The Vocal Memnon and Solar Thermal Automata

M.R. Duffey

ABSTRACT

A *memnonium* is a self-actuating system that generates music using solar energy. The name comes from the statue of Memnon, a famous tourist attraction in the Greco-Roman world that was said to emit sound when warmed by the morning sun. The Memnon statue inspired the design of musical automata in later periods, to which there are many historical references. Several intriguing technologies and engineering methods may be well suited for modern memnonium design efforts. However, full realization of solar thermoacoustic and thermokinetic sculpture would likely require deep collaboration between physics, music and other disciplines. In modern times, only a few simple proof-of-concept memnonia have been constructed.

THE VOCAL MEMNON

Accounts of solar-driven sound automata have survived from ancient texts and even include a few very old technical drawings. Most of these accounts reference the famed Memnon statue, which later inspired poetry by Edgar Allen Poe, Erasmus Darwin and Oscar Wilde, as well as music by Franz Schubert [1]. However, it remains uncertain whether any Memnon-derived design concepts were ever physically realized, let alone whether they proved functional. The story of the statue and its legacy merits a properly researched scholarly account. In its absence, the following is offered to introduce this project.

Memnon, an Ethiopian king of archaic Greek legend, was killed by Achilles in the Trojan War, and mourned by his mother, the dawn goddess Eos/Aurora. A colossal 64-ft-high statue in Thebes, believed by the ancient Greeks to be of Memnon, became a major tourist attraction. The story goes that in 27 BC an earthquake caused a fissure in the quartzite sandstone statue (one of a pair—the other nearby, similar statue has no legend attached). After the earthquake there were many accounts by visitors to "the stone image of Memnon, which, when struck by the sun's rays, gives out the sound of a human voice" [2]. The sound was thought to be a song from Memnon to his mother as the sun rose.

In 130 AD the Roman emperor Hadrian, the scientist Hero and other dignitaries visited the statue and claimed to have heard the sound several times (which hugely increased its status as a tourist destination). Inscriptions documenting this visit are cut into the base of the statue, which still stands today in a sugarcane field in Luxor, Egypt. The "vocal Memnon" phenomenon is described by many classical writers, including Strabo, Tacitus Philostratus and Pausanius. In 199 AD the emperor Septimus Severus attempted to repair the statue, after which it ceased to make the sound (although local buskers likely devised ways to fleece gullible tourists [3]).

Some have speculated that the invention of the steam engine was inspired by Hero's conjecture that the Memnon sound was caused by steam expansion in the cracked sandstone. However, it is uncertain whether Hero really designed, let alone fabricated, the steam novelty attributed to him. Another Greek scientist who predates the vocal Memnon, Ctesibius, has a stronger association with solar-driven automata. Ctesibius (c. 285–222 BC, also possibly the first head of the Library of Alexandria) is credited with designing a solar-actuated version of his *hydraulis*, an ancestor of the pipe organ, which was driven by siphoning water between chambers to affect air pressure. (The only existing ancient hydraulis was unearthed in an archeological dig in 1992, near Mount Olympus.) Prior to adding manual keyboard actuation, the earliest hydrauli were probably musical automata, integrated into religious statuary. In the English translation of his book on garden waterworks in 1659, Isaac de Caus (a collaborator of Inigo Jones) provided two technical drawings and descriptions of Memnon-inspired statues [4]. One incorporated a hydraulis-type mechanism [5]. Whether these designs were actually fabricated and operational is unknown but certainly questionable. There are other historical accounts of solar-driven musical automata [6], often described in tandem with autonomic garden statuary relying on wind (Aeolian harps) or water (water organs) and other mechanical curiosities. In modern times, the "solar music" idea has been used by several artists, including Remedios Varo, the Spanish surrealist painter and mathematician. Autonomic solar light and kinematic effects have also been explored by modern artists. There have even appeared a few manually actuated, heat-driven (but nonsolar) musical sculptures/instruments (most famously by the French fire organist Michel Moglia). However, to my knowledge, no one in modern times has built an autonomic solar heat-driven instrument/sculpture.

Fig. 1. Possible system architecture for a memnonium. (© M. Duffey) There are many alternative design configurations and functional interdependencies.

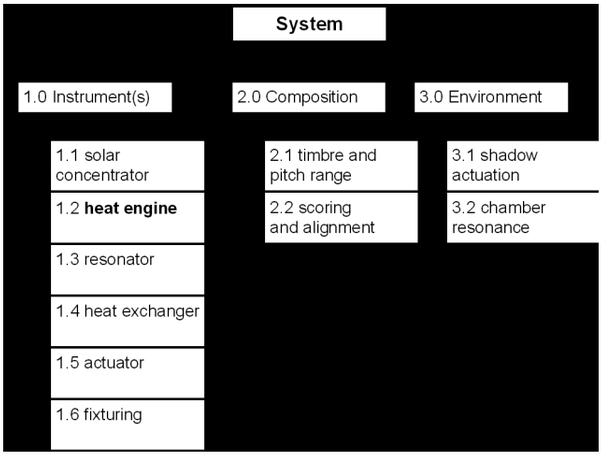

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Fig. 2. A memnonium prototype demonstrated at The Tank in New York City, July 2003. (Photo © M. Duffey) Three parabolic solar concentrators have their focal areas aligned with "singing tubes" for a chord triad. Note the need for eye protection.

Design of Modern Memnonia

A memnonium is fundamentally a *system* for energy transduction, and the technical challenges of memnonium design are related to those of other energy systems. There are many feasible alternative designs, using various heat-to-sound physical principles, materials and design methodologies; for some discussion of them, see *Proceedings of the American Solar Energy Society* [7,8]. Technical requirements might be summarized as follows:

1. Generation of sound shall be effected by solar energy.
2. Actuation of sound (control for onset and duration) shall be effected by solar energy.
3. Mechanical heat-to-sound engines shall be used for generation and actuation. These include, but are not limited to: aero-thermoacoustic engines (singing tubes, a.k.a. acoustic lasers); bimaterial expansion (bimetallic metal coils, shape memory wire/springs, vibration effects [such as Trevelyan's Rocker]); contained gas/liquid systems (such as a hydraulis, or a "Dippy Bird" engine); pulse combustion systems; and thermal-magnetic systems.

Sound-generating heat engines, actuators, resonators, concentrators and other subsystems can be integrated in many complex ways. One possible way to begin decomposing a memnonium system architecture might be as follows (Fig. 1):

Sound-generating heat engines and mechanical actuators are critical-path subsystems in the design process. They can take many different forms and combine different physical principles and functions (Figs. 2–4). One particularly intriguing heat engine technology uses a branch of physics known as aero-thermoacoustics, in which heat can be used to vibrate columns of air directly, without any moving mechanical parts. Thermoacousticians have only recently provided adequate quantitative models for this so-called glassblower's phenomenon. For hundreds of years, glassblowers have observed how certain heated glass shapes have spontaneously emitted their fundamental tones. In the past 10 years or so, new thermoacoustic modeling techniques have resulted in development [9,10] of applications including refrigeration, liquefaction of industrial gases and acoustic Stirling engines. An easy-to-build kit for beginners is the "acoustic laser" developed by the Penn State University Graduate Program in Acoustics, led by Steven L. Garrett [11].

Other technologies widely available to solar robotics hobbyists may be useful for memnonia. A very simple photovoltaic circuit called a solarengine [12] can be integrated with a singing tube to regulate "off-on" solar actuation (Fig. 5) or to vary pitch by changing the length of the resonator. Bimetal alloys used by hobbyists, such as nickel-titanium "muscle wire," also have thermal shape-changing properties that can be used for solar-activated kinematics.

Further technical discussion is beyond the scope of this paper, but suffice it to

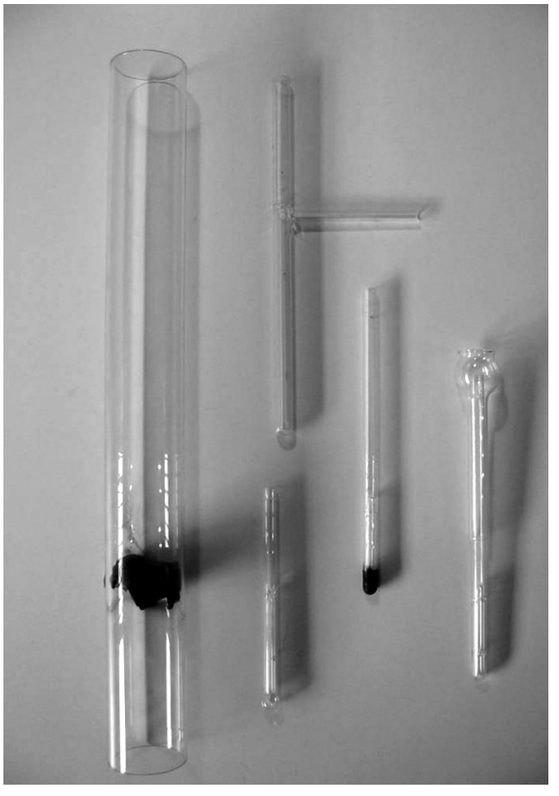


Fig. 3. Various singing tubes based on designs from the 19th- and 20th-century technical literature [15–18]. (Photo © M. Duffey) Most were built by master glassblower Gordon Good.

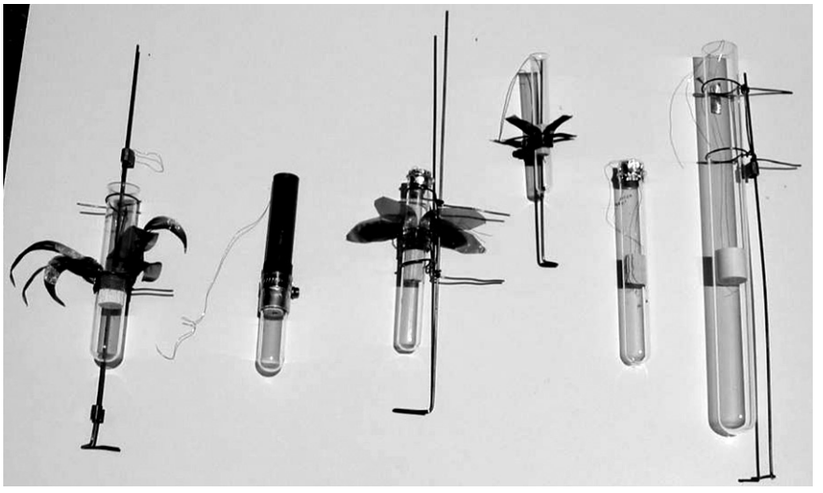


Fig. 4. Singing tube variants based on Penn State's "acoustic laser" [19], using different materials for stack components, tube dimensions, heat exchangers, etc. (Photo © M. Duffey)

say that there are many interesting technologies that might be employed for solar thermoacoustic and thermokinetic statuary. There are also many engineering design methodologies that might be useful, including statistical design of experiments, finite element analysis and physics-based simulation tools for thermoacoustic engines. Although such projects would be technically feasible, the scope of effort might resemble that required for a complex weapons system rather than the labors of an individual artist. Failure is an option.

Conceptual Design

Four design concepts for more complex and large-scale memnonia are provided in Fig. 6.

Throat Memnonia

The legend of the "Vocal Memnon" describes a human-divine voice singing in response to the rising sun. The mouth and throat are acoustically resonant cavities aligned with the sun, a literalization of Goethe's oft-quoted reference to architecture as "frozen music." Solar heating could also deform walls of resonant cavities, to perhaps mimic the changing formants of vowel sounds in speech (diphthongs). Shadow and sun movement in a deep, properly aligned "throat" could effect the sound in various ways (Fig. 6a).

Floral Memnonia

Flora change shape and orientation in response to diurnal cycles. Flower petals might function both as solar reflectors and as resonant cavities, thermokinetically unfolding and orienting in preparation for the music (Fig. 6b). The flower's stamen would be a *fasces* of singing tubes aligned with focal areas of the petal-concentrators.

Memnonic Lattice

A network of sound generators/actuators could respond to transient thermal and shadow interactions between subsystems (Fig. 6c). One could imagine a solar-configured, 3D *harmonic network,* for example, that automatizes the time-of-day associations of North Indian ragas [13]. To sonify environmental inputs, there may be other useful models from network theory.

The Washington Monumemnonium

Figure 6d shows a snapshot from a shadow-moving simulation study of the Washington Monument as musical sun-

Fig. 5. A hybrid automaton combining singing tube (generator) and a simple "solarengine" photovoltaic circuit patented by Mark Tilden (actuator). (Photo © M. Duffey) The solarengine rotates a slotted cover over the tube to control on/off cycling. It can also be used to vary pitch.

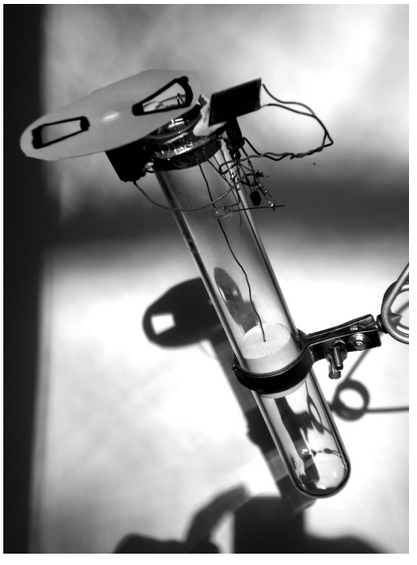
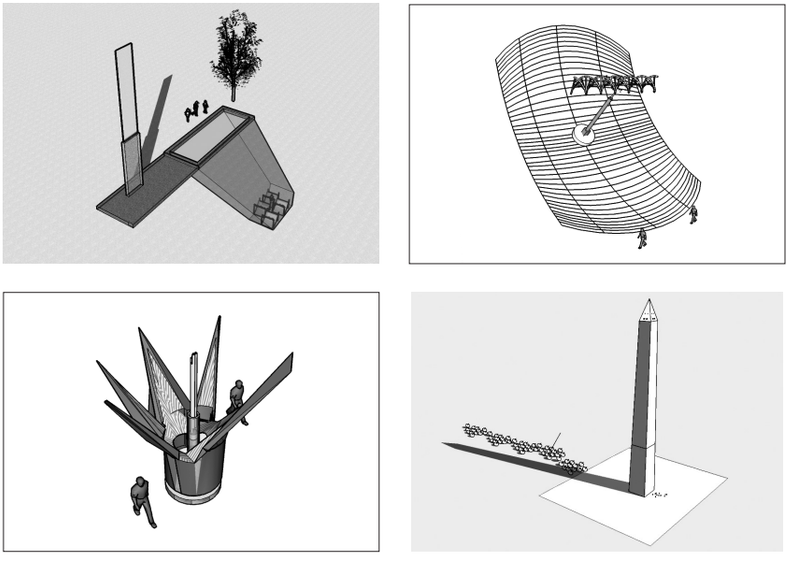


Fig. 6. Design proposals: (top left) Throat memnonia. Shadow and sun movement in a deep, properly aligned "throat" could effect the sound in various ways. (bottom left) Floral memnonia. Flower petals might function both as solar reflectors and as resonant cavities. (top right) Memnonic lattice. A network of sound generators/actuators could respond to transient thermal and shadow interactions between subsystems. (bottom right) The Washington Monumemnonium. Snapshot from a shadow-moving simulation study of the monument as musical sundial. (All illustrations © M. Duffey)



dial. A memnonium can be considered a *distributed* system, with orchestral composition as one aspect of meta-design. Simulation tools can be used to coordinate the solar orientation/actuation of distributed instruments.

THE MEMNON COMPETITION

In summary, many design variations appear technically feasible, some easy to build, some highly complex. For this and other reasons, memnonia make excellent projects for student design teams, and a "Memnon Competition" has been discussed by some educators, perhaps similar to the popular student robot competitions, but more interdisciplinary [14]. Such a competition might be a good way to attract creative students to the urgent problems of energy system design, as well as help speed the evolution of memnonic systems. The curriculum can relate memnonium design to basic energy literacy as well as more subtle concepts in thermodynamics and other energy-relevant disciplines. Some preliminary Memnon-related projects have been undertaken by students and faculty at George Washington University, Hampshire College, J.C. Terrell Junior High School in Washington, D.C., and Oberlin College. However, as mentioned, no one has yet built a modern memnonium of any merit, and the tales of ancient memnonia are unsubstantiated.

Acknowledgments

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