100 mechanical devices with detailed illustrations, categorized into six groups. These groups include water-clocks, candle-clocks, vessels for carousals, hand-washing, phlebotomy, fountains, musical automata, water-lifting machines, and miscellaneous items. The start of every chapter includes a thorough explanation of the device, along with a sequence of pictures and detailed guidance on building and using it.

Al-Jazarī's most important work, Kitāb fī maʿrifat al-ḥiyal al-handasiyya (The Book of Knowledge of Ingenious Mechanical Devices), has attracted considerable interest from scholars studying the progress of mechanical engineering in the Islamic Golden Age. His book, frequently referenced as the peak of Islamic technological success, serves as evidence of the significant connection between Greek mechanical customs and Islamic creativity. According to George Sarton (1931, II, 510), "this treatise is the most elaborate of its kind and may be considered the climax of this line of Muslim achievement".

Al-Jazarī's writing demonstrated his strong knowledge of engineering principles and emphasized his creative thinking. Contrary to earlier works that mainly talked about theory, al-Jazarī's work gave elaborate guidance on building and using mechanical devices, along with detailed drawings and diagrams.

Additionally, al-Jazarī's treatise acted as a connection between diverse cultural and intellectual customs, illustrating the fusion of Greek, Persian, Indian, and Islamic ideas. His mention of Greek engineering concepts and predecessors shows the significant influence of Greek traditions on Islamic engineering practices (Jackson 1987-1988, 369-390).

3 Al-Jazarī's mechanical devices

Many researchers have concentrated on the intricate mechanical devices outlined in al-Jazarī's work, analyzing their technical intricacy and unique characteristics. Hill (1974) offers a thorough examination of al-Jazarī's water-lifting mechanisms, emphasizing their importance in the advancement of hydraulic engineering. Also, he discusses how al-Jazarī's automata were not only impressive technologically but also served as symbolic representations of the intellectual and artistic progress during the Islamic Golden Age.

Saliba's (2007) research has showed how technological knowledge from al-Jazarī's work spread to Europe, indicating that his ideas impacted the creations of European engineers and clockmakers in the Renaissance era. Al-Jazarī's contributions have a significance that goes beyond the Islamic world, as demonstrated by the sharing of knowledge among diverse cultures.

According to Hill (1993, 124), "the importance of the book lies partly in the machines, components and ideas that are described in it. Of equal importance is the fact that al-Jazarī composed the book with the declared intention of enabling later craftsmen to reconstruct his machines".

3.1 Water-Raising machines

Water-raising machines are among the most practical and innovative devices in al-Jazarī's work. An example worth mentioning is the reciprocating suction pump, which includes two cylinders with pistons, powered by a crankshaft and a connecting rod. This creation showcases one of the first instances of utilizing the crankshaft mechanism, an essential part in contemporary equipment that transforms circular movement into straight movement (Hill 1974, 186-189 and 266). For its use, al-Hassan and Hill (1986, 49) remarked that "it would have been particularly useful in al-Jazarī's homeland, the area between the upper reaches of the Tigris and the Euphrates, where the waterways are generally well below the level of the surrounding fields".

Al-Jazarī's advancements in water-lifting technology showcase a profound grasp of hydraulics and mechanics, illustrating the pragmatic use of scientific principles to address everyday challenges. Also, the description of water-raising machines by al-Jazarī shows "an awareness of the need to develop machines with a greater output than the traditional ones" (Al-Hassan, and Hill 1986, 42).

3.2 Water clocks

Al-Jazarī's water clocks showcase his brilliance in blending functionality with visual charm. His clocks go well beyond anything known from pre-Islamic times. According to al-Hassan and Hill (1986, 58), "al-Jazarī's clocks are full of ideas and techniques that are of importance in the history of machine design. These clocks were designed not just for timekeeping, but also to amuse and impress viewers with intricate displays and moving figures. The "Elephant Clock" is a sophisticated automaton from which can be told the passage of the constant hours (Hill 1974, 58-70). This clock "combined water principles from Archimedes with an Indian elephant and water timer, Chinese dragons, an Egyptian phoenix, a Persian carpet and Arabian figures" (Masood 2009, 163). It had a number of automata, and the mechanisms for activating them (Hill 1996, 395).

Another remarkable example is the "Castle Clock", which featured multiple automata and displayed the zodiac signs, solar and lunar orbits, and a range of other astronomical indicators. This clock was programmable, allowing users to set the duration of daylight and nighttime hours (Hill 1974, 17-41).

3.3 Automata

Al-Jazarī's automata demonstrate his ability to create lifelike movements using mechanical components. An example is a basin of the peacock for washing the hands, which is a decorative water fountain that utilizes a sophisticated system of levers, pulleys, and cams to create a sequence of automated actions (Hill 1974, 149-152). The fountain functioned both as a practical hand washing device and as a sophisticated exhibition of mechanical skill.

Al-Jazarī also mentions the noteworthy basin of the slave that includes a mechanical assistant serving water and towels for drying hands (Hill 1974, 153-155). This mechanism used an advanced setup of hydraulic pumps and levers to imitate movements similar to humans. These devices might be the first examples of domestic technology to simplify the household work.

3.4 Fountains and drink dispensers

Al-Jazarī also designed a variety of fountains and drink dispensers that were both functional and decorative. These devices frequently used intricate hydraulic systems to manage the movement of water or other liquids, showcasing his extensive knowledge of fluid dynamics. For instance, a boat which is placed on a pool during a drinking party, was an advanced vessel suitable for drinking sessions that produced music by utilizing water flow and air pressure to control musical instruments (Hill 1974, 107-109).

These devices were not just examples of advanced technology but also masterpieces of creativity, crafted to bring joy and amusement to their users. Al-Jazarī's expertise in designing complex and versatile machines demonstrates his talent for combining technical skill with innovative thinking.

4. The Graeco-Arabic translation movement - Al-Jazarī's Greek sources

It is well known that the medieval Arabic translations of Greek scientific and philosophical books played a great role in the formation and development of the sciences and philosophy in Arabic language. The transmission of Greek knowledge to the Islamic world was primarily aided by the Graeco-Arabic translation movement, occurring between the 8th and 10th centuries. During this period, scholars within the Islamic society translated a large amount of Greek scientific and philosophical writings into Arabic to ensure they were safeguarded and shared.

Translating Greek texts into Arabic involved more than just transmitting knowledge; it also entailed interpreting, adjusting, and enriching the original content. Islamic scholars frequently included annotations, revisions, and improvements, which resulted in the emergence of fresh areas of research and technological advancement.

Furthermore, the translation effort played a key role in granting Islamic intellectuals such as al-Jazarī the opportunity to study Greek wisdom. Al-Jazarī's work exemplifies his ability to not only preserve Greek engineering knowledge but also enhance and adapt it to meet the technological needs of his time. The translations included important texts on mechanics by Archimedes, Heron of Alexandria, and Philon of Byzantium. By incorporating Greek ideas, Arab scholars had the chance to delve into various subjects like hydraulics, pneumatics, mechanics, and geometry, enabling Islamic engineers and inventors to expand scientific inquiry and technological innovation.

For example, Qusṭā ibn Lūqā, a Melkite Christian scholar of Greek descent, was a significant member of this movement and was instrumental in translating Heron of Alexandria's

Mechanics into Arabic around 250/864. Heron of Alexandria, an engineer and mathematician, who lived in the first century AD, was famous for his contributions to automata, pneumatics, and mechanics. His *Mechanics*, extant only in Arabic, set the foundation for many of the subsequent advancements in Islamic engineering, such as those by al-Jazarī (Hill 1974, 11).

Another work that had a major impact on Islamic mechanical engineering was Philon of Byzantium's *Pneumatics*. Philon, a third-century BC engineer, was known for his work on hydraulic systems and automata. Although the exact date and translator of Philon's *Pneumatic*s into Arabic are unknown (Hill 1974, 11-12), the text became an important source for Islamic engineers, including al-Jazarī, who drew upon its principles in designing his own hydraulic devices. The translation of these works preserved Greek engineering knowledge and helped integrate it into the Islamic intellectual tradition, leading to further development and refinement.

The influence of Greek engineering on Islamic scholars can be seen in the work of the Banū Mūsā, (the three sons), who were leading scientists in the 9th century. Their book *Kitāb al-ḥiyal* (The Book of Ingenious Devices) is a compilation of mechanical plans and automata that show the impact of Greek engineers like Heron and Philon (Hill 1974, 12). The work of Banū Mūsā is known for its intricate mechanisms and creative designs, often drawing inspiration from Greek prototypes. For example, their use of siphons and valves in hydraulic devices mirrors the earlier designs found in Heron's *Pneumatics*.

Al-Jazarī explicitly refers to the Banū Mūsā, acknowledging the debt he owed to their earlier work. This link highlights the ongoing presence of the Greek mechanical tradition in the Islamic world, where it was both maintained and built upon. The work of Banū Mūsā acted as a crucial connection between ancient Greek engineers and later Islamic scholars such as al-Jazarī, who expanded on their advancements to develop further.

5. Greek engineering

5.1 Integrating and advancing Greek engineering

As said, al-Jazarī's work reflects the influence of Greek engineering. However, although the Greek tradition laid a strong groundwork, al-Jazarī's work stands out for its methodical approach to engineering issues and its focus on usefulness and feasibility. His thorough explanations and visual aids in *The Book of Knowledge of Ingenious Mechanical Devices* helped other engineers and craftsmen by connecting theoretical ideas with practical uses.

The significance of Greek engineering texts in shaping Islamic technological development cannot be overstated. These translations did not just offer practical knowledge and theoretical insights; they also encouraged an atmosphere of innovation and experimentation among Islamic scholars and engineers. By incorporating and adjusting Greek concepts, Islamic society combined various intellectual customs, leading to notable progress in fields like astronomy, optics, and mechanics.

Al-Jazarī's work is deeply influenced by ancient Greek engineering, specifically the Hellenistic mechanical brilliance, which greatly impacts his writing with hints of old wisdom and creativity. By carefully examining al-Jazarī's work, it is clear that Greek engineering principles and ideas had a significant impact on the advancement of Islamic technology. Certainly, al-Jazarī's work connects ancient Greek learning with Islamic engineering methods, demonstrating the fusion of various intellectual customs.

The impact of Greek ideas on Islamic engineering shows a blending of intellectual customs, in which ancient knowledge was saved, enhanced, and passed down to future times. Studying how Greek ideas influenced Islamic technological innovation allows us to better understand how human knowledge is interconnected and the lasting effects of cross-cultural exchange (see articles by various authors in Brentjes 2022).

5.2 The significance of al-Jazarī's references to Greek engineers

Al-Jazarī's frequent references to Greek engineers underscore the continuity and influence of Greek mechanical traditions within Islamic civilization. The inclusion of these references serves several purposes. First, it showcases al-Jazarī acknowledging the intellectual obligation to previous scholars, situating his work within a wider historical framework of scientific and technical expertise. By recognizing the contributions of Greek engineers, al-Jazarī places himself in the company of respected intellectuals, enhancing the credibility of his own inventions.

Second, these references highlight the interconnectedness of scientific knowledge across cultures and eras. During al-Jazarī's time, the Islamic world was a center of intellectual exchange where knowledge from various cultures was gathered, translated, and further developed. The Graeco-Arabic translation movement introduced numerous Greek texts to the Islamic world (Gutas 1998). Al-Jazarī's mentions of Greek engineers show how the Islamic world acted as a connector for passing on knowledge from ancient Greece to the European Renaissance.

Finally, al-Jazarī's mentions of Greek engineers demonstrate the inquisitiveness and thoroughness of Islamic scholars. Instead of just copying Greek ideas, Islamic engineers such as al-Jazarī aimed to enhance them, showing the evolving nature of knowledge in the medieval Islamic society. This process of adaptation and innovation is evident in the way al-Jazarī references and builds upon the works of his Greek predecessors mentioned in what follows.

6. Archimedes: The master of mechanical engineering

Archimedes of Syracuse (c. 287 to 212 or 211 BC) made significant impacts on mathematics and engineering, such as establishing principles in hydrostatics and mechanical advantage (Heath 1897).

Archimedes' impact on future engineering and scientific ideas has been thoroughly recorded. His contributions to hydrostatics and mechanical principles provided a basis for understanding complex fluid systems and levers (Heath 1897). Al-Jazarī incorporated these principles into mechanical and hydraulic devices, showcasing advanced innovation. Archimedes' lasting impact during the Islamic Golden Age highlights the important spread of knowledge across different cultures and eras.

6.1 Archimedean principles in hydraulic systems

Archimedes is famous for his contribution to the principle of buoyancy and the creation of different hydraulic devices. His invention of the Archimedean screw to raise water demonstrates his impact on hydraulic engineering (Heath 1897).

Al-Jazarī's hydraulic systems, particularly his water-raising machines, are notable for their incorporation of Archimedean principles. A water-raising machine, a pump driven by a water-wheel (Hill 1974, 186-189 and 266), featured in his book, uses a modified Archimedean screw to elevate water for irrigation and other needs. This device showcases Archimedes' impact by employing a spiral screw system to raise water effectively. Al-Jazarī improved Archimedes' screw design to better suit medieval Islamic engineering requirements.

6.2 Mechanical advantage and levers

Archimedes' work on levers and mechanical advantage is another area of significant influence. His principles provided the basis for understanding how to amplify force using simple machines.

Al-Jazarī's "Elephant Clock" (Hill 1974, 58-70) incorporates mechanical advantage through a complex system of levers and gears. The clock employs Archimedean principles of leverage to achieve precise and efficient motion. Employing levers in the clock's operation demonstrates a sophisticated comprehension of Archimedes' principles, which improves the clock's overall performance and dependability. The clock's structure demonstrates al-Jazarī's skill in utilizing and improving upon Archimedes' mechanical principles with complex automata and timekeeping devices.

6.3 Buoyancy and floating devices

Archimedes' principle of buoyancy, which explains how objects float in fluids, is another significant area of his influence. This principle is essential for designing devices that interact with fluids.

Al-Jazarī's invention of the musical for a drinking party (Hill 1974, 107-109) showcases the implementation of Archimedes' buoyancy principle. The table creates a visually striking effect by using principles of buoyancy, giving the appearance of floating on a cushion of water. Its design reflects an understanding of fluid mechanics and buoyancy, showcasing al-Jazarī's ability to adapt Archimedes' principles to create engaging and functional mechanical devices.

Analysis of al-Jazarī's innovations shows a noticeable impact of Archimedes' theories on his mechanical and hydraulic creations. Al-Jazarī's achievements show how Greek scientific knowledge was incorporated and enhanced in an Islamic setting. Al-Jazarī's improvements to Archimedes' plans show his creativity and how scientific and technological advancement builds upon previous achievements.

7. Ctesibius: The master of pneumatics and water clocks

Ctesibius (fl. 270 BC) is frequently recognized as the pioneer of pneumatics, which involves studying the mechanical characteristics of gases. Ctesibius, commonly known as the "father of pneumatics", established the foundation for hydraulic and pneumatic technology. Ctesibius is famous for his advancements in creating water clocks (*clepsydrae*), which were commonly used in Greek and Islamic civilizations to track time.

7.1 The use of water clocks

Both Ctesibius and al-Jazarī are famous for their water clock creations, which show a combination of scientific innovation and creative skill. Ctesibius' water clock, also known as the clepsydra, employed a straightforward but efficient system that relied on the movement of water to track time. It included a buoyant mechanism that would ascend along with the water level, causing a sequence of gears to track the passing of time.

Al-Jazarī's water clocks, on the other hand, were more elaborate. For instance, the "Castle Clock" (Hill 1974, 17-41), described in his book, incorporated multiple automata and mechanical figurines that performed various actions at specific intervals. While the basic principle of using water flow to measure time remains consistent with Ctesibius' design, al-Jazarī introduced significant enhancements. These include the use of a more complex gear system, water flow regulators, and feedback mechanisms to ensure greater accuracy and reliability. Hill (1974, 276) notes that Vitruvius described "how Ctesibius attempted to control the water flow of water from a vertical pipe". Al-Jazarī's advancements demonstrate a clear understanding and application of Ctesibius' hydraulic principles, adapted to the technological context of his era.

The complexity and versatility of al-Jazarī's water clocks are among their most remarkable features. In contrast to Ctesibius' basic designs, al-Jazarī's clocks frequently included automated mechanical figures that reacted to the movement of water. Al-Jazarī's use of automata in his water clocks represents a significant advancement over earlier Greek designs, illustrating how Islamic engineers built upon Greek foundations to create more sophisticated and intricate devices.

7.2 Automata and mechanical devices

Ctesibius is credited with inventing early forms of mechanical automata, such as singing birds and moving figures, operated by air pressure and hydraulic systems. These automata were primarily designed for entertainment and religious purposes, showcasing the potential of combining mechanics with artistic expression.

Al-Jazarī expanded on these ideas, designing various automata, such as a "humanoid robot" capable of serving drinks and programmed by him. This intricate device, as explained in *The Book of Knowledge of Ingenious Mechanical Devices*, used a complex mix of hydraulics, pulleys, and levers to imitate movements similar to those of humans (Hill 1974, 107-109). Al-Jazarī's utilization of air and water pressure is clearly inspired by the work of Ctesibius, but his automata surpass those of previous inventors in both intricacy and efficiency. Al-Jazarī was able to advance the field of mechanical engineering by introducing feedback mechanisms and control systems, which Ctesibius did not have in his designs, thus achieving a higher level of automation and programmability.

The principles of automation and programmability in al-Jazarī's devices foreshadow modern robotics and mechatronics. His work on humanoid automata can be directly linked to modern efforts in robotics to create machines that mimic human actions. The concepts of hydraulics and pneumatics he employed are still fundamental in contemporary robotics, manufacturing, and automation technologies, particularly in creating robots that interact safely with humans.

The comparison of specific inventions reveals a clear line of influence from Ctesibius to al-Jazarī. The act of sharing and adjusting knowledge shows the wider cultural and scientific interactions between the Hellenistic and Islamic civilizations. The progress achieved by al-Jazarī showcases both his cleverness and the gradual development of scientific and technological advancements. By expanding on Ctesibius' groundwork, al-Jazarī developed advanced and practical devices, showcasing a deep knowledge of mechanics and hydraulics.

8. Philon of Byzantium: The hydraulic engineer

Philon (fl. c. 200 BC), a Greek engineer and inventor, significantly impacted the field of mechanics with his advancements in pneumatics and hydraulics. Years later, al-Jazarī enhanced these mechanical principles, constructing numerous intricate machines and devices that demonstrate an advanced comprehension of previous works.

Philon's work, notably his treatises on pneumatics and mechanics, laid the foundation for many principles later adopted and refined by Islamic engineers. His inventions were well-documented and translated into Arabic, making them accessible to scholars like al-Jazarī.

8.1 The use of water pumps

Philon of Byzantium, in his *Pneumatics*, described the force pump, an early tool for transporting water through a pipe by using air pressure and suction (Drachmann 1963, 156, Hill 1974, 273). This technology was essential for irrigation, firefighting, and supplying water to urban areas. The design consisted of a piston and cylinder mechanism that utilized alternating suction and pressure to move water.

Al-Jazarī expanded upon this concept by developing a series of advanced water-raising machines that combined the basic principles of Philon's force pump with innovative design elements. As an example, al-Jazarī's "double-action reciprocating pump" made use of a two-chamber setup, enabling a constant water flow, leading to a significant enhancement in the efficiency and effectiveness of water lifting (Hill 1974, 186-189). This shows al-Jazarī's grasp of Philon's ideas and his skill in coming up with new solutions for the shortcomings in previous designs.

The principles underlying Philon's force pump and al-Jazarī's improvements are still relevant in modern engineering. The concept of a reciprocating pump is foundational to many contemporary mechanical and hydraulic systems, including those used in modern water supply networks and industrial applications. Al-Jazarī's use of dual chambers for continuous operation is akin to the modern piston pump mechanisms used in automotive and aerospace engineering.

8.2 Automata and mechanical devices

Philon was known for his work on automata, which were early mechanical devices designed to perform certain actions automatically, such as his famous wine-dispensing machine (Drachmann 1963). These devices often employed simple hydraulic and pneumatic systems to achieve motion and control, serving both practical and entertainment purposes.

Al-Jazarī took inspiration from these early automata and significantly enhanced their complexity and functionality. His basin of the peacock for washing the hands (Hill 1974, 149-152), for example, was not just a decorative automaton but also incorporated a sophisticated system of levers, weights, and water flow control to dispense water in a timed manner, much like Philon's devices. Al-Jazarī's automata also included humanoid figures that performed specific actions, showcasing an advanced understanding of mechanics and fluid dynamics. The influence of Philon's pneumatic principles is evident in al-Jazarī's use of air pressure and water flow to drive these automata, yet al-Jazarī expanded upon these concepts by integrating feedback control and more complex sequences of motion (Drachmann 1963).

The comparison of specific inventions reveals a clear line of influence from Philon of Byzantium to al-Jazarī. Building upon Philon's foundation, al-Jazarī progressed in creating complex and functional machinery, demonstrating a profound understanding of mechanics and hydraulics.

9. Apollonius: The enigma in al-Jazarī's references

Apollonius of Perge (fl. c. 200 BC) was a famous Greek mathematician known for his contributions to conic sections, which set the stage for future technological progress. In al-

Jazarī's work, there is a mysterious reference to a person called "Apollonius the carpenter, the Indian" at the beginning of Chapter 7 in Category IV. It seems highly probably that he is referring to the same man, and that 'Indian' is an error for 'geometrician' - '*hindī*' for '*handasī*'. This has sparked considerable discussion among scholars about the true identity of this person. Wiedemann, however, identifies the writer of this work with Apollonius of Perge, the geometrician (fl. c. 200 BC) (Hill 1974, 12). If this identification is accurate, it would show that al-Jazarī had a strong interest in the mathematical principles of mechanical design, as Apollonius' work was essential in the field of geometry. Nonetheless, the reference to Apollonius in any capacity underscores al-Jazarī's engagement with a tradition of precise, mathematically informed engineering - a hallmark of both Greek and Islamic scientific thought.

Apollonius' research on ellipses, parabolas, and hyperbolas provided valuable information on the characteristics of curves necessary for engineering purposes. These principles were integrated into Islamic engineering, as evidenced by al-Jazarī's intricate designs.

9.1 Geometric principles in gear mechanisms

Apollonius' research on conic sections, particularly focusing on ellipses and hyperbolas, laid the groundwork for the development of mechanical gears and linkages (Heath 1896). His geometric theories, explaining the movement of these shapes, were essential for comprehending gear mechanisms and their usage in intricate mechanical systems.

Al-Jazarī's "Elephant Clock" is an important example of how Apollonius' geometric principles influenced Islamic mechanical engineering. This clock, mentioned in al-Jazarī's *Book of Knowledge of Ingenious Mechanical Devices*, features a sophisticated gear mechanism (Hill 1974, 58-70). The clock's design employs circular and elliptical gears to create complex movements and timekeeping functions, reflecting Apollonius' influence.

9.2 Automata and mechanical devices

Apollonius' exploration of geometric principles influenced the design of automata and complex mechanical systems. His research on the practical uses of conic sections laid the groundwork for comprehending the movement of automata and complex machines.

The automata created by al-Jazarī, like the basin of the peacock for washing the hands (Hill 1974, 149-152) and the boat which is placed on a pool during a drinking party (Hill 1974, 107-109) show a complex use of geometric principles. The incorporation of conic sections in the design of these devices enables accurate and synchronized movements. For instance, the basin of the peacock integrates geometric mechanisms to produce a sequence of complex movements, reflecting Apollonius' influence. Al-Jazarī's advancements in automata showcase an enhancement of Apollonius' geometric principles, creating devices with intricate motion and functionality.

9.3 Hydraulic systems and mechanical engineering

Apollonius' work on geometry contributed to the understanding of hydraulic systems and their integration with mechanical components (Heath 1896). His geometric studies provided insights into the design of efficient hydraulic mechanisms.

Al-Jazarī's hydraulic systems, such as the "Castle Clock" (Hill 1974, 17-41) and various water-raising machines, reflect advanced mechanical and geometric principles. His designs use geometric shapes and principles to achieve effective hydraulic operations and precise timing mechanisms. The "Castle Clock", for example, incorporates a complex system of gears and hydraulic components, demonstrating a sophisticated application of Apollonius' geometric concepts. It is noticeable that al-Jazarī's innovations in hydraulic systems represent an adaptation of Greek geometric knowledge, enhancing the functionality and efficiency of mechanical devices.

Studying al-Jazarī's creations shows a significant impact from Apollonius of Perge's geometric theories. Al-Jazarī's achievements show how Islamic teachings absorbed and improved upon Greek geometry. Transfer of knowledge and adaptation demonstrate extensive cultural and scientific interactions between the Greek and Islamic civilizations. Al-Jazarī's innovations demonstrate his creativity and the gradual development of scientific and technological advancements. Building on the groundwork of Apollonius, al-Jazarī developed intricate and practical devices showcasing an advanced grasp of geometry and mechanics.

10. Heron of Alexandria: The innovator of automata

Heron of Alexandria (fl. c. AD 62), an ancient Greek engineer and mathematician, played a key role in advancing the fields of pneumatics, automata, and hydraulics, which were used for both practical and entertainment purposes. Many years later, al-Jazarī expanded upon the concepts of Heron, developing a variety of creative tools that showed a thorough grasp of earlier Greek achievements (Hill 1974, 12).

Heron's pneumatics laid the foundation for many principles later adopted and refined by Islamic engineers. These treatises detailed various devices, including the *aeolipile*, a steam-powered device, and various automata that utilized water, air, and steam to create motion and achieve specific effects. These works were converted into Arabic and gained popularity in the Islamic world, impacting scholars like al-Jazarī. Qusṭā ibn Lūqā, a respected Melkite Christian scholar from Baalbek in Lebanon with Greek heritage, translated The *Mechanics of Heron* of Alexandria, an important ancient engineering text, into Arabic about 250/864 (Hill 1974, 11). This translation helped share Greek mechanical knowledge with Arabic-speaking audiences, setting the stage for future developments in Islamic engineering.

10.1 The use of pneumatics and automata

Heron's pneumatics describes the various ways in which air, water or steam can be used (Woodcroft 1851). One of the most famous examples is Heron's *aeolipile*, which is considered the first recorded steam engine. This device used steam pressure to create rotational motion, demonstrating an early understanding of pneumatic principles. Additionally, Heron's work included numerous automata that used air and water pressure to animate figures, create sounds, and simulate actions, such as singing birds and self-operating temple doors (Woodcroft 1851).

Al-Jazarī's mechanical devices, showcased in his *Book of Knowledge of Ingenious Mechanical Devices*, show a notable inspiration from Heron's creations, especially in their utilization of pneumatic systems for generating motion and sound. An example is al-Jazarī's creations, the water-clock of the peacocks, from which can be told the passage of the constant hours (Hill 1974, 75-82) and the boat which is placed on a pool during a drinking party (Hill 1974, 107-109), which are intricate mechanisms utilizing air and water pressure to bring figures to life and produce music. These devices illustrate a sophisticated understanding of pneumatic principles, building directly on the foundational work laid out by Heron. However, al-Jazarī introduced improvements such as the use of camshafts and escapement mechanisms, which allowed for more precise control of motion and timing, enhancing the complexity and functionality of the automata.

10.2 Hydraulic innovations

Heron's contributions to hydraulics are evident in his various devices that utilized water pressure to perform tasks, such as his water fountains and hydraulic doors (Woodcroft 1851). These inventions showcased the potential of hydraulics for both practical applications, such as irrigation and urban water supply, and entertainment, through automated water displays.

Al-Jazarī expanded on Heron's hydraulic principles by developing several advanced water-raising machines and automated water clocks. His "Elephant Clock" (Hill 1974, 58-70) and "Castle Clock" (Hill 1974, 17-41) are notable examples that combine hydraulic mechanisms with complex gear systems to measure time and display astronomical information. These devices not only reflect an understanding of Heron's hydraulic concepts but also demonstrate significant innovation in integrating multiple mechanical principles into a single, coherent system. Al-Jazarī's use of hydraulic power to drive automata and timekeeping mechanisms represents a significant advancement over Heron's more basic applications of water pressure.

10.3 Advancements in mechanical engineering

Heron's work on mechanical engineering, particularly his development of the first known programmable automaton in the form of a "robotic" theater, laid the groundwork for future innovations in mechanical design. Heron frequently utilized simple mechanical parts such as gears, pulleys, and levers in his contraptions to generate automated motions and sequences.

Al-Jazarī demonstrated his impact on mechanical engineering through his intricate inventions utilizing common elements like gears, cams, and pulleys, but with increased complexity and usefulness. His "Beaker (*Ka's*) Water-Clock" (Hill 1974, 71-74) demonstrates an advanced understanding of mechanical linkages and control mechanisms, allowing for more precise and varied movements. These innovations show a direct lineage from Heron's work, but with significant enhancements that reflect the evolving technological landscape of the Islamic Golden Age.

The comparison of specific inventions reveals a clear line of influence from Heron of Alexandria to al-Jazarī. This exchange of knowledge and adjustment highlights the broader cultural and scientific interactions between the Greek and Islamic societies. Al-Jazarī's accomplishments showcase his intelligence involved in scientific and technological progress. Expanding upon Heron's pioneering research, al-Jazarī created more sophisticated and effective machines demonstrating a profound understanding of mechanics, pneumatics, and hydraulics.

Conclusion

Al-Jazarī's *Kitāb fī maʻrifat al-ḥiyal al-handasiyya* is a significant accomplishment in engineering history, showcasing the author's cleverness and the impact of Greek mechanical customs. Greek engineering knowledge was passed on, safeguarded, and improved in the Islamic world, all thanks to the hard work of translators and scholars who made sure that these old ideas were not just preserved but also developed.

His work shows not just the impact of Greek mechanical understanding, but also introduces new ideas that go beyond the Greek models that came before. Although his devices were based on Greek models, they frequently displayed a degree of sophistication and intricacy that had never been seen before in ancient times. For instance, his plans for machines that lift water, featuring both basic and complex tools, utilize various mechanical concepts such as gears, levers, screws, and pulleys in original ways to enhance effectiveness and performance. Yet, al-Jazarī's creations frequently exceed the Greek designs in terms of intricacy and usefulness, showcasing his skill in creating new and enhanced versions of the initial models.

Al-Jazarī acknowledges the influence of Greek mathematicians and engineers, as Archimedes, Ctesibius, Philon, Apollonius, Heron on Islamic engineering, and also shows how Islamic scholars enhanced these earlier designs through their own innovations. Greek engineering's influence on al-Jazarī's creations exemplifies the diverse cultural collaboration during the Islamic Golden Age, when scholars of various origins worked together to develop groundbreaking technologies. Al-Jazarī's work, which includes in-depth explanations of mechanical devices and direct mentions of Greek origins, acts as a connection between the old and medieval eras, showcasing the lasting impact of Greek engineering.

Furthermore, his work shows that Islamic engineers during the medieval era not only preserved Greek knowledge but also expanded upon it to develop more advanced technologies.

Indeed, al-Jazarī's work holds significant historical value. Initially, it verifies the presence of a long-standing practice of mechanical engineering in the Eastern Mediterranean and the Middle East starting from Hellenistic eras until the 7th/13th century. Al-Jazarī recognized the importance of upholding this tradition and made sure to give credit to those who came before him. By building upon previous works and providing detailed descriptions of each device's construction and function, he allows us to accurately gauge the Arabs' advancement in mechanical technology by the end of the 6th/12th century.

In sum, al-Jazarī's *Kitāb fī maʿrifat al-ḥiyal al-handasiyya* serves as an acknowledgment of the accomplishments of his Greek forerunners and a manifestation of the inventive mindset present during the Islamic Golden Age. By studying the works of Greek engineers, al-Jazarī not only upheld their legacy but also pushed the boundaries of mechanical engineering, ensuring the ongoing evolution and inspiration of ancient ideas for future generations. The enduring significance of al-Jazarī's principles in present-day engineering highlights the timeless value of his contributions and the crucial role of historical wisdom in influencing current technological advancements.

Bibliography

Brentjes, S. (ed.) 2022. *Routledge Handbook on the Sciences in Islamicate Societies. Practices from the 2nd/8th to the 13th/19th Centuries*. First Edition. London and New York: Routledge.

Drachmann, A. G. 1963. *The Mechanical Technology of Greek and Roman Antiquity: A Study of the Literary Sources*. Copenhagen, Munksgaard, Madison: University of Wisconsin Press.

Gutas, D. 1998. *Greek Thought, Arabic Culture: The Graeco-Arabic Translation Movement in Baghdad and Early ʻAbbāsid Society (2nd-4th/8th-10th Centuries)*. London and New York: Routledge.

Al-Hassan, A. Y. and D. R. Hill, 1986. *Islamic Technology: An Illustrated History*. Cambridge: Cambridge University Press.

Heath, T. L. 1896. *Apollonius of Perga. Treatise on Conic Sections*. Cambridge: At the University Press.

Heath, T. L. 1897. *The Works of Archimedes*. London: C. J. Clay and Sons, Cambridge University Press Warehouse.

Hill, D. R. (transl.) 1974. *The Book of Knowledge of Ingenious Mechanical Devices by Ibn al-Razzāz al-Jazarī*. Dordrecht-Holland / Boston-U.S.A.: D. Reidel Publishing Company.

Hill, D. R. 1993. *Islamic Science and Engineering*. Edinburgh: Edinburgh University Press.

Hill, D. 1996. *A History of Engineering in Classical and Medieval Times.* London and New York: Routledge.

Hill, D. R. 2004. Al-Djazarī. In: P. J. Bearman, Th. Bianquis, C. E. Bosworth, E. van Donzel and W. P. Heinrichs (eds.), *The Encyclopaedia of Islam*. New Edition, vol. XII, Supplement. Leiden: Brill, pp. 266-267.

Jackson, D. E. P. 1987-1988. Scholarship in Abbasid Baghdad with Special Reference to Greek Mechanics in Arabic. *Quaderni di Studi Arabi* 5/6, pp. 369-390.

Masood, E. 2009. *Science & Islam. A History*. London: Icon Books.

Özsoy, F. E. 2023. In Pursuit of the Past: Artuqid Patronage of the Ancient Sciences. Unpublished master's thesis. Koç University.

Saliba, G. 2007. *Islamic Science and the Making of the European Renaissance*. Cambridge, MA: The MIT Press.

Sarton, G. 1931. *Introduction to the History of Science* (Vol. II: From Rabbi ben Ezra to Roger Bacon). Baltimore: The Williams & Wilkins Company.

Woodcroft, B. (transl. and ed.) 1851. *The Pneumatics of Hero of Alexandria From the Original Greek*. London: Taylor Walton and Maberly.