

# **Gromaticus Maximus: The Great Greek Surveyor of Roman Egypt – Hero of Alexandria (10-75 A.D.)**

**John F. BROCK, Australia**

**Key words:** Hero of Alexandria, first century AD, Egypt, Roman occupation,

## **SUMMARY**

When individuals are asked to name the greatest inventor of all time most will probably say Leonardo da Vinci. Others with a more engineering orientation may suggest Archimedes while some may throw in Alexander Graham Bell (the telephone), Benjamin Franklin (electricity), Marconi (the radio), John Logie Baird (the television) or even Mike Nesmith's mother (white out liquid). However it is my great pleasure to introduce you to possibly the most innovative and prolific inventor that ever walked the face of the earth, nearly two thousand years before any of these other genius-come-latelys made the world the bequest of their revolutionary devices.

The person of whom I wax lyrically is a surveyor based in the Egyptian city of Alexandria during the Roman occupation of the Late Period of that civilization whose name has a Greek derivation – Hero (sometimes referred to as Heron) of Alexandria. My choice is to call him “Hero” because that is what I believe him to be and when you hear exactly just what he invented and the texts he wrote on technical matters of physical science you may understand why I have done this.

In the following paper I shall list the seventy eight (78) inventions which are attributed to him along with the various technical treatises on physical science that can be reasonably accredited to this amazing man of the antiquarian era. He is said to have invented the first vending machine, which dispensed holy water, the first steam engine and the first wind-powered device which was a musical organ. In true ancient Greek tradition he even has a mathematical formula bearing his name which I will make known to you later. More specifically I will highlight the detailed manual, for which he has been credited, setting out instructions on how to perform accurate surveying work and calculations together with the assemblage data to manufacture the surveying instrumentation introduced by the Greeks at some time a couple of hundred years prior to the birth of Jesus Christ. He is even given the kudos for creating an instrument which could be attached to a chariot for measuring the distance travelled by that rapidly moving vehicle called the odometer which can also be regarded as the first speedometer for distance recording. Consequently I have titled Hero as the Gromaticus Maximus which can be translated from the ancient Latin to mean literally “the best/greatest surveyor” for more than just his brilliant written legacy which chronicles the Greek measuring techniques and instrumentation but also due to his claim to the mantle of the world's greatest inventor, at least before it became fashionable to lay claim to such a distinction.

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## **1. INTRODUCTION**

For around three hundred (300) years the Greek Empire ruled over Egypt from Alexander the Great's annexure of 332 B.C. to Augustus Caesar's deposing of Cleopatra in 33 B.C. Egypt was greatly changed by the Hellenistic influences especially under the lengthy dominion of the Ptolemy's. Even before this first Greek conquest the ancient Greek philosopher/mathematicians such as Thales and Pythagoras had travelled to Egypt learning much from the ancient Egyptian Scribes of the Field who were engaged in the physical applications of numeration and mensuration on the ground for the purposes of boundary reinstatement after the Nile floods along with agricultural yield determinations for taxation purposes. From modern re-measurement of the positioning and dimensions of the many stone monuments which still exist today it is patently clear that these exceptional ancient geometers (which is derived literally from Greek to mean "earth measurers") applied their practical skills to the precise set out of these structures. Indeed the only Wonder of the World which survives up until now from the original seven erected is the Great Pyramid complex at Gizeh. Indeed a more recent re-survey in the twentieth century by Cole ascertained that the differences between the sides of the monolithic tower only vary by from 6 to 14 millimetres in level over 230 metres and between 1' 57" and 5' 30" in alignment with true north !! Only last year the noted English Egyptologist John Romer revealed the evidence of the survey marks left by the Egyptian surveyors in and around the Great Pyramid of Khufu at Sakkara to conclusively demonstrate that this impeccable precision was in no way accidental.



## **2. INFORMED ACCEPTANCE OF THE PERIOD OF HERO'S LIFE**

Various scholars have given their estimation for the period during which Hero lived varying from 150 B.C. to 300 A.D. mainly due to the fact that none of his writings survive contemporaneously with when he actually lived. All available texts and manuscripts which can be attributed to Hero were reproduced in later eras of history some in ancient Greek and others in Latin and Arabic. In addition to this dilemma there is the added confusion associated with the common occurrence of the name Hero during this time coupled with the issue that some of these "other" Heros were also scholars who left knowledge of their

teachings to be reproduced by their later successors. A general consensus has been arrived at for the most likely period of his life to have been from 10 to 70/75 A.D. with a number of identifiable factors confirming this likely lifespan. Such period indicators are his use of Latin vocabulary which only came into common usage in the first century AD, his detail of a small olive press with only one screw in his treatise *Mechanics III* which is said by Pliny to have been introduced in 55 AD plus a quotation by Plutarch (died 120 AD) about the angle of incidence of light reflection said to be attributable to Hero from his work *Catoptrica*. Some authors purport that his lifetime is proven through his mention of a lunar eclipse which is said to have taken place in 62 A.D. (Please note there is some speculation about whether he mentions an eclipse of the sun or the moon and I am yet to verify if it was actually either !).

### 3. EGYPT UNDER THE GREEKS

Already with a recognised interrelationship existing between the Greek and Egyptian measuring professionals it is not surprising that an apparently harmonious assimilation formed amongst this group. Even Alexander the Great adopted Egyptian customs in dress and rule when assuming his role as the supreme patriarch of his occupied colony. Various statuary and images of Alexander portraying the true projection of the native tradition of his new state have been found in all areas of the northern African civilization with the full blending of the two cultures becoming complete under the lengthy rule of the Ptolemy's as king up until the overthrow of Cleopatra by the Roman Emperor Caesar Augustus in 33 B.C. After nearly three hundred years of this Greek/Egyptian multi-culturalism it is understandable that there would have been a noticeable Greek quarter still present in Egypt by the time the first hundred years of Roman occupation had been reached. Thought to have been born in Alexandria in about 10 A.D. Hero was clearly part of one of the families from this community of Greek origin. Despite the fact that the Roman surveyors already had long established techniques of surveying utilising equipment developed within their own highly capable system, the Greek measuring technology had evolved independently of this nation, quite in advance of this later culture. In addition to the artifacts discovered from the archaeological excavation at the lava-encrusted site of Pompeii various instructional texts for the agrimensori and gromatici such as the *Corpus Agrimensorum* have been translated from the original Latin manuscripts which clearly demonstrate that the Roman surveying differed from the Greek mainly with regard to the instruments used. Therefore when Hero taught his techniques to the students at the Musaeum of Alexandria, where he is believed to have been a lecturer, it is not surprising that his material bore a predominant content of the Greek methods of land surveying. To our great fortune Hero is credited with the authorship of a work titled *On the Dioptra* which not only describes the construction of the Greek-style angle measuring device, the Dioptra, it also covers a vast compendium of the solution of various mathematical problems for the calculation of areas and volumes as well as instructions as to how to perform the fieldwork for setting out tunnels and measurement techniques to determine distances to objects which were inaccessible for direct contact. Many examples of these instructions will be detailed later in this paper.

#### 4. AUTHOR OF MANY TECHNICAL TREATISES

Through a scholarly process of analysis and elimination learned students of ancient history have been able to more clearly cite authorship of a series of technical treatises to Hero. The list of his works is likely to be *Automata*, *Liber Geoponicus*, *Metrica*, *Pneumatica (I and II)*, *Mechanica (I, II and III)*, *Belopoeica*, *Catoptrica* and *On the Dioptra*. Other works which may have been written by Hero are disputed by some authors and thus are not included by me. Many of these publications are geometrical treatises consisting of directions for obtaining, from given variables, the areas and volumes of plane and solid figures. His work contains a formula for the calculation of the area of a triangle given the length of the three sides which some believe was taken from Archimedes but now nonetheless the formula bears his name, Heron's Formula:

$$K = \sqrt{s(s-a)(s-b)(s-c)}$$

where a, b and c are the sides of the triangle  
and s is half the sum of the sides

Some of his instructional volumes refer to the lifting of heavy objects, mainly for architects and builders, a description of war machines and about the progression of light, reflection and the use of mirrors. He has even been termed an ancient "rocketeer" by one journalist in recognition of his expertise in projectile technology. However he deserves his immortality in renown for his two incredible journals of inventive genius, *Pneumatica* and *Automata*.

#### 5. THE GREATEST INVENTOR OF ANTIQUITY

Hero's two amazing compilations mentioned in the previous section set him apart from other teachers of his time through the genius of his inventions which perpetuated the image of him as a magician or handyman of the gods with the temple going populace who were spellbound by the phenomena of his devices which adorned the places of worship to which they would flock. At this time I would like to stress that there has been some doubt raised by various authors as to whether or not Hero was the genuine "inventor" of all of these contraptions or whether he had merely been the recorder of the creations of other individuals. Whatever may be the eventual outcome of further research there can be no dispute that without the vast writings of Hero very few of these amazing items would have survived for the scrutiny of modern scholars and scientists with his momentous contribution to the corpus of technical knowledge being a singular achievement in its own right.

There is a huge list of devices which have been attributed to Hero in antiquity which add up to 78 in total (see Appendix A for the full list) which place him at the pinnacle of archaic masterminds of machinery. One author has called Hero the creator of the first "robot." The device he built in about 60 A.D. has been described as a programmable robot which was a three-wheeled cart carrying a group of automata to the front of a stage where they would make a performance for the crowd. The power was provided by a falling weight which pulled

on a string wrapped around the drive axle of the cart such mechanism being the exact equivalent of a modern programming language.

Most notable of his cornucopia of inventions are the introduction of the very first vending machine dispensing holy water in exchange for the insertion of coinage, the first wind-driven instrument being a musical organ powered by a windmill, the initial automatically opening temple doors operated by fire on the altar, and his piece-de-resistance steam engine known as the aeolipile variously described as a rotary steam engine or rocket-like device consisting of a sphere mounted onto a boiler with two bent nozzles which would rotate as a result of the escaping steam. Within his works is also a detail for a syringe exactly like that which is still used today. Another of his unique mechanisms was a standalone fountain operated by self-contained hydrostatic energy now known as Hero's Fountain.

Hero's consideration of air as a substance composed of minute particles was 1500 years ahead of its time as well as his adoption of this material to be compressed and expanded as an explanation for the concept of suction and other associated apparatuses such as the pipette. It is said that he was a follower of the Atomists and some of his ideas were derived from the works of Ctesibius.

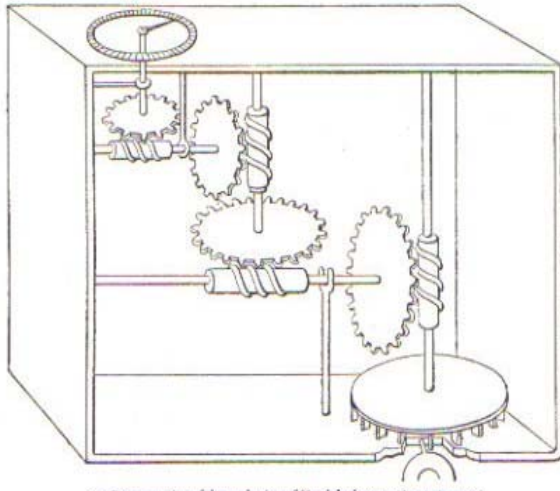
Not only did Hero materialise his genius in the physical form of his devices he also put forward postulations in Optics with regard to the behaviour of light waves. Formulating the Principle of the Shortest Path of Light he pronounced that a ray of light propagating between two points in the same medium would follow a path length which was the shortest possible, a notion which was not to be expanded to both reflection and refraction nearly a thousand years later by Ibn al-Haytham. The principle espoused was not stated in that form until 1662 by Pierre de Fermat.

Available to all on the internet is a most fantastic list of all of Hero's inventions with full descriptions and sketches of each device originally compiled by Bennet Woodcroft who was a Professor of Machinery at University College in London in 1851 such abridged list of each item being contained in Appendix A of this paper for your reference.

## **6. HERO'S GREAT LEGACY TO ALL SURVEYORS**

Before Hero's Greek predecessor, Herodotus, had begun the writing of history for the posterity of later generations to gaze back upon, we only have artifacts and art which survive within the archaeological excavations of more modern day sites. Within such contexts it is often very difficult and sometimes impossible to comprehend how some of the materials unearthed were put to use in prehistoric times or even what is represented within the images of the artists who penned or carved them. Therefore it is left to the conjecture of modern historians and engineers to put together possible recreations for such monumental archaic achievements as the construction of the Great Pyramids along with the techniques of surveying employed to set them out and other mystifying accomplishments of the ancients such as the Mayans, Incas and Aztecs.

However, amongst the various treatises which can be definitively ascribed to Hero, we have a work titled *On the Dioptra* which not only passes down a handbook of ancient Greek surveying and calculating instruction but also provides us with the description of the construction of the antique equipment which was utilised by the ancient Greek surveyors in the performance of their tasks. There is even a contraption called the H odometer which is the



22. Reconstruction of the mechanism of Hero's odometer (description p 79)

early forerunner of the modern devices which measure distance through the revolution of the wheels of the moving vehicle to which the adaptation of certain connections provides the linear distance. Some doubt is put forward as to whether Hero actually invented this instrument or simply detailed its construction from some other ancient engineer such as Archimedes, but nonetheless it is still included as an ingenious piece of equipment for the first century AD.

Included in Michael Lewis's book "*Surveying Instruments of Greece and Rome*" the author includes a translation

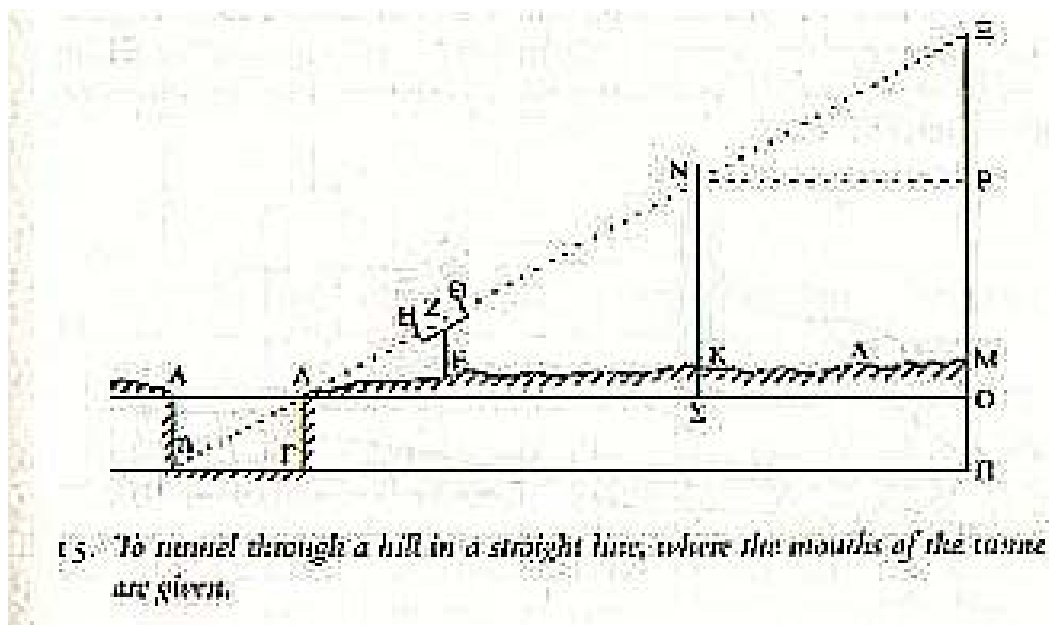
of Hero's work *On The Dioptra* taken from the classical ancient Greek which contains the following instructions to the gromatici (surveyors) of his time:-

- 1/ and 2/ Introduction to "the science of dioptrics".
- 3/and 4/ Instructions on how to construct a dioptra instrument.
- 5/ Instructions on how to produce a stave for measurement.

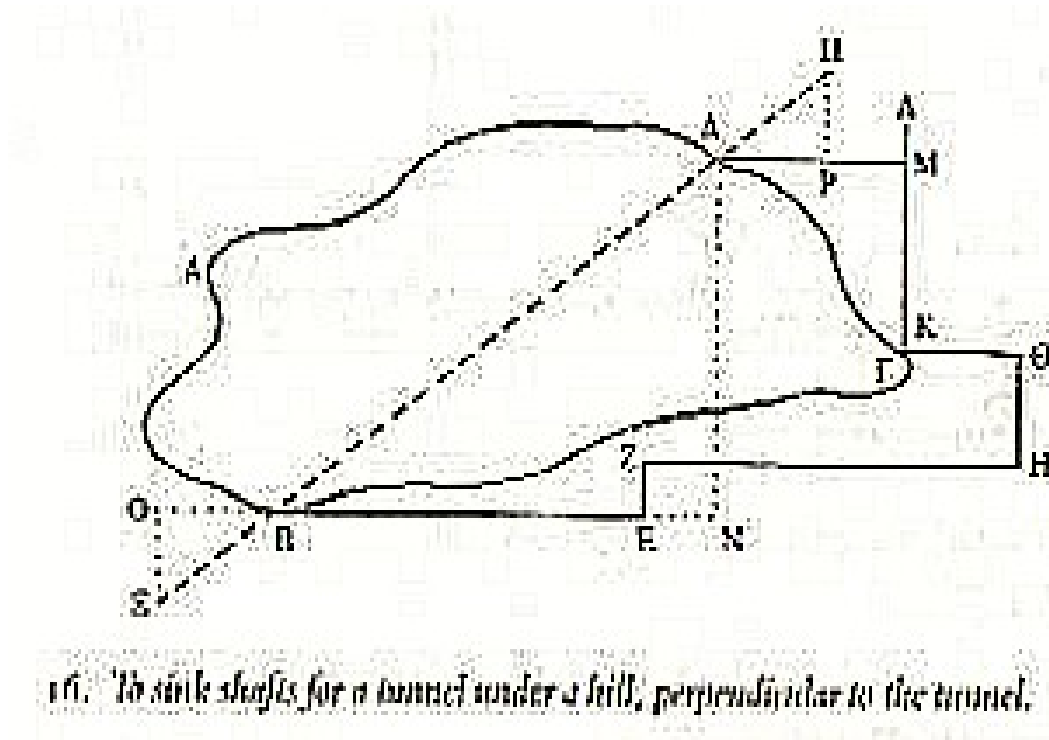
From now on the solution of various measurement problems is detailed, but I will supply only the summary of the heading:-

- 6/ To observe the difference in height between two points or if their height is the same.
- 7/ To draw a straight line by dioptra from a given point to another invisible point, whatever the distance between them.
- 8/ To find the horizontal (pros diabeten) interval between two given points, one near us, the other distant, without approaching the distant one.
- 9/ To find the minimum width of a river while staying on the same bank.
- 10/ To find the horizontal interval between two visible but distant points, and their direction.
- 11/ To find a line at right angles at the end of a given line, without approaching either the line or its end.
- 12/ To find the perpendicular height of a visible point above the horizontal plane drawn through our position, without approaching the point.
- 13/ (a) To find the perpendicular height of one visible point above another, without approaching either point.

- (b) To find the direction of a line connecting two points, without approaching them.  
 14/ To find the depth of a ditch, that is the perpendicular height from its floor to the horizontal plane either through our position or through any other point.

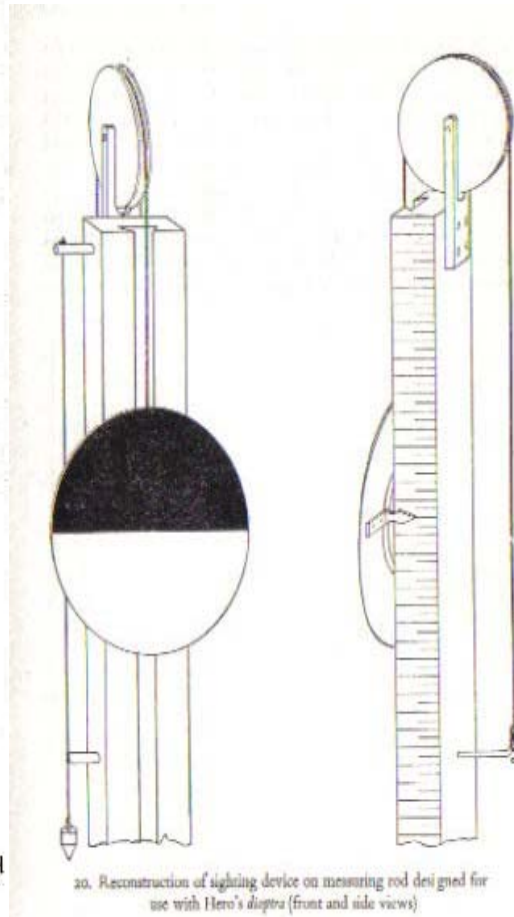
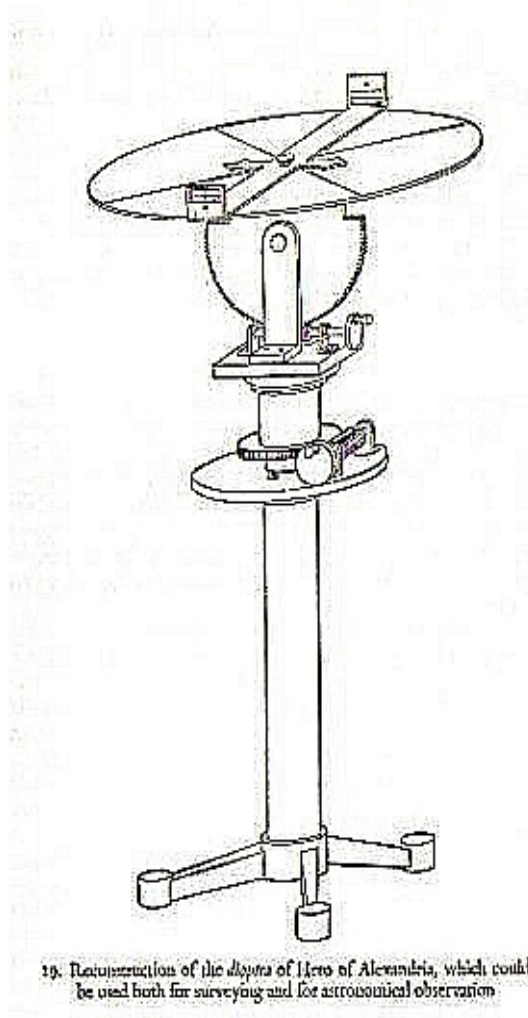


- 15/ To tunnel through a hill in a straight line, where the mouths of the tunnel are given.



- 16/ To sink shafts for a tunnel under a hill, perpendicular to the tunnel.  
 17/ To lay out a harbour wall on a given segment of a circle between given ends.

- 18/ To mound up the ground in a given segment of a spherical surface.
- 19/ To grade the ground at a given angle, so that on a level site with the shape of an equal-sided parallelogram its gradient slopes to a single point.
- 20/ To find a point on the surface above a tunnel so that an auxiliary shaft can be sunk.



### Hero's Dioptra And Staff

- 21/ To lay out with the dioptra a given distance in a given direction from us.
- 22/ To lay out with the dioptra a given distance from another point, parallel to a given line, without approaching the point having the line on which to lay it out.
- 23/ to 30/ The first five chapters refer to the dioptra setting out irregular shaped plots of land, while the remaining three explain how to determine the areas from those figures.
- 31/ To measure the discharge or outflow of a spring.
- 32/ and 33/ Describes how to utilize the dioptra in a vertical mode for the purposes of astronomical observations.



34/ This chapter informs the reader about the usage of another measuring instrument called the hodometer, which was a device fitted to the wheels of a carriage such that the horizontal distance is evaluated in a very similar fashion to which a modern day perambulator gives distance.

## 7. CONCLUSION

Fortunately, Hero left to us through his writings this comprehensive compilation of instructions on how the Greeks were able to compute distances in many varied situations, as well as detailing the construction of the surveying instruments themselves, which serves to highlight Greece's legacy of geometric and surveying knowledge derived from the practical applications originated by the Egyptians. From closer examination of this instruction list it would scarcely be out of place as a manual of modern surveying in the offices of surveyors well into the twentieth century nearly two thousand years from its authorship. Indeed we should all pay homage to this singularly amazing individual, truly a man well ahead of his time – Hero, the Great Greek Surveyor of Roman Egypt !!!

## DEDICATION

May I dedicate this paper to all of those brilliant and diligent scholars who have collected, analysed and translated the ancient Greek and Roman texts so that characters like Hero can be reanimated for the surveyors and historians of today and tomorrow.

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**Note:** **JARCE** stands for Journal of the American Research Center in Egypt.  
**JEA** stands for Journal of Egyptian Archaeology

## BIOGRAPHICAL NOTES

**John Brock** holds a Bach of Surveying (UNSW,1978), MA Egyptology (Mac. Uni.,2000) Registered Surveyor NSW (1981), Licensed Surveyor QLD (1990), Rose Atkins Assoc., Blacktown (10 years), H. Ramsay & Co., Rosehill (4 ½ years) surveying for 35 years, **Honorary Fellow** ACSM 2008 **Fellow** of ISA, former Vice Pres., committee, convenor of PR & History Subcommittees ISNSW, papers to Survey Congresses in Sydney, Cairns, Perth, Newcastle, Launceston, Queenstown, NZ, Brisbane, Little Rock, Las Vegas and Hawaii, USA, Port Moresby, FIG Belgium, San Diego, FIG Washington, USA and Canada 2002. Surveying History Seminars in Sydney 1991, '94, '96, '97 (paper) & 2003 (paper) Paper to the inaugural FIG Congress History Seminar Brighton U.K.1998, ACSM Arizona, FIG Paris, RICS London, Hong Kong 2003, FIG Athens, Jakarta, Auckland, NZ 2004, FIG Cairo, Brunei 2005, ACSM Florida USA, Jasper, Canada, FIG Congress Munich 2006, FIG Hong Kong, SEASC Christchurch NZ 2007,ACSM Spokane Washington USA 2008 **Halloran Award 1997** for contributions to history of surveying, **Professional Surveyor of the Year 2002** at ISNSW Excellence Awards **FIG Article of the Month** March 2005 for “Four Surveyors of the Gods: In the New Kingdom of Egypt – c.1400 B.C.” **Life member** Rundle Foundation for Egyptian Archaeology, **Foundation member** Australian Nat. Maritime Museum, Friends of Nat. Museum of Australia, Bradman Legacy **Member** National Trust of Australia, Historic Houses Trust of Australia, Friends of Bradman Museum, Royal Aust. Historical Society, Society of Aust Genealogists, Surveyors Historical Society of the USA, Aust. Society for the History of Engineering and Technology , International Map Collectors Society, Parramatta & District Historical Society, Brush Farm Historical Society, Prospect Heritage Trust.

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## APPENDIX A

### THE LIST OF HERO'S INVENTIONS

- 1/ The bent Siphon
- 2/ Concentric or enclosed Siphon
- 3/ Uniform discharge Siphon
- 4/ Siphon which is capable of discharging a greater or less quantity of Liquid with Uniformity
- 5/ A Vessel for withdrawing Air from a Siphon
- 6/ A Vessel for retaining or discharging a Liquid at pleasure
- 7/ A Vessel for discharging Liquids of different temperatures at pleasure
- 8/ A Vessel for discharging Liquids in varying proportion
- 9/ A Water Jet produced by mechanically compressed Air
- 10/ A Valve for a Pump
- 11/ Libations on an Altar produced by Fire
- 12/ A Vessel from which the contents flow when filled to a certain height
- 13/ Two Vessels from which the contents flow, by a Liquid being poured into one only
- 14/ A Bird made to whistle by flowing Water
- 15/ Birds made to sing and be silent alternately by flowing Water
- 16/ Trumpets sounded by flowing Water
- 17/ Sounds produced on the opening of a Temple Door
- 18/ Drinking horn from which either Wine or Water will flow
- 19/ A Vessel containing a Liquid of uniform height, although a Stream flows from it
- 20/ A Vessel which remains full, although Water be drawn from it
- 21/ Sacrificial Vessel which flows only Money is introduced
- 22/ A Vessel from which a variety of Liquids may be made to flow through one pipe
- 23/ A Flow of Wine from one Vessel , produced by Water being poured into another
- 24/ A Pipe from which flows Wine and Water in varying proportions
- 25/ A Vessel from which Wine flows in proportion as Water is withdrawn
- 26/ A Vessel from which Wine flows in proportion as Water is poured into another
- 27/ The Fire-Engine
- 28/ An Automation which drinks at certain times only, on Liquid being presented to it

- 29/ An Automation which may be made to drink at any time, on a Liquid being presented to it
- 30/ An Automation which will drink any quantity that may be presented to it
- 31/ A wheel in a Temple, which. On being turned liberates purifying Water
- 32/ A Vessel containing different Wines, any one of which may be liberated by placing a certain Weight in a Cup
- 33/ A self-trimming Lamp
- 34/ A Vessel from which Liquid may be made to flow, on any portion of Water being poured into it
- 35/ A Vessel which will hold a certain quantity of Liquid when the supply is continuous, will only receive a portion of such Liquid if the supply is intermittent
- 36/ A Satyr pouring Water from a Wine-skin into a full Washing-Basin, without making the contents overflow
- 37/ Temple Doors opened by Fire on an Altar
- 38/ Other intermediate means of opening Temple Doors by Fire on an Altar
- 39/ Wine flowing from a Vessel may be arrested on the Introduction of Water, but, when the Supply of Water ceases, the Wine flows again
- 40/ On an Apple being lifted, Hercules shoots a Dragon which then hisses
- 41/ A Vessel from which uniform Quantities only of Liquid can be poured
- 42/ A Water-Jet actuated by compressed Air from the Lungs
- 43/ Notes from a Bird produced at intervals by an intermittent Stream of Water
- 44/ Notes produce from several Birds in succession, by a Stream of Water
- 45/ A Jet of Steam supporting a Siphon
- 46/ The World represented in the Centre of the Universe
- 47/ A Fountain which trickles by the Action of the Sun's Rays
- 48/ A Thyrsus made to whistle by being submerged in Water
- 49/ A Trumpet, in the hands of an Automation, sounded by compressed Air
- 50/ The Steam-Engine
- 51/ A Vessel from which flowing Water may be stopped at pleasure
- 52/ A Drinking-Horn in which a peculiarly formed Siphon is fixed
- 53/ A Vessel in which Water and Air ascend and descend alternately
- 54/ Water driven from the Mouth of a Wine-skin in the Hands of a Satyr, by means of compressed Air
- 55/ A Vessel, out of which Water flows as it is poured in but if the supply is with-held, Water will not flow again, until the Vessel is half filled and on the supply being again stopped, it will then flow until the Vessel is filled
- 56/ A Copping-Glass, to which is attached, an Air exhausted Compartment
- 57/ Description of a Syringe
- 58/ A Vessel from which a Flow of Wine can be stopped, by pouring into it a small Measure of Water
- 59/ A Vessel from which Wine or Water may be made to flow, separately or mixed
- 60/ Libations poured on an Altar, and a Siphon made to hiss, by the Action of Fire
- 61/ Water-flowing from a Siphon ceases on surrounding the End of its longer Side with Water
- 62/ A Vessel which emits a Sound when a Liquor is poured from it

- 63/ A Water-Clock, made to govern the quantities of Liquid flowing from a Vessel
- 64/ A Drinking-Horn from which a mixture of Wine and Water, or pure Water may be Made to flow alternately or together, at pleasure
- 65/ A Vessel from which Wine or Water may be made to flow separately or mixed
- 66/ Wine discharged into a Cup in any required quantity
- 67/ A Goblet into which as much Wine flows as is taken out
- 68/ A Shrine over which a Bird may be made to revolve and sing by Worshippers turning A Wheel
- 69/ A Siphon fixed in a Vessel from which the Discharge shall cease at will
- 70/ Figures made to dance by Fire on an Altar
- 71/ A Lamp in which the Oil can be raised by Water contained within its Stand
- 72/ A Lamp in which the Oil is raised by blowing Air into it
- 73/ A Lamp in which the Oil is raised by Water as required
- 74/ A Steam-Boiler from which a hot-Air blast, or hot-Air mixed with Steam is blown Into the Fire, and from which hot Water flows on the introduction of cold
- 75/ A Steam-Boiler from which either a hot Blast may be driven into the Fire, a Blackbird made to sing, or a Triton to blow a horn
- 76/ An Altar Organ blown by manual Labour
- 77/ An Altar Organ blown by the agency of a Wind-mill
- 78/ An Automation, the head of which continues attached to the body, after a knife has entered the neck at one side, passed completely through it, and out at the other, which animal will drink immediately after the operation

*Source:* “The Pneumatics of Hero of Alexandria” from the original Greek translated for and edited by Bennet Woodcroft, Professor of Machinery in University College, London (1851)