Natural Philosophy and the Development of Mechanics and Engineering from the 5th century B.C. to Middle-Ages

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Development of logic into a science served as an instrument for the progress in natural philosophy and the scientific method in the 6th and 5th Centuries BC in China, India, and the Arabian world, the Middle East, the Ancient Greece and Rome. Rapid advancements in natural sciences were followed by systematic attempts to organize knowledge in the 4th to 1st Centuries BC in the Greek and the Hellenistic world, reaching maturity in the Roman Empire after the 2nd Century AD. Parallel development of philosophy, science and technology can be traced in the East too. The essentially random growth of machines and mechanisms driven by the pressure of necessity was followed by the development of complicated machines using design rules and concepts in a systematic way, and not arrived at empirically through a process of long evolution, were investigated very early in history. The influence of natural philosophy in classical times to the development of mechanics and engineering as a science from the 5th century B.C. to the Middle-Ages is discussed here..

Keywords: *Natural Philosophy, Logic, Mechanics, Mechanism Design, Engineering.*

1. INTRODUCTION

Philosophy of science, refers to the elements of scientific inquiry from a philosophical perspective that led to the development of a generalized science as distinct from a set of unrelated empirical rules. Three main branches of investigation concerning nature in Ancient Greece were the subject of Natural Philosophy (including Physics and Cosmology), Mathematics and Astronomy, Biology and Medicine. Philosophy in the Ancient Greek World (in Greek *Φιλοσοφία* – love of wisdom) had a more general meaning and encompassed the study of natural phenomena.The question of how Natural Philosophy actually functioned in physical science, mechanics and engineering has been the subject of numerous investigations [1-6].

Since the dawn of human history, activities combining elements and forms of art and technology can be identified. In the ancient great empires of Mesopotamia and Egypt, and the feudal societies of the East, India and China parallel developments of crafts and technology were not associated with a concurrent development of science. Technical advances were arrived at by long evolution or invention. Moreover, the political and social system did not allow for liberal thinking, necessary for the development of scientific thought, and the knowledge was confined to the clergy or the ruling cast. In the Greek Society there was a production surplus which allowed members of the society to be employed in tasks which were not of immediate use, such as arts and philosophy. The general use of steel in agriculture and war, the popularization of the alphabet, and the general use of papyrus paper for book writing was among the reasons for rapid advancements of learning and science in ancient Greece [1-6].

Machines are spoken about early in history since man found his power inadequate for the tasks he set himself, among them moving heavy weights. Lever and the wedge are technology heritage from the Paleolithic era [7]. Levers appeared as early as 5000 BC in the form of a simple balance scale, and within a few thousand years, workers in the Near East and India, were using a crane-like lever, called the shaduf, to lift containers of water (Fig. 1). The balance scale shown in Fig. 1 consists of a stone beam approximately 80 mm in length with stone counterweights attached with slim ropes to reduce friction, possibly for weighing gold [3].

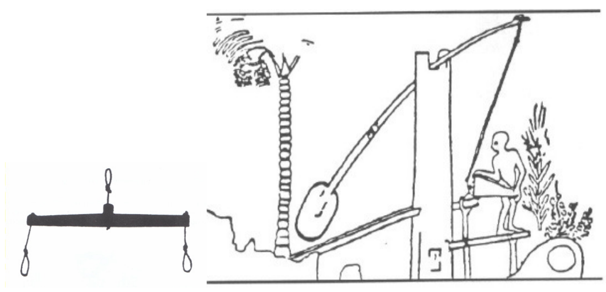

Figure 1. Balance scale from Egypt ca. 4500 B.C. and the shaduf, first used in Mesopotamia ca.3000 BC [3].

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Initially in history of engineering conception, design, and manufacture were the work of a single person and consequently, the first products were simple and of human proportions. Machine designers were the master builders of the Potamic Civilizations (Mesopotamia, India, China, and Egypt). Those designers rose to the level of engineering in the Thalassic (great seas) societies of ancient Greece and Rome. Much later, mass production caused the breaking of this process into distinct smaller ones and led to the separation of design from manufacturing. However, the principles underlying design activity were investigated very early in history [1-6].

Fig. 2 shows carpenters in Egypt using the bow-drill. Although Reuleaux [8] suggested as the earliest machine the twirling stick for starting fire, probably the bow-drill is the first mechanical tool used by humans, ca.2800 BC [3-4].

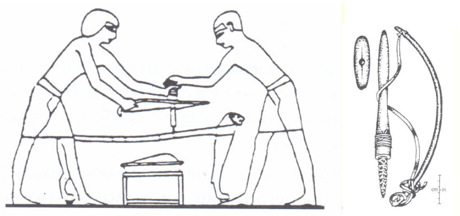

Figure 2. Carpenters in Egypt using the bow-drill, probably the first mechanical tool ca.2800 BC [3-4].

A light chariot with spoked wheels was developed in Syria or Northern Mesopotamia at about the beginning of the 2nd millennium B.C. and quickly propagated all over Middle East as military vehicle. Chariots and wheels craftsmen from Egypt circa 1475 B.C., and a chariot from Thebes Egypt ca. 1450 BC on display at Luxor museum, provide information on crafts concerning chariots, parts of the chassis, wheels, and axles as shown in Fig. 3. An important piece of information yielding from Fig. 3 refers to the consecutive phases of wheel production by different craftsmen [3-4].

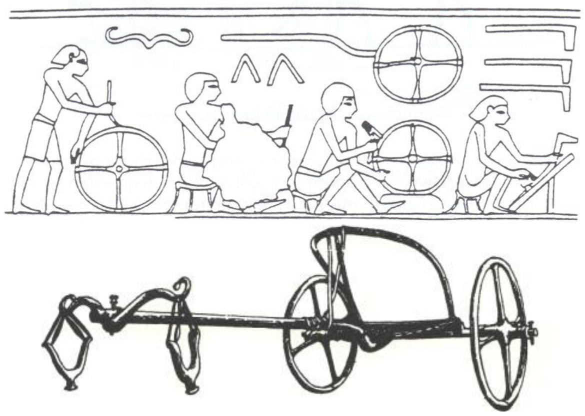

Figure 3. Chariots and wheels craftsmen from Egypt ca. 1475 B.C. and a chariot from Thebes Egypt ca. 1500 B.C. [3-4].

A recent reconstruction of the Trojan Horse based on Homeric shipbuilding, along with a study of traction dynamics and lateral stability, provides evidence of a pioneering design task, incorporating skills and knowledge gathered at the time. The Trojan Horse development is of great engineering significance since it involves the seeds of a primitive design activity in response to specifications imposed by the needs of the war at the late bronze age (1100 B.C.). Epeios, the wooden-horse maker is directly linked to the mechanopoios, the machine maker or engineer, the man who designed, built and operated the mêchanê for the stage needs in the ancient drama some centuries later in the 5th century B.C. [9].

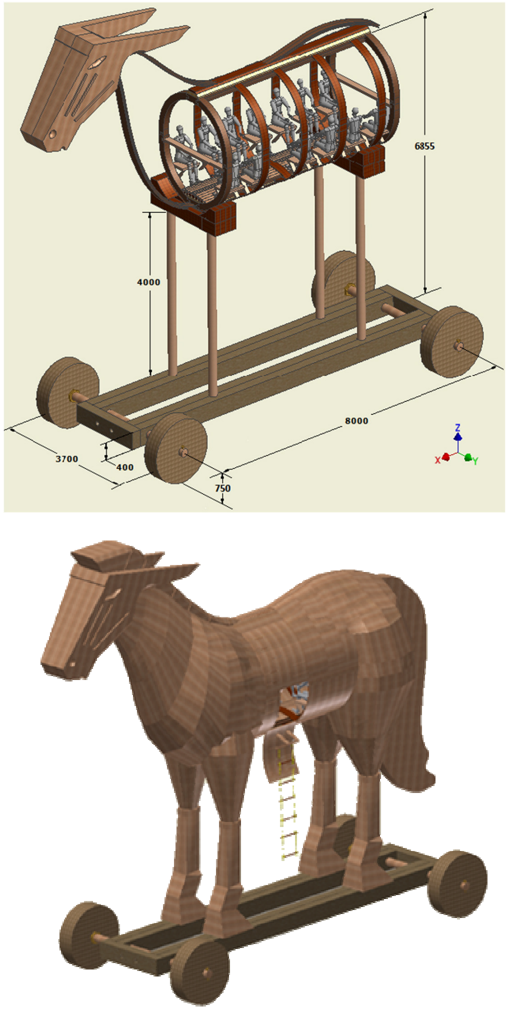

Figure 4. The Trojan Horse reconstruction [9].

The first known written record of the word *machine* appears in Homer (ca. 800 BC) and Herodotus (ca. 484-425 BC) [10], to describe political manipulation (Dimarogonas1 [1]). The word was not used with its modern meaning until Aeschylus ca 450 BC used it to describe the theatrical device used extensively in the ancient Greek theatre as a stage device to lift actors, chariots or flying horses in the air, as though flying, portraying the descent of gods from the sky and similar purposes. The *mechane* is also known with the Latin term Deus Ex Machina. *Mechanema* (mechanism), in

[1] Professor Andrew D. Dimarogonas (1938-2000) was widely recognized as a distinguished authority in various specialties of mechanical engineering. He made important contributions to the mechanical design and vibrations, and received the 1999 ASME Engineer-Historian Award for his many works on integrating the history of mechanical engineering.

turn, as used by Aristophanes (448-385 BC), means an assemblage of machines [3-4].

Deus-Ex-Machina was the achievement of engineering (intelligence) in response to specifications imposed by the needs of the stage production. The *mechanism* together with other mechanical devices such as the *periaktos* and the *ekkyklema*, used as stage machinery in the ancient Greek theatre, are the very early heritage of mechanical engineering. It is believed that *mêchanê* establishes the point of origin of engineering as a science, using mathematics and reason. Fig. 5 shows Sharpedon, son of Europa, carried through the air by Sleep (Ypnos) and Death (Thanatos), most probably from Aeschylos' *Europa*. Apulian vase, Metropolitan Museum of Art, New York [3,11].

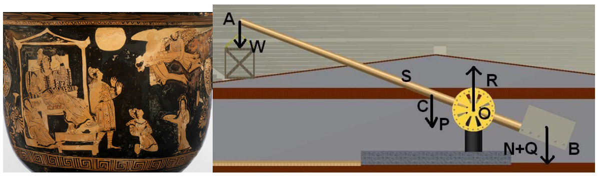

Figure 5. Sharpedon, son of Europa, carried through the air by Sleep (Ypnos) and Death (Thanatos), most probably from Aeschylos' *Europa*. Apulian vase, Metropolitan Museum of Art, New York left, the reconstructed mechanism and force balance, right [11]

Vitruvius (1st Century AD) [12] defined a machine as "a combination of timber fastened together chiefly efficacious in moving great weights". A century later, Heron of Alexandria (10-70 AD) [13] summarized the practice of his day by naming "the five simple machines" for "moving a given weight by a given force [1]. In the Renaissance Alberti (1404-1472) describes a variety of mechanisms needed in the construction of buildings [14-15]. Reuleaux in 1872 discussed early machinery such as water mills [9].

The science of mechanics was esteemed by philosophers and mathematicians in the classical times [16]. The development of the theory of machines and the principles underlying design activity were investigated very early in history. The essentially random growth of machines and mechanisms was driven by the pressure of necessity. Making the tools of labor, buildings, and the first machines, regarded in antiquity as the science of machines, has been developed under the influence of the practical demands of society that are linked to production, technology, and the study of the motion of celestial bodies (primarily for navigation) [17-19].

The term "Engineer" comes from the Latin word "ingenium" that can be translated with "geniality"; the linguistic root of the Latin word that came from the Sanskrit root "gen". The same root is still found in English and Greek words like genealogy, genetics, etc. Dimarogonas mentions that the term Engineering has been used, especially in literature on the History of Engineering, as synonymous with Technology and, in many instances with Craft. The first design theory was part of aesthetics, where aesthetic (Beautiful) included also functional (Useful) and ethical (the Good) attributes. Function and Ethical were inseparable from Form [4].

Attempts at understanding the fundamentals of mechanics go back to antiquity, but scientific conception concerning mechanical phenomena accumulated and developed very slowly during the first stages of the history of human culture. This process involves traversing the exceedingly difficult path "from living perception to abstract thought and from this to practice". Dimarogonas, also discussed the problem of existence and uniqueness of the solution to the design problem together with the possibility of an axiomatic foundation in engineering design. He also traced the origin of vibration theory in classical times and brought to light certain important historical developments in the field of engineering design [1-6].

Aristotle (384-322 BC) gave Engineering a sense of wonder: Nature works against the man's needs, because it always takes its own course. Thus, when there is need for achieving something going beyond Nature, difficulties can be overcome with the aid of Engineering. Technology encompasses *Craft*, *Invention* and *Engineering* without any distinct dividing line, each of the three including part of the other two [3-4].

Engineering is sometimes defined as the application of science to the solution of a problem of society at a profit. The accrediting agency for U.S. engineering curricula, the Accreditation Board for Engineering and Technology (ABET), prepared the following more formal definition: "Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind". Both of these definitions explain that engineering is based on mathematics and science but is focused on the solutions of specific problems. Also, the solutions, because they are needed or desired by society, must meet certain legal, environmental, and economic constraints [20].

Engineering and design are interrelated through mechanics and mathematical foundation. The precise nature of the design process is infinitely varied and therefore difficult to summarize in a simple design formula, or a precise definition. Whatever the particular situation, machine design today is a process of creation, invention and definition, involving an eventual synthesis of contributory and often conflicting factors, capable of reproduction, with acceptable quality of products and with specified reliability. Machine design is an applied science relying heavily on engineering science because no machine can defy the laws of physics or the strength limits of the materials the machine is made of. Machine design is a systematic process. Even if a new machine was conceived by invention systematic machine design is needed to transform the invented concept into a working system that users will appreciate [4].

Artobolevski (1905-1977) presented a brief history of the development of the theory of machines and mechanisms. He quotes the words of the outstanding physicist and creator of quantum mechanics, W. Heisenberg (1901-1976), writing: "To grasp the progress of science as a whole, it is useful to compare cotemporary problems of science with the problems of the preceding epoch and to investigate the specific changes that one or another important problem has undergone over decades and even centuries". However, in describing the history of machines, it is necessary to establish at least approximately the point of its origin as a science. This is particularly difficult and this process is confined with the machines and mechanisms which were designed in a systematic way and not arrived at empirically through a process of long evolution. This is a point that separates engineering science from technology and crafts. However, in describing the history of mechanics and machines it is important to establish at least approximately the point of its origin as a science [21].

The philosophical foundation of knowledge, aesthetics and ethics and their implications in engineering design that are discussed in the works of Dimarogonas [1-6] provide evidence that although the fundamental axioms of design were discovered during the middle of the last century in Europe, design rules and concepts were practiced extensively by the engineers of ancient times leading to machine design from machine elements to the design of a machine as a system.

The influence of Natural Philosophy and Logic in the 6th and 5th Centuries BC in the philosophical inquiry, and the scientific method developed in the 4th to 1st Centuries BC that have contributed to the establishment of mechanics and the principles involving the initial steps of building machines and its evolution during the Roman Times and the Arabian era, in the progressive trend of human knowledge are discussed here. This investigation aims at identifying significant issues and personalities that have enhanced Mechanics, Engineering and Design from ancient times, along with their impact on modern Mechanism and Machine Science from both a philosophical and an engineering viewpoint. Furthermore, the relevance of those contributions will enhance the issues discussed in the course History of Technology taught at the Mechanical Engineering and Aeronautics Department of the University of Patras in relation to Natural Philosophy.

2. DEVELOPMENT OF LOGIC AND NATURAL SCIENCES

The wealth of empirical knowledge generated in the great Potamic civilizations of the Neolithic and bronze ages was transformed by the ancient Greeks into science. The Homeric Epics provide evidence that a solid background of knowledge existed at that time, approaching the limits of scientific knowledge [22]. Understanding Greek science is not possible without understanding the shortcomings of Lord Bacon's (1561-1626) theory that "*technological discoveries... are much older than philosophy and the natural sciences. To say the truth, when the theory and dogmatism made their appearance, then came stagnation in the applied fields*". This is true if technology is thought to be only invention or the construction of large edifices that impress the layman. Engineering, however, was born out of the development of the natural sciences [23].

Since the 6th century BC parallel development of philosophy and logic took place in China, India, Iran, the Middle-East and Ancient Greece. Lao Tzu (ca 600 *BC*) wrote the *Daodejing*, one of the most significant treatises in Chinese cosmogony. Similar principles can be found in Heraclitus (ca. 550-475 *BC*) and the dialectical method used by Socrates (469-399 *BC*) as described by Plato (429-347 *BC*) [24].

Plato (429-347 *BC*) and Aristoteles (ca.384-322 *BC*) developed logic into a science, and this served as an instrument for the parallel development of the natural sciences. The search for Reason led to the development of a generalized science as distinct from a set of unrelated empirical rules. Rapid advancement in natural sciences was followed by systematic attempts to organize knowledge. The appearance and refinement of mathematical methods permitted the statement and solution of complicated problems in mechanics. Rigorous proof was introduced, based in deductive logic and mathematical symbolism Abstract reasoning based on mathematical analysis and rigorous proof, distinguished from mere empiricism, formed the basis for engineering as a science beyond the level of a mere craft. In classical times concrete principles upon which engineering is developed as a science using mathematics and reason were established [1-6,25].

3. THE CLASSICAL TIMES – THE IONIAN AND ELEATIC PHILOSOPHERS

Diogenes Laertius (ca. 3rd century *BC*) was a biographer of ancient Greek philosophers. His *Lives of the Philosophers* (*Philosophoi Bioi*), in ten books, is still extant and is an important source of information on the development of Greek philosophy. Diogenes divides all the Greek philosophers into two classes: those of the *Ionic* and those of the *Italic* school, the *Eleatics*. He derives the first from Anaximander from Miletus (ca. 610 *BC*), the second from Pythagoras of Samos (ca.569-475 *BC*). The first seven books are devoted to the *Ionic* philosophers and the last three to the *Italic* school [26-27].

In the 6th century *BC*, Thales (620-546 *BC*), founded the *Miletian* School of natural philosophy and developed the scientific method to investigate the basic principles and the question of the originating substances of matter [27]. The *Miletian* (*Ionian*) philosophers in the cities of Ionia, the Greek-inhabited coast of Asia Minor, sought the principle of the Universe in the concrete material substance that is perceivable by the senses [28]. The Ionian philosophers are also referred to as pre-Socratic philosophers, as much of their contribution was completed before the time of Socrates (469-399 *BC*). After Socrates, Diogenes Laertius [26] divides the Ionian philosophers into three branches: (a) Plato (429-347 *BC*) and the Academics, down to Clitomachus (187-110 *BC*) head of the Academy in Athens around 127 *BC*; (b) the Cynics, down to Chrysippus (280–206 *BC*); (c) Aristotle (384-322 *BC*) and Theophrastus (c.372-c.287 *BC*). Theophrastus, born on Lesvos studied in Athens at the Academy, which he headed from 323 *BC* until his death.

Thales (620-546 *BC*) was interested in almost everything, investigating almost all areas of knowledge, philosophy, history, science, mathematics, engineering, geography, and politics. He proposed theories to explain many of the events of nature, the primary substance, the support of the earth, and the cause of change. Thales, Anaximander (ca. 610 *BC*) and Anaximenes (ca. 560-528 *BC*), all inhabitants of Miletos, developed their views about Universe and the laws describing its behavior [27-28]. The later Ionians were Heraclitus of Ephesus, in the coast of Asia Minor (ca. 550-475 *BC*), Anaxogoras of Clazomenae (500-428 *BC*), Empedocles of Acragas (in Sicily) (492-432 *BC*), (470-385 BC), and the Atomists Leucippus (5th century *BC*) and Democritus (460-370 *BC*) from Abdera. Empedocles was a contemporary of Anaxagoras and, it is possible that Anaxagoras was partially reacting to Empedocles' theories in the development of his own views [27-28].

Heraclitus of Ephesus (ca. 550-475 *BC*), was active around 500 *BC*. Heraclitus was a contemporary of Pythagoras, Lao-Tzu, Confucius, and Siddhartha, the Buddha. He is best known for his doctrines that things are constantly changing (universal flux), that opposites coincide (unity of opposites), and that fire is the basic material of the world. Heraclitus appears to have been the first to separate the study of motion itself from dynamics, the forces causing the motion, and introduced the principle of retribution, or change, in the motion of celestial bodies [28-29].

Anaxagoras (500-428 *BC*), an important Presocratic natural philosopher and scientist lived and taught in Athens for approximately thirty years. He was the first to formulate a molecular theory of matter and to regard the physical universe as subject to the rule of rationality or reason. Although he insisted that the earth is flat he was the first to describe the circumstances under which eclipses occur and the way light is reflected by the moon [30].

Leucippus (5th century *BC*) is regarded as the founder of atomic physics. Possibly, student of Zeno of Elea (490-420 *BC*), devised the atomic philosophy in order to answer the problems raised by Parmenides of Elea (515-450 *BC*) and his followers. Leucippus is reported that the atoms are always in motion. Democritus (460-370 *BC*) expanded the atomic theory of Leucippus. He maintained the impossibility of dividing things *ad infinitum*. Epicurus (341-270 *BC*) borrowed the principal features of his philosophy from Democritus [31].

Pythagoras of Samos (ca.569-475 *BC*) made important developments in mathematics, astronomy, and the theory of music. Pythagoras studied under Thales before traveling to Egypt and Mesopotamia, then establishing his own school of philosophy in Croton (southern Italy). The theorem known as Pythagoras' theorem was probably known to the Babylonians 1000 years earlier, but he was the first to prove it. Pythagoras related music to mathematics. He conducted experiments with hammers, strings, pipes, bells and shells, and established the first vibration research laboratory as shown in Fig. 6. The Pythagoreans describe the three "lower" arts: logic, grammar, and rhetoric and the four "mathematical" arts: arithmetic, geometry, astronomy, and acoustics [6, 32]. Philolaus (470-385 BC) from Croton a student of Pythagoras and a contemporary of Socrates probably he has written the book *On Nature* [33].

Figure 6. Pythagoras experimenting with hammers, strings, pipes, bells and shells in the first vibration research laboratory [6].

The *Eleatic* philosophy was founded by Xenophanes of Colophon who lived in various parts of the ancient Greek world during the late 6th and early 5th centuries *BC*. Xenophanes was associated with the founding of the city state of Elea in Southern Italy in 540 *BC*. Parmenides of Elea (515-450 *BC*), Zeno of Elea (490-420 *BC*), and Melissus of Samos (475-410 *BC*), student of Parmenides, are considered to be the Eleatic philosophers [45]. In the search for truth, the *Eleatics*, in contrast with the *Ionian* philosophers rejected any input from sensory experience. The *Eleatics* felt mathematics to be the method of arriving at the truth. They argued that the true knowledge of being can be discovered through reason, beyond the false impressions of the senses. Empedocles, Anaxagoras, and Philolaus, tried to meet the same challenge in very different ways [1-3,34].

Parmenides of Elea (515-450 *BC*) is one of the most significant pre-Socratic philosophers; however, of his known work only the conventionally entitled *On Nature* (written between 480 and 470 BC) has survived. From the original 3,000 lines poem only 150 lines remain today. Student of Ameinias (6th century *BC*) was influenced by the philosophy of Samos through Xenophanes (6th century *BC*). In *Parmenides*, Platon portrays that Socrates who was about 20 years old in 450 *BC* met Parmenides, when Parmenides and Zeno visited Athens for the first time. Plato describes that Parmenides who looked like God with white beard was 65 years of age, and Zeno 40 years old. Parmenides' considerably influenced the thinking of Plato, and in this respect Parmenides has influenced the evolution of Western philosophy [35].

Zeno (490-420 *BC*), through his effective argumentation, contributed to make clear the unfeasibility of Ionian natural philosophy, which presupposed the motion of generation and corruption. Aristotle and his school are the main sources on Zeno. Zeno, according to Aristotle was the inventor of "dialectic" and the so called "indirect proof". Melissus (475-410 *BC*) was born in Samos, the same birth place as Pythagoras and thus he grew up with the Pythagorean philosophy, together with the tradition of the Ionian natural philosophers. He was the last significant member of the Eleatic school of philosophy. Melissus was the Admiral of Samos' navy, he revolted against Athens, and won a ship battle with the Athenians lead by Pericles in 441-440 [34-35].

Although the *Eleatic* thinking was not perfect, important beginnings of logic were developed. Platon (429-347 *BC*) and Aristoteles (ca. 384-322 *BC*) formulated the *Eleatic* philosophy into a science that served as an instrument for the parallel development of the natural sciences, especially mathematics and physics. The search for *Reason* led to the development of a generalized science as distinct from a set of unrelated empirical rules. The subject of philosophy, as it is often conceived - a rigorous and systematic examination of ethical, political, metaphysical, and epistemological issues, armed with a distinctive method – is considered Plato's invention. The most fundamental distinction in Platon's philosophy is between the many observable objects that appear beautiful (good, true, big) and one object, absolute beauty (goodness, justice, moral) from which those many beautiful things receive their names and corresponding characteristics [1-2, 34-35].

Cratylus, a student of Heraclitus (late 5th century) brought Heraclitus' philosophy to Athens, where Plato heard it. Plato seems to have used Heraclitus' theory (as interpreted by Cratylus) as a model for the sensible world, as he used Parmenides' theory for the intelligible world. Both Plato and Aristotle viewed Heraclitus as violating the law of non-contradiction, and propounding an incoherent theory of knowledge based on a radical flux [3-4,34-35].

One of Plato's contemporaries and friends and a student of Pythagoras, Archytas of Tarentum (ca. 400-365 *BC*) is said to have written the first systematic treatise on machines based on mathematical principles. This is lost. Archytas built an air-propelled flying wooden dove (Aulus Gellius, ca. 150 *AD*). Details about Archytas's dove are not known but it seems to be the first flying machine. Archytas provides a complex solution for doubling the cube and defended the view that the universe is unlimited [26,34-35].

Aristotle from Stagirus, Thrace (384-322 *BC*) at the age of 17 joined the *Academy* and studied under Plato, attending his lectures for a period of twenty years. At the invitation of Philip of Macedonia he became the tutor of his 13 year old son Alexander. Upon the death of Philip, Aristotle returned to Athens, which he had not visited since the death of Plato. He found the *Platonic* school flourishing under Xenocrates (396-314 *BC*) head of the Academy for 25 years after Speusippus (ca 410-339/8 *BC*) the successor of Plato, and *Platonism* the dominant philosophy of Athens. Speusippus of Athens was the son of Plato's sister Potone; he became head of the Academy on Plato's death in 348/347 and remained its head for eight years, apparently until his death. Aristotle, discussing the ways in which people have answered the question 'what are the substances?', ascribes to Plato the view that there are not only perceptible substances but eternal ones of two types: forms and mathematical objects. He then says that Speusippus thought there were even more types of substance; he "started from the "One" and adopted principles (*archai*) for each of his types of substance: "one for numbers, another for magnitudes, then for soul". So we have at least four layers of beings: numbers, magnitudes, souls, and perceptible beings; the One is Speusippus' starting-point, but he has different principles for each level of being [36].

Aristotle set up his own school, the *Peripatetic school*, at the *Lyceum*. Members of the Peripatetic school include: Theophrastus (371 or 372 -287/286 *BC*), born in Erresos on Lesbos, a student of Aristotle and succeeded him as a director of the Lyceum in Athens. He worked on the philosophy of Aristotle reshaping, commenting, and developing it. Theophrastus thinking leads to empirism by means of observation, acquisition, and classification. He was the director of the Lyceum for 35 years and a teacher of up to 2000 students; Straton of Lampsacus (ca. 340–270 *BC*) was the third head of the Lyceum, following Aristotle's successor Theophrastus (ca. 372-287 *BC*) in about 286 *BC*. Satyrus the Peripatetic (late 3rd century *BC*) best known as the author of a biography of the Athenian dramatist Euripides and Philip of Macedon; Eudemus of Rhodes (ca. 370-300 *BC*) was the first historian of science. He organized Aristotle's philosophical legacy in a systematic and didactical way. At the insistence of Aristotle, he wrote about the early history and development of Greek science, mathematics and astronomy between 600 and 350 *BC*; Alexander of Aphrodisias (late 2nd century *BC*) head of the lyceum the most celebrated of the Greek commentators on the writings of Aristotle; and Demetrius Phalereus (d. ca 280 *BC*) who wrote extensively on the subjects of history, rhetoric, and literary criticism, were the first *Peripatetics* [36-37].

Aristotle's definition of *substance* states that it is "the being which exists by itself and does not need anything else for its existence" yielding the ontological, Cartesian definition. This definition of substance considered both the Heraclitus philosophy, everything is changing, as well as the Eleatics philosophers inquiry of truth through mathematics. Aristotle mentions gears around 330 *BC*, (wheel drives in windlasses). He said that the direction of rotation is reversed when one gear wheel drives another gear wheel. A single pulley provides little mechanical advantage, but by about 400 *BC* the Greeks had put to use compound pulleys, or ones that contained several wheels. The earliest indisputable evidence for knowledge of compound pulley systems is referred in the *Mechanical Problems* attributed to Aristotle. Fig. 7 shows a *dikolos* lifting machine with compound pulleys [1-4,17].

The principles of statics and dynamics were discussed by Aristotle (ca. 384-322 *BC*) in *Mechanica (Problems of Machines)*, the first extant treatise on the design of machines, probably written by one of Aristotle's students in Lyceum. *Mechanica* starts with the definition of *machine*, which in that era was synonymous with *mechanism.* In. fact, mechanisms were the only machines known. *Mechanica* contains remarkable discussions of the mechanics of the lever, the balance, the wedge, rolling friction, the strength of beams, impact, mechanical advantage, and the difference between static and kinematic friction.

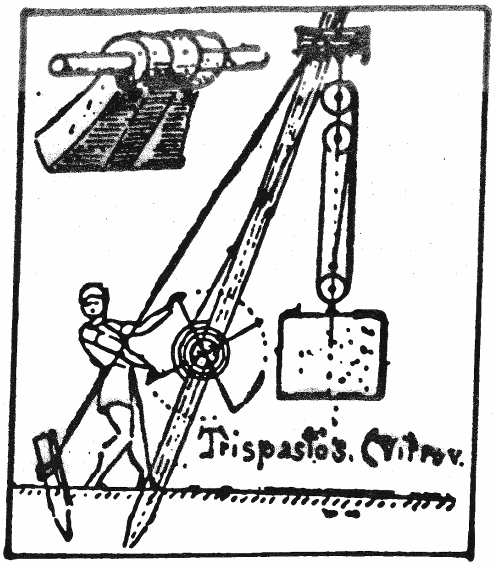

Figure 7 A dikolos lifting machine with compound pulleys [3].

Aristotle, further discusses several purely kinematic aspects of mechanisms. such as: the vectorial character of velocity, the superposition of velocities, and the parallelogram law for velocity addition, the concepts of absolute and relative velocity of points along a link of a machine. For circular motion: the velocity of every point on a wheel rotating about its geometric centre is directed along a tangent to its circular path and is proportional to the radius of the circle and the angular velocity The motion of two wheels rolling against one another without slipping; they rotate in opposite directions. For the rhomboid four-bar linkage and the relative velocities of the opposing joints Aristotle developed rational geometric methods and proofs. Aristotle's work on explaining how machines function, making a first attempt for machine dynamics, unlike the approaches of Euclid (330 BC - 260 BC) and Archimedes (287 BC – 212 BC), who studied situations of equilibrium in machines, establish him as the founder of machine theory [1-4, 17, 38-39].

Xenocrates of Chalkedon (396-314 *BC*) was explicit about the division of philosophical topics implicit in Plato, into 'physics', 'ethics', and 'logic'; this became the norm in Stoicism. Metaphysics and theory of knowledge are included in 'physics' and 'logic', respectively [53]. Epicurus, (341–270 *BC*) was raised in Samos, he came to Athens when he was eighteen, when Xenocrates was head of the Academy. The philosophy of Epicurus was a complete and interdependent system, involving a view of the goal of human life, an empiricist theory of knowledge, a description of nature based on atomistic materialism, and a naturalistic account of evolution, from the formation of the world to the emergence of human societies [40].

Strato (Straton) of Lampsacus, (ca. 340–270 *BC*), was known in Latin as *Strato Physicus*. His extensive writings included a non-teleological reinterpretation of Aristotle's physics, which influenced Alexandrian philosophers such as Hero. His view - that the universe is self-explanatory and self-sustaining, and thus in no need of the introduction of a god or other extra-natural explanatory factor - was known as *Stratonician atheism*. Strato introduced an important kinematic criterion of equilibrium, the *principle* of *virtual velocities*. Strato's other theories included the notion space was porous, objects containing different amounts of the void (which accounted for differences in weight); he also corrected Aristotle's claim that bodies fall at a constant speed, noting that in fact they accelerate. Strato proved that the composition of two uniform movements is a uniform movement along the diagonal of the parallelogram formed by the distances covered in the two movements in a given time [41-42].

4. THE ALEXANDRIAN TIMES

The decline of Greek civilization is followed by the rise of Alexandria, founded in honour of Alexander the Great (356–323 *BC*) in the Nile Delta in Egypt. Alexandria was the greatest city of the ancient world, the capital of Egypt from its founding in 332 *BC* to *AD* 642, and became the most important scientific centre in the world at that time and a centre of Hellenic scholarship and science [43].

The library at Alexandria was planned by Ptolemy I Soter (367-282 *BC*): friend and biographer of Alexander the Great, after his death king of Egypt, founder of the Ptolemaic dynasty. The library came to fruition under his son Ptolemy II Philadelphus, based on copies of the works in the library of Aristotle. Ptolemy II Philadelphus (309-246 *BC*) appointed one of Eratosthenes' teachers Callimachus (305-240 *BC*) from Cyrene, a colony of the Greeks from Thera at about 630 *BC*, now Shahhat in Libya, North Africa, as the second librarian. When Ptolemy III Euergetes (266-222 *BC*) succeeded his father in 245 *BC* he persuaded Eratosthenes to go to Alexandria as the tutor of his son Ptolemy IV Philopator. Eratosthenes became the third librarian at Alexandria in about 240 – 235 *BC* after Apollonius of Rhodes (librarian in 240-235 *BC*), Callimachus of Cyrene (librarian in 260-240 *BC*) and Zenodotus of Ephesus (librarian in 284-260 *BC*) [43].

The library is said to have contained hundreds of thousands of papyrus and vellum scrolls. Demetrius Phalereus (d. ca 280 BC) from 317 BC to 307 BC was governor of Athens, serving under Cassander. After Demetrius I of Macedon conquered Athens, Demetrius Phalereus was overthrown, and he fled to Egypt where he met Ptolemy I and inspired him for the creation of the Library of Alexandria. Agents travelling all over the known world to collect books and fill the Library of Alexandria. The books of all visitors of Alexandria were confiscated and stored in the Library and the owners obtained a copy of their books. This copy process was very important and some copies are extant today. The Library of Alexandria attracted the most important scientists to Alexandria, that became the scientific and cultural centre of the ancient World. In its University, the Museum, meaning, the house of Muses, the protectresses of the Arts and Sciences, flourished a number of great mathematicians and engineers. With the Romans gaining power a large fraction of books that survived were transported to Rome. Lucius Aemilius Paullus (229 -160 *BC*) consul of the Roman Republic and a noted general took books from Pergamon in 167 *BC* to Rome, Sylla (138-78 *BC*) the Roman general and later Dictator of Rome, in 86 *BC* transported the remains of the Library of Aristotle in Athens to Rome [42-43].

Euclid of Alexandria (325-265 *BC*) is the most prominent mathematician of antiquity best known for his treatise on mathematics *The Elements*. Euclid was one of the most well-known scholars who lived in Alexandria prior to Archimedes' arrival in the city. Euclid's *Elements*, written about 300 *BC*, a comprehensive treatise on geometry, proportions, and the theory of numbers, is the most long-lived of all mathematical works. This elegant logical structure, formulated by Euclid based on a small number of self-evident axioms of the utmost simplicity, undoubtedly influenced the work of Archimedes. No complete Greek mathematics text older than Euclid's *Elements* has survived, because the *Elements* was considered such a fine piece of work, that it made the older mathematical texts obsolete [44].

Archimedes (287-212 *BC*) was born in Syracuse, in the Greek colony of Sicily. His father was the astronomer and mathematician Phidias, and he was related to King Hieron II (308–216 *BC*). The name of his father – Pheidias – suggests an origin, at least some generations back, in an artistic background. Archimedes went to Alexandria about 250–240 *BC* to study in the Museum under Conon of Samos (ca. 280-ca. 220 *BC*), a mathematician and astronomer (the custodian of the Alexandrian library after Euclid's death), Eratosthenes and other mathematicians who had been students of Euclid. Archimedes established the principles of plane and solid geometry. Some of Archimedes' accomplishments were founded with mathematical principles, such as his calculation of the first reliable value for π to calculate the areas and volumes of curved surfaces and circular forms. He also created a system of exponential notation to allow him to prove that nothing exists that is too large to be measured. Archimedes invented the field of statics, enunciated the law of the lever, the law of equilibrium of fluids, and the law of buoyancy. Archimedes around 260 *BC*, used gears in various constructions and were well-known to the Alexandrian engineers. He discovered the concept of specific gravity and conducted experiments on buoyancy. He invented the entire field of hydrostatics with the discovery of the Archimedes' Principle. With regard to the screw, Archimedes was the first mathematician to introduce mechanical curves as legitimate objects of study. It proved particularly useful for lifting water from the hold of a ship, and for drawing water out of the ground (Fig. 8). The decline of Greek civilization is followed by the rise of Alexandria, founded in honour of Alexander the Great (356–323 *BC*) in the Nile Delta in Egypt. Alexandria was the greatest city of the ancient world, the capital of Egypt from its founding in 332 *BC* to *AD* 642, and became the most important scientific centre in the world at that time and a centre of Hellenic scholarship and science [17-18, 43-45].

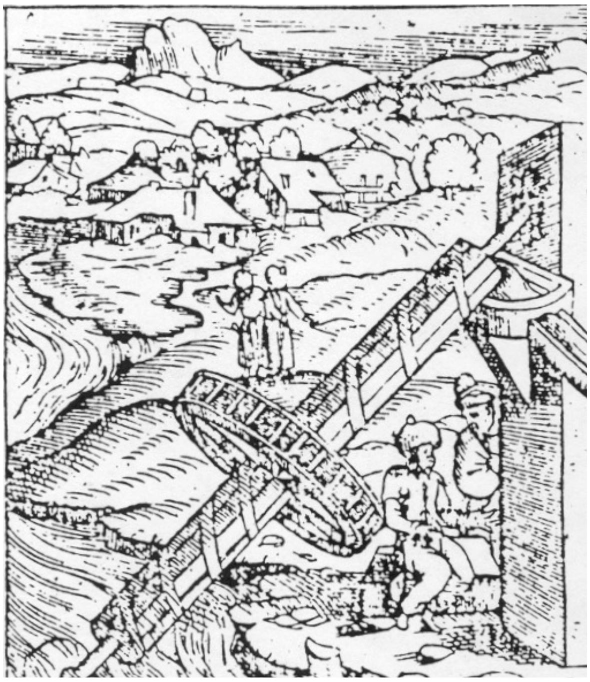

Figure 8. Drawing of Archimedes Water Screw pump obta–ined from Vitruvius book reproduced in the Renaissance (Barbaro 1584) [45].

Archimedes introduced step-by-step logic combined with analysis and experiments in solving mechanical problems and the design of machines and mechanisms. Archimedes earned the honorary title "father of experimental science" because he not only discussed and explained many basic scientific principles, but he also tested them in a three-step process of trial and experimentation. The first of these three steps is the idea that principles continue to work even with large changes in size. The second step proposes that mechanical power can be transferred from "toys" and laboratory work to practical applications. The third step states that a rational, step-by-step logic is involved in solving mechanical problems and designing equipment. His works contain a set of concrete principles upon which design can be developed as a science using mathematics and reason [43-46].

Ctesibius (ca. 283-247 *BC*), was the designer of the precision water clock (Fig. 9). He left many writings, which were subsequently lost, and only references to them by his students, notably Philo and Hero, are extant. Vitruvius in *De Architectura* [12] describes the method used by Ctesibius to design a device for lifting a mirror for a barber shop. In fact this can be considered the first original mechanism that has been designed to order on the basis of engineering reasoning [1-4].

Philo of Byzantium (ca. 280-220 *BC*) also known as Philo Mechanicus (Engineer in Greek), was a student of Ctesibius at the Museum, one of the first who used gears in water raising devices. Some fragments of an extensive treatise, *Mechanike syntaxis* (Compendium of Mechanics) exist. Most of this treatise is lost, and only parts of it as well as references to it are extant in other works. This treatise contained the following sections: *Isagoge* - an introduction to mathematics, *Mochlica* - on general mechanics, *Limenopoeica* – on harbor building, *Belopoeica* - on artillery, *Pneumatica* - on devices operated by air or water pressure, *Automatiopoeica* - on mechanical toys and diversions, *Poliorcetica* - on siegecraft and *Peri Epistolon* - on secret letters.

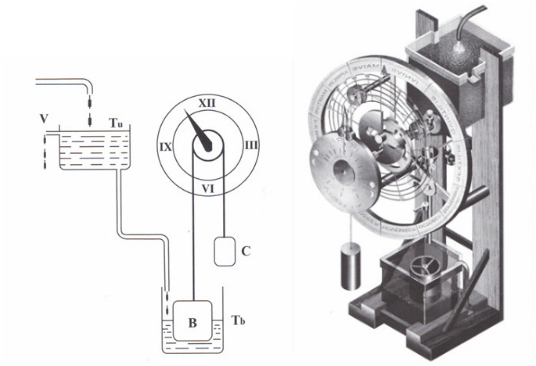

Figure 9. Working principle of a water clock and a virtual representation of the water clock by Ctesibius [3].

The military sections *Belopoeica* and *Poliorcetica* are extant in Greek, detailing missiles, the construction of fortresses, provisioning, attack and defense. Fragments of *Isagoge* and *Automatiopoeica.* of the work, on pneumatic engines, has been preserved in the form of a Latin translation *De ingeniis spiritualibus* made from an Arabic version (Heron of Alexandria *The Works*). Further portions probably survive in a derivative form, incorporated into the works of Vitruvius and of Arabic authors. His treatise dealt among other things with the idea of *machine elements,* a small number of simple elements that constitute every machine. Different machines are constituted from different syntheses of these basic machine elements. A section of Philo's *Pneumatics* which has been regarded as a later Arabic interpolation, includes the first description of a water mill in history [1-4,47].

In Philon's treatise on artillery *Belopoeica* (Technology of Arrow Making) he describes an analytical method of design of ballistae (heavy stone thrower) based on fitting experimental results with a function obtained mathematically on the basis of certain assumptions from the physics of the problem and extrapolating to design equipment beyond the state of the art. In Philon's formula, the cubic root relationship for the stone-thrower formula is derived theoretically while a numerical constant is used as a safety margin to account for the error involved in the approximation for the cubic root. This method of systematic design is further exemplified by Heron in his *Arrow Making* (artillery) where he also introduces the idea of the sensitivity to variations of the design parameters [43,48].

The Greeks from Syracuse developed the first catapults; a result of engineering research financed by the tyrant Dionysius the Elder in the early 4th century BC. Early catapults probably fired arrows from a bow not much stronger than one a man could draw. By mechanizing the drawing and releasing of the arrow, however, the catapult inventors made possible the construction of much more powerful bows. To mechanize the archer's motions the catapult engineers incorporated a number of appropriate design features. One of the crucial steps in designing the torsion springs was establishing a ratio between the diameter and the length of the cylindrical bundle of elastic cords. All the surviving catapult specifications imply that an optimum cylindrical configuration was indeed reached. This phase of the investigations culminated in quantified results of a distinctly modern kind. Archytas of Tarentum (ca. 428-450 *BC*) and Eudoxus of Cnidus (ca. 400-350 *BC*) had devised elegant theoretical solutions for the stone-thrower formula, but they were three-dimensional, very awkward physically and of no use in performing calculations. This optimization of the cord bundle was completed by roughly 270 BC, perhaps by the group of Greek engineers working for the Ptolemaic dynasty in Egypt, Thera and at Rhodes. The widest use of catapults occurred during the reign of Philip of Macedonia and Alexander the Great who perfected their use. Fig. 10 depicts the reconstruction of a bow stone thrower with throwing distance 200-750 m, and stone mass 40-300 Kgs [3,43,48].

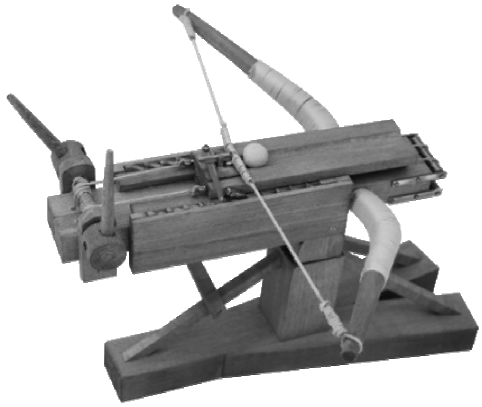

Figure 10. A stone thrower device with a bow and its reconstruction. Throwing distance 200-750 m, stone mass 40-300 Kgs. [3,48].

Eratosthenes (273-192 *BC*) was born in Cyrene, now in Libya North Africa. His teachers included the scholar Lysanias of Cyrene and the philosopher Ariston of Chios (3rd century *BC*) who had studied under Zeno of Elea, the founder of the Stoic school of philosophy. Eratosthenes also studied under the poet and scholar Callimachus of Cyrene (ca. 305-240 *BC* responsible for producing the catalogue of all the volumes contained in the Library. His *Pinakes* (tablets), 120 volumes long, provided the complete and chronologically arranged catalogue of the Library, laying the foundation for later work on the history of Greek literature). Eratosthenes then spent some years studying in Athens, and became the third librarian at Alexandria in about 240–235 *BC*. Although Pythagoras had been the first to claim that the earth was spherical during the 6th century *BC*, Eratosthenes proved the earth was spherical, and measured its circumference within one percent accuracy. Details are given in his treatise *On the measurement of the Earth* now lost. However, some details of these calculations appear in works by other authors such as astronomer Cleomedes (1st century *AD*), Theon of Smyrna (ca.70-135 *AD*) and Strabo the Geographer (64 *BC*-23 *AD*). Eratosthenes worked out a calendar that included leap years, and he laid the foundations of a systematic chronography of the world when he tried pointing the dates of literary and political events from the time of the siege of Troy. Eratosthenes stated explicitly that the catapult was the chief practical reason for working on cube-root problems [18-19].

Cicero (106–43 *BC*) writes that the Roman consul Marcellus brought two devices to Rome from the sacked city of Syracuse. One device mapped the sky on a sphere and the other predicted the motions of the sun and the moon and the planets. He credits Thales and Eudoxus for constructing these devices. For some time this was assumed to be a legend of doubtful nature, but the discovery of the Antikythera mechanism in 1900, Fig. 11, assures that during Archimedes times such devices existed [18-19,43,49].

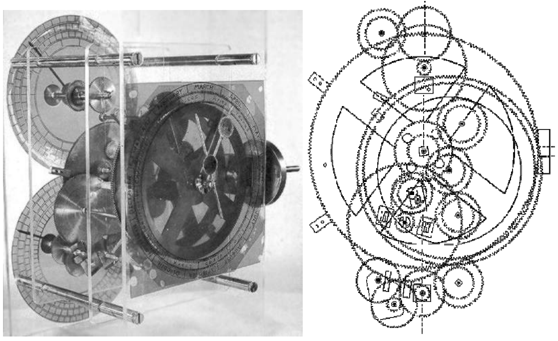

Figure 11. Reconstruction of the *Antikythera* mechanism [49].

Heron of Alexandria born possibly in Alexandria, Egypt (ca. 10 – 85 *AD*) almost three centuries after Archimedes, expanded on his laws concerning levers. Heron taught at Alexandria's Museum and wrote a number of important treatises mathematics geometry, and mechanics still in use in medieval times [3, 13].

Hero separated the study of particular machines and the general concepts of machines from standardized elements. He introduced five simple mechanical elements for the solution of the general problem of moving a weight with a given force: wheel and axle, lever, windlass, wedge, and screw. In fact, he asserted that all five solutions are physical devices embodying the lever principle, a simple function module in terms of contemporary literature. His most important invention was the *Aeolipile*, the first steam turbine, while he invented automated machines for temples and theatres, surveying instruments, and military machines and weapons. Hero wrote such texts for particular categories of devices, such as pneumatic machines, automata, optical instruments, balances, and artillery machines (Fig. 12) [3-4].

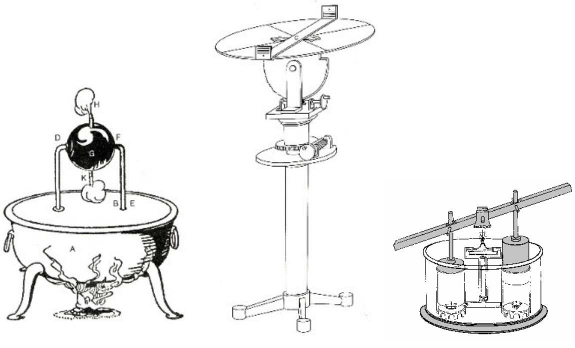

Figure 12. Heron's Aeolilpile and dioptra and Heron's double-piston water pump for fire extinguishing [3-4,13].

Concerning mechanisms, technological innovation was either related to invention of machines functioning using external means such as, animal or wind power, or related to invention of automatic devices. A mechanism for the automatic opening of the temple's gate after completion of the sacrifice on the altar is shown in Fig. 13. The device was used for ceremonial and devotional purposes, but also to fill the faithful with a sense of awe. Underground of the temple, balance chains were wrapped around the rotating axles of the temple doors. The balance had a container at one side and a counterweight at the other. Fire of sacrifice, expanded the air inside the closed container of the altar, and through a pipe was led to a sealed water container. Water was pressed through a siphon, and then led to the container on the balance that tipped, outweighing the counterweight [3].

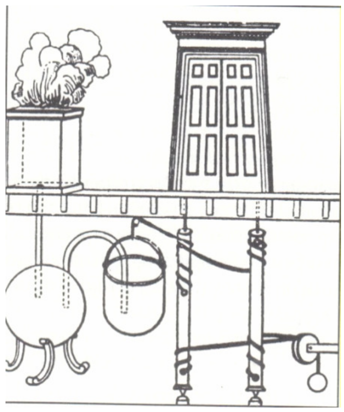

Figure 13. Heron's mechanism for the automatic opening of the temple,s gates [3].

Pappus of Alexandria (290-350 AD), the last of the great Greek geometers wrote commentaries on Euclid's Elements and Ptolemy's Almagest. In his treatise Mathematical Collection, Pappus discusses the study of mechanics. The Hellenistic period, 300-100 B.C., with main representatives Euclid, Archimedes, Apollonius, Ctesibius, Philon of Byzantine and Heron of Alexandria has been termed as the Golden Era of Science and Technology. Their pioneering contributions influenced the western science and technology and their writings were reprinted until the 16th century A.D. It must be mentioned here that the development of Science and Mathematics during the Alexandrian times, apart from the inheritance of Natural Philosophy could be connected to the expedition of Alexander the Great in the East. Some aspects of parallel development seem to suggest it [18-19,46].

Mesopotamian-influenced gold from 2,000 BC, Indian-inspired ivory fittings and Greek carvings from the outpost of Alexander the Great. Afghan artifacts and ornaments were displayed in the British Museum's exhibition Crossroads of the Ancient World in 2011. Afghanistan's treasures were discovered in six tombs at Tillya Tepe in 1978 by the team of archeologist Victor Sarigiannidis [50-51]. Alexander the Great founded Alexandria on Oxus (Ai Khanoum) in the borders between Bactria and Sogdiana, along with Alexandria Eschate in Ferghana in the north, and Alexandria in the Caucasus and Alexandria in Arachosia at south. Those Alexandrias are located on the crossroad of the Silk

Road, extending from northern India to Central Asia, thus enhancing evidences of cross-fertilization of Alexandrians with the East.

5. THE ROMAN TIMES

The end of the Alexandrian era marked the eclipse of the ancient Greek science, and the systematic study of the design of machines became stagnant for a long period of time. The death of Archimedes by the hands of a Roman soldier is symbolical of a world-change of the first magnitude: the Greeks, with their love of abstract science, were superseded in the leadership of the European world by the practical Romans [1-3].

The Roman Empire with the take-over of Egypt and Alexandria at the time of Julius Caesar (101-44 *BC*), Cleopatra (69-30 *BC*) and Christ although produced little in the way of inventing new machines but accomplished much in the exploitation of the Alexandrian inheritance by way of bigger and better machines. The Romans were great engineers and designers; they gave the world sophisticated legal and administrative systems and separated the professions of civil and mechanical engineering. The Romans build ducts and devices for the water distributions that have no comparisons in the past; moreover they stated for the first time an unification system for almost any device (and also components and spares) that was produced all over the Empire: were unified, as example, the pipes and the valves for the distribution of water, the parts of all the war machines, all the charts an all their components, all the equipment needed by the legions and lots of other things. The Roman effort was oriented towards the construction of buildings and roads network, while the principle Roman invention was the hydraulic cement [1-4, 52].

Fig. 14 shows the standardization of the plumbing used to supply water supply in the city of Rome [4]. The lead pipe diameters set by the Roman standards had sizes 5, 8, 10, 15, 20, 30, 50, 60, 100 digits (1 digit = 4.3 mm). This series is remarkably close to the R7 series (The Renard Series -introduced in Napoleonic times- $\sqrt[m]{10}$, m=1, 2, 3, ..., where *m* is the series index.)

The Roman authors Marcus Tullius Cicero (106–43 *BC*) and Marcus Terentius Varro (116–27 B.C.) might have been the first to use divisions of knowledge as a basis for classification, by the phrase *artes liberals* all seven arts—the three language and the four mathe–matical. This attempt was made by the Pythagoreans for the first time in the sixth century *BC* [53].

Marcus Terentius Varro, studied under the Roman philologist Lucius Aelius Stilo (154-74 *BC*), and later at Athens under the Academic philosopher Antiochus of Ascalon (130-68 *BC*). Varro proved to be a highly productive writer with more than 74 Latin works on a variety of topics. Among his many works, two stand out for historians; *Nine Books of Disciplines* and his compilation of the *Varronian chronology*. His *Nine Books of Disciplines* became a model for later encyclopedists, especially Pliny the Elder (23-79 *AD*). The most noteworthy portion of the *Nine Books of Disciplines* is its use of the liberal arts as organizing principles. Varro decided to focus on identifying nine of these arts: grammar, rhetoric, logic, arithmetic, geometry, astronomy, musical theory, medicine, and architecture. Using Varro's list, subsequent writers defined the seven classical *liberal arts* of the medieval schools [54].

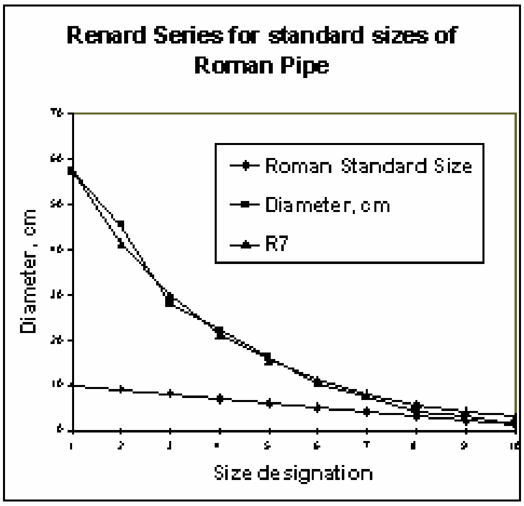

Figure 14. The standardization of the plumbing used to supply water supply in the city of Rome [4].

Romans were mostly unaware of Greek mathematics until the 2nd Century AD, when Greek mathematical works started being translated into Latin. Commentators on the classics flourished in Rome. They not only preserved most of the classical culture but made substantial advances of their own. A substantial number of treatises in architectural and mechanical design exists, mainly encyclopaedic in nature: the one by Roman architect Marcus Vitruvius Pollio (ca 31 *BC*-14 *AD*?), Roman engineer and master builder during the reigns of Julius Caesar and the Emperor Augustus, (1st century *BC*) is the most notable [3, 43, 54].

Vitruvius ten books *De Archetecture* (on Architecture) [12] contained important material on the history of technology and on the design of machinery. Vitruvius defined a machine as "a combination of timbers fastened together, chiefly efficacious in moving great weights". Vitruvius studied Greek philosophy and science and gained experience in the course of professional work. He was one of those appointed to be overseas of imperial artillery or military engines, and was architect of at least one unit of buildings for Augustus in the reconstruction of Rome. Late in life and in ill health he completed, sometime before 27 *BC*, *De Architectura* which, after its rediscovery in the fifteenth century, was influential enough to be studied by architects from the early Renaissance to recent times [3].

Ancient engineers invented bearings lubricated with fat, and Romans introduced the ancestors of ball bearings for their wagons and carts. Romans developed all kinds of carts, farm carts pulled by braces of oxen, freight carts to transport heavy objects, barrel carts for oil and wine, container carts with high sides to move soil or sand and even stage coaches for the public with seats on top, fast private carts with folding tops, and sleeping wagons with leather pavilions and four or six cots [55].

Figure 15. A Roman coach cart with a brake [55].

The first description of a vertical water wheel is from Vitruvius 1[2]. Vitruvius described an undershot wheel, but remarked that it was among the "machines which is rarely employed. One of the most remarkable Roman application of a waterwheel was at Barbegal, near Arles in southern France. Dating from the 4th Century AD, the factory was an immense flour mill which employed 16 overshot water wheels. Fig. 16 depicts a Roman water powered saw for cutting stone at Hierapolis, Asia Minor ca. second half of 3rd century A.D. The existence of a crank shaft is obvious [56].

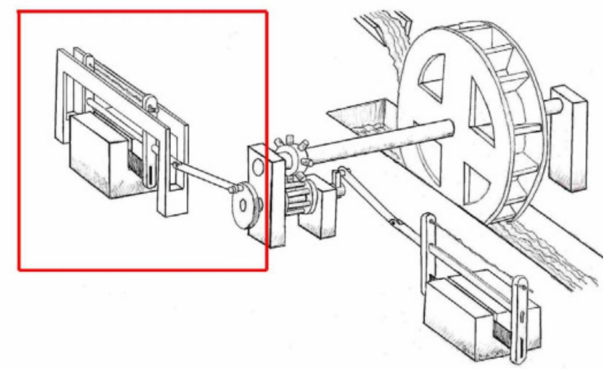

Figure 16. A Roman water powered saw for cutting stone at Hierapolis, Asia Minor ca. second half of 3rd century A.D [54].

Other important Roman invention is the hydraulic saw that used a water turbine with a crank and slider mechanism moved through a gearing train; sometimes both were (incorrectly) considered as inventions made during the Renaissance [56].

Sextus Julius Frontinus, (35-103 *AD*),Roman soldier, governor of Britain, and author of *De aquis urbis Romae*, with complete technical details on the aqueducts of Rome, along with their history and the regulations governing their use, Pliny the Elder, (23-79 *AD*) received education in literature, oratory, and law, as well as military training. He was the author of at least 75 books. included volumes on cavalry tactics, biography, a history of Rome, a study of the Roman campaigns in Germany, grammar, rhetoric, contemporary history, and his most famous work, his one surviving book, *Historia Naturalis*, published in A.D. 77. *Historia Naturalis* (*Natural History*) consisting of thirty-seven books includes knowledge about the natural world in the fields of cosmology, astronomy, geography, zoology, botany, mineralogy, medicine, metallurgy, and agriculture. The unifying thread of this work was anthropocentrism [57]. Publius Flavius Vegetius Renatus, (ca 390 *AD*) is the author of the *Epitomae rei militaris* an essay on military science, the Anonymous author of the *De Rebus Bellicis* including images of war machines (Circa 337 – 378 *AD*) [58].

Late antiquity was a time of rearrangement, not least of ancient books. Most important, books were transformed from papyrus rolls (typically holding a single treatise in a roll) into parchment codices (typically holding a collection of treatises). It thus appears that a book collecting several treatises by Archimedes was prepared in the sixth century *AD* by Isidore of Miletus (ca 530 *AD*) and Anthemios the Tralleus, the architects of Agia-Sofia in Constantinopole. Isidore of Miletus had earlier taught physics at Alexandria and then later at Constantinople, and had written a commentary on earlier books on building. Anthemius of Tralles (474-534 *AD*) was professor of geometry at Constantinople and architect. Anthemius had previously written a book on conic sections, an excellent preparation for designing the elaborate vaulting of Hagia Sophia. He compiled a survey of mirror configurations in his work on remarkable mechanical devices which was known to certain of the Arab mathematicians such as Al-Haytham [59].

It is clear that Isidore of Miletus and Anthemios the Tralleus were influenced by the books of Archimedes and had those books in their collection. This book was copied by Leo the Geometer (ca. 820) or his associates, once again in Constantinople, in the ninth century *AD*. At this time Eutocius the Ascalonites (ca 480-540 *AD*), a student of Anthemios, wrote his commentaries on several books of Archimedes that were subsequently lost [43,59].

6. CHINA

Red and black pottery craft industries since the Yangshao culture (4950 BC-2950 BC, the Neolithic times) have been rep Red and black pottery craft industries since the Yangshao culture (4950 BC-2950 BC, the Neolithic times) have been reported in China. Silk weaving might be well advanced by 3650 BC. Spinning and weaving indicate the use of advanced tools with wheels. Writing, mathematics and astronomy came to be part of Chinese civilization. The technology of writing developed independently in China from the time of the Shang dynasty (1600-1046 *BC*), developed with 5000 characters in the ninth century *BC* and characters became standardized by the time of China's unification in 221 *BC*. Confucius who lived during the Zhou dynasty (1030 BC-222 BC) expanded ideas and doctrine about how life should be lived. These issues gave Chinese people standards and morals to live by [60-61].

Although China was an isolated civilization due to physical barriers of the Cobi and Taklamakan desert, the Tibetan and Yunnan plateau and Himalayas, there are evidences of relations with other civilizations during the centuries. Samples of knotted rugs found in western China indicate influence from Central Asia of the 5th century BC. Textiles and tapestry weave possibly of the Han Dynasty (202 BC- 220 *AD*) with figure of centaur: half animal-half human creature indicate distinctive Greek influence since this figure can be found only in pottery of Greek origin. Trade within the Chinese borders was established in very early times. Trade with the west officially began during Emperor Wu Di's reign (140 BC – 87 BC) [60-62].

The magnetic compass, gunpowder, cast iron, the sciences of astronomy, physics, chemistry, meteorology, seismology, engineering, and mathematics can trace their early origins to China. In China the oldest documents regarding water clocks are dated to the 6^{th} century B.C. The working principle of a Chinese water clock ca. 6^{th} century B.C. is shown in Fig. 17 [3].

Cast iron, abacus, calendars were in use in China before the reign of the Qin Dynasty (221-206 *BC*). Though Chinese were not the first to make steel, they did invent two particular steel manufacturing processes: removing the carbon out of cast iron and melting wrought and cast iron together to produce steel. The North-South Highway built by Qin Shihuang's general Meng Tian in 212 *BC* after 4 years of work by 200,000 workers, was a 700-900 km long road, around 100m wide that served as a line of advance and supply for the Great Wall [62-63].

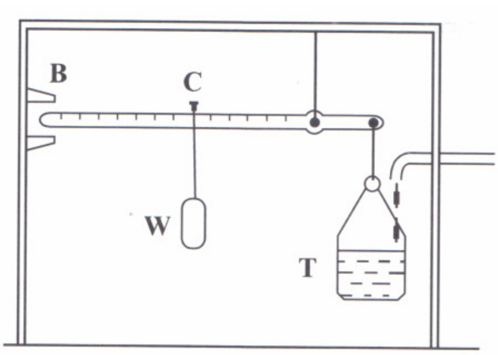

Figure 17 Water clock in China ca. 6^{th} century B.C. [3].

Although borders and political units fluctuated, Chinese emperors controlled a huge, densely populated territory about the size of Europe. Since its first unification in 221 *BC* China was the world's most populous country. Geography isolated China from outside influences. The first part of the Great Wall (1250 miles in the 4th-2nd century *BC*, later it became 3,000 miles) and the 1,100 miles long Grand Canal (581-618 *AD*) are the great engineering works of Chinese civilization. The road network of the Qin dynasty is considered to be the earliest, longest and widest road network in the world [3,61-63].

Modern paper was invented for the first time in ancient China, during the period of the Han Dynasty (202 BC- 220 *AD*), gunpowder was discovered somewhere between 600 to 900 *AD*. The origin of the compass in China can be traced back to the fourth century *BC*, but a magnetic device used for navigation at sea was first invented during the Song Dynasty (960-1279 *AD*). The square-pallet chain pump consisting of an endless circulating chain bearing square pallets which hold water, earth, or sand originated from China. This pump can haul large quantities of water from lower to higher levels. The mechanical clock was invented in China in the eighth century *AD*. The driving-belt transmitting power from one wheel to another existed as early as the first century BC in China, it was developed for use in machines connected with silk manufacture, which wound the long silk fibers on to bobbins for the weavers' shuttles. The invention of roller bearings might have been used by Chinese and Romans in the second and first centuries *BC* [3,61-63].

Waterpower was important source of energy in ancient China civilization. One of the most intriguing applications was for iron casting Fig. 18. According to an ancient text, in 31 *AD* the engineer Tu Shih "invented a water-powered reciprocator for the casting of steel agricultural tools." Smelters and casters were "instructed to use the rushing of water to operate their bellows." Waterpower was also applied at an early date to grinding grain. Large rotary mill appeared in China about the same time as in Europe (2nd century BC). But while for centuries Europe relied heavily on slave-and donkey-powered mills, in China the waterwheel was a critical power supply. Chinese waterwheels were typically horizontal. The vertical wheel, however, was known. It was used to operate trip hammers for hulling rice and crushing ore. The edge-runner mill was another commonly used crushing device. With the latter, a circular stone on edge running around a lower millstone was used to pulverize. The edge runner appeared in China in the 5th century *AD*. Both the trip hammer and edge runner were not used in Europe until eight centuries later [3,61-63].

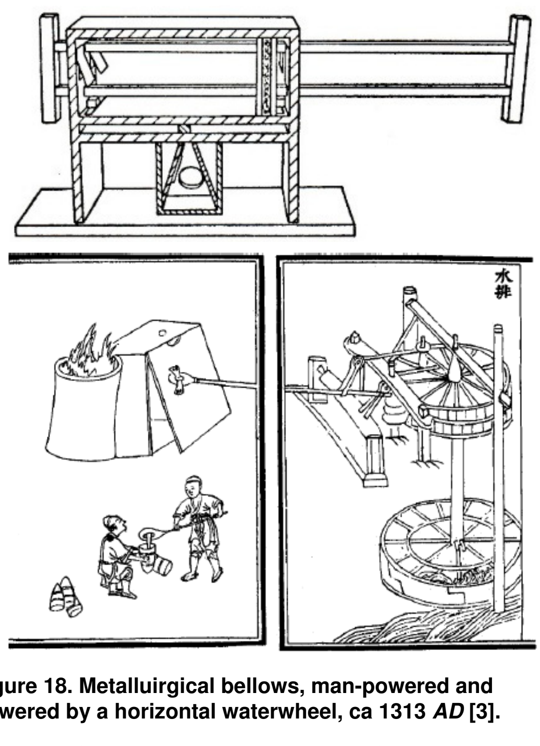

Figure 18. Metalluirgical bellows, man-powered and powered by a horizontal waterwheel, ca 1313 *AD* [3].

In 1954, J. Needham (1900-1995) - along with an international team of collaborators - started a project to study the science and civilization of ancient China. This project produced a series of volumes published by Cambridge University Press. The project is continuing under the guidance of the Publications Board of the Needham Research Institute.

7. THE ARABIAN ERA

In 642 the Arabs conquered Egypt. From this time, scientific and technological progress was distinctly Arabian for the next centuries. The Arabs played an important role in the preservation of the Alexandrian and Greek science and engineering, and made substantial contributions of their own. They devised ingenious mechanisms with a high degree of automation and control. Ibn al-Razzaz Jazari (1136-1206), an engineer and constructor of machines had much in common with Hero [64-65].

Al-Jazari left a work published in 1206 entitled *Treatise on the Theory and Practice of the Mechanical Arts***.** It is a type of theoretical manual which describes machines which can be reconstructed, providing detailed, drawings. This book described a great number of ingenious mechanisms and automata. Due to the repercussions they would have on industrial processes, the most important machines from the Arab period are water wheels, watches and later the steam engine [64-70].

The water wheel, ancestor of the hydraulic turbine, made rapid progress from the eleventh century onwards due to its importance for the economic system of Western Europe. From the technical point of view these water wheels did not differ much from those used by the Greek and Romans several centuries before. Their importance was due more to the fact that they functioned as an essential part of a productive unit, located in the field or in the city preparing the passage to the new era of the industrial revolution.

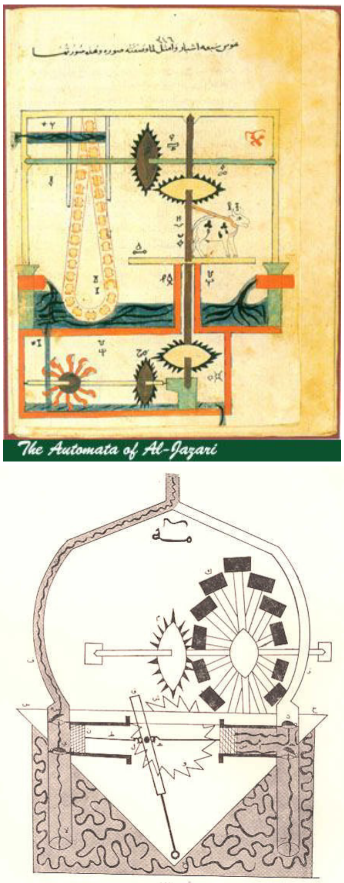

Figure 19. A double powered machine, with a donkey and a waterwheel from [108], and wheels with curved blades onto which the flow was directed axially (9th century) [70-71].

The classic work on the study of the origins of the water wheel is Vitruvius' treatise On Architecture, published in the first century BC. A double powered machine, with a donkey and a waterwheel from al-Jazari's book and wheels with curved blades onto which the flow was directed axially are shown in Fig. 19 [65-71].

Taqi al-Din (1526–1585) born in Damascus and educated in Cairo, Egypt, was the author of more than 90 books on a wide variety of subjects, including astronomy, clocks, engineering, mathematics, mechanics, optics and natural philosophy. He invented an early practical steam turbine engine as a prime mover for the first steam powered and self-rotating spit. He wrote a book on water clocks and ingenious machines in 1552, and another on mechanical clocks in 1556 [70-71]

8. CONCLUSIONS

Among the Eleatic philosophers important beginnings of Logic were developed by Platon and Aristoteles into a science and served as an instrument for the parallel development of the Natural Sciences, especially mathematics and physics, by such pioneers as Pythagoras, Aristoteles, Euclid and Archimedes. The search for Reason led to the development of a generalized science as distinct from a set of unrelated empirical rules. Pythagoreans, for example, sought the principles of geometry, originally practiced by Egyptians, in ultimate ideas and investigated its theorems abstractly and in a purely rigorous way. The rigorous proof was introduced, based in deductive logic and mathematical symbolism. Experimentation was established as a method for scientific reasoning.

Although the seeds of a primitive design activity can be traced back to the Bronze Age, basic scientific principles discussed and explained by Archimedes in the 3rd century *BC* formed the instrument upon which engineering was established as a science distinct from crafts and unrelated empirical rules. Archimedes was the first to utilize mathematics for the treatment of a physical problem.Ctesibius, and his students Philo and Heron, and Pappus of Alexandria have introduced analytical methods for the study and design of advanced machines and mechanisms, not always driven by practical needs.

The appearance and refinement of mathematical methods permitted statement and solution of more complicated problems of mechanics. In turn, problems of mechanics stimulated the intensive development of mathematical methods. The nature of Mechanics and furthermore Mechanical Engineering was recognized as a science and an art, as well as the need for specialization and experimentation.

Kinematics and machine design have a distinct place in the history of engineering because they comprised a rational step-by-step logic to receive further a mathematical foundation. The design of machines and mechanisms in a systematic way, using a mathematical axiomatic foundation and experiments, is a process not arrived at empirically through long evolution, and this point separates engineering science from technology and crafts. The development of mechanics was closely associated with the development of mathematical methods. The history of mechanics and mechanisms is strictly connected with the development of human society.

Technological innovations filtered slowly from the East from the times of Alexander the Great and then through the Silk Route and later by sea to the Roman Empire and the Arabs conquering Europe till the 6th century AD. A review of original manuscripts from the 15th to the 19th centuries provides the influence of Archimedes on the so-called *theatre of machines books* and furthermore the continuity of knowledge of ancient Greek theory of machines, and Archimedes principles of statics, hydrostatics and concepts of centres of gravity on the development of machine science.

The subject matter of mechanics is made up of motion and forces, that is specific phenomena of nature; and the history of mechanics is an unalienable part of the history of development of human society. This asks for a simultaneous dialectical and historical approach. Understanding the fundamentals of mechanics needs a travel back to time, in antiquity, but scientific conceptions concerning mechanical phenomena accumulated and developed very slowly during the first stages of the history of human culture. Mechanics, which grew out of knowledge accumulated in the making of the tools of labor, of buildings and the first machines, and which was regarded in antiquity as the science of machines, has always developed mainly under the influence of the practical demands of society that are linked to production, technology, and the study of the motions of celestial bodies (primarily for navigation).

The first design theory was part of aesthetics, where aesthetic (beautiful) included also functional (useful) and ethics (the good) attributes. Function and Ethics were inseparable from Form. The philosophical inquiry of knowledge, aesthetics and ethics had implications in engineering design. Design methodologies appeared in gear sizing, screw threads, weight lifting, catapult engineering, pneumatic machines, and hydraulics. The idea that principles continue to work even with large changes in size was introduced followed by the proposition that mechanical power can be transferred from "toys" and laboratory work to practical applications. Then a rational, step-by-step logic was involved in solving mechanical problems and designing equipment.

General historical and socioeconomic factors are important for the interpretation of the development of Science, a large series of studies is devoted to the history of mechanics, this contribution is investigating the influence of Natural Science on mechanics and engineering from the 6th century BC to the Middle-Ages. There was a question to be answered, where "history" ends and where "contemporary science" begins. Unfortunately, this question is ambiguous-something like the question of childhood verses about where the tail of the serpent begins. A next paper will cover the early-modern and modern times of mechanics and mechanism design in conjunction with engineering education, highlighting the role of scientific schools and authorities in the progressive trend of human knowledge.

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ПРИРОДНА ФИЛОЗОФИЈА И РАЗВОЈ МЕХАНИКЕ И ТЕХНИКЕ ОД 5. ВЕКА П.Н.Е. ДО СРЕДЊЕГ ВЕКА

Т.Г. Хондрос

Када је логика добила статус науке постала је инструмент напретка у области природне филозофије и научни метод у 6. и 5. веку п.н.е. у Кини, Индији и арапском свету, на Блиском истоку, у античкој Грчкој и старом Риму. Брз напредак природних наука пратили су систематски напори у грчком и хеленис–тичком свету у периоду од 4. до 1. века п.н.е. да се знање организује, при чему је врхунац достигнут у Римском царству после 2. века н.е. Истовремено су се филозофија, природне науке и технологија развијале и на Истоку. Случајни развој машина и механизама настао из потребе пратио је развој сложених машина систематским коришћењем правила и концепција пројектовања до којих се није дошло емпиријски већ истраживањима од најранијих времена. У раду се разматра утицај природне филозофије класичног доба на развој механике и технике као науке у периоду од 5. века п.н.е. до средњег века.