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Varieties of Wonder

John Wilkins' mathematical magic and the perpetuity of invention

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Abstract

Akin to the mathematical recreations, John Wilkins' *Mathematicall Magick* (1648) elaborates the pleasant, useful and wondrous part of practical mathematics, dealing in particular with its material culture of machines and instruments. We contextualize the *Mathematicall Magick* by studying its institutional setting and its place within changing conceptions of art, nature, religion and mathematics. We devote special attention to the way Wilkins inscribes mechanical innovations within a discourse of wonder. Instead of treating 'wonder' as a monolithic category, we present a typology, showing that wonders were not only recreative, but were meant to inspire Wilkins' readers to new mathematical inventions.

Keywords

John Wilkins; Mathematical Magic; mathematical recreations; machines; wonder; mathematics and religion; innovation; MSC 01A45;

1. Introduction

In July 1654 the English virtuoso John Evelyn paid a visit to the "Civilities of Oxford" (Evelyn, 1955, p. 111). He was shown different collections, some "adorn'd with some rarities of natural things", such as a "prodigious large *Parot*" and "two humming birds, not much bigger than our *humble bee*", as well as with "Magical Charmes" and "divers *Talismans*"; others containing a "store of Mathematical Instruments" (*ibid.*, 108). On his last day, Evelyn visited "that most obliging & universally Curious Dr. *Wilkins's*, at Waddum". The warden of Wadham College (or Waddum, as Evelyn had it) showed him among other things "an hollow Statue which gave a Voice, & utterd words, by a long & conceald pipe which went to its mouth, whilst one spake thro it, at a good distance, & which at first was very Surprizing". Besides this, he also "had above in his Gallery & Lodgings variety of *Shadows*, Dyals, Perspectives, places to introduce the Species, & many other artificial, mathematical, Magical curiosities: A Way-Wiser, a *Thermometer*; a monstrous *Magnes*, *Conic* & other *Sections*, a Balance on a demie Circle" (*ibid.*, pp. 110-111).[1] Six years earlier, before taking up his post at Oxford, the same Dr. Wilkins had already published a treatise entitled *Mathematicall Magick, or, The wonders that may be performed by mechanicall geometry.*[2] In it, he treated of numerous such "artificial, mathematical,

[1] We should be careful with Evelyn's account, of course, which does not necessarily reflect exactly the contents of Wilkins' collection. Such lists of wondrous instruments belonged to a genre of wonder literature, and Evelyn's account is as much a literary trope as an observation report of his visit.

[2] Page references in the text will be to Wilkins, J. (1648). *Mathematicall magick, or, The wonders that may be performed by mechanicall geometry in two books*. London: Sa. Gellibrand.

and magical curiosities", including some of the ones that Evelyn would later see at Wadham, but also flying chariots, submarines, and perpetuum mobiles.

Although John Wilkins would later become one of the founders of the Royal Society, there has been little sustained interest in his work.[3] In particular, the *Mathematicall Magick* has remained mostly uncharted territory.[4] For the older literature, it might have been Wilkins' elevated status as protagonist in the institutional establishment of modern science that caused some unease with respect to the scientific value of this "strange, almost baroque assembly"[5] of curiosities. But at least since the 1980's there has been a growing interest in the role played in the development of modern science by exactly this typical baroque practice of collecting, and its concomitant focus on both wonder as a powerful cognitive attitude and wonders as a category of objects and events.[6] In this context, Wilkins' *Mathematicall Magick* is sometimes cited, but a detailed analysis of the registers of wonder used in that work has never been undertaken.

In this paper we will offer an analysis of the multifaceted and original ways in which Wilkins inscribes mechanical innovations within a discourse of wonder. The secondary literature has usually treated of 'wonder' as a homogeneous category. A close study of the *Mathematicall Magick* allows us to distinguish different registers of wonder, however, based on long-standing traditions on which Wilkins could draw. A focus on wonder also makes it possible to explore different relevant contexts for the *Mathematicall Magick*. It will yield more insight in other aspects of the literature of wonder, including the genre of mathematical recreational literature. It will also help us to explore the relation between religion, science and technology in early modern England. The wonders of nature, artificial marvels and religious admiration are closely intertwined, and we will show that wonder provides exactly the pivotal point around which the mutual articulation of religion, science and technology revolves in Wilkins' early work.[7] This does not seem to be without some further significance, as Wilkins is not

[3] A general intellectual biography (Shapiro 1968) and an insightful piece in the *Dictionary of Scientific Biography* (Aarsleff 1976) are the most relevant general pieces on Wilkins. More recent literature has focused on his position as a patron of Robert Hooke and Christopher Wren (Jardine 2004), his work on an universal language (Subbiondo 1992, Stillman 1995, Maat 2004, Lewis 2007), his views on natural theology (Mandelbrote 2007), or his astronomical work in which he not only defends Copernicanism but also treats of travel to the moon (Chapman 1991, Aït-Touati 2005, Kaoukji & Jardine 2010).

[4] To some extent, Alfonso-Goldfarb (1998) is an exception, but she mainly treats Wilkins' views on alchemy in the discussion on perpetually burning lamps in the second book of the *Mathematicall Magick;* and only after having rather misleadingly characterized the first book as "mechanisitic", characterizing this as the propagation of a "nonteleological" theory of matter and the "borrowing from machinery the model to interpret each and every phenomenon of motion" (p. 135). This is a very forced reading of the first book, so the opposition she tries to set up between a "modern" and "an "older" view about matter" in Wilkins' work, seems to be without good grounds. We will argue for a different, more fine-grained way to characterize the differences, but also similarities between the two books making up the *Mathematicall Magick*. Recently, Natalie Kaoukji's unpublished PhD dissertation also devotes a chapter to the *Mathematicall Magick*, but she treats the work as an exclusively literary enterprise (Kaoukji 2008, p. 11).

[5] Aarsleff (1976, p. 366).

[6] See e.g. Céard (1986), Pomian (1988), Findlen (1994), Daston & Park (1998), Campbell (1999), Benedict (2001), Tybjerg (2003), Evans & Marr (2006). Especially Marr (2006) is essential background reading for this article, as it treats of automata and wonder-working.

[7] Hans Aarsleff already commented: "Whether we call some of his writings scientific and others religious is a matter of emphasis; they all have the same aim: to guide man's conduct toward moral virtue, religious devotion, and ultimately the hope of salvation." (Aarsleff 1976, p. 361). Aarsleff did not offer much insight in how this intertwinement can be traced in detail in Wilkins' apparently more "scientific" writings, such as his *Mathematicall Magick* (which Aarsleff reads primarily in utilitarian terms).

only hailed as one of the driving forces behind the foundation of the Royal Society, but has also been called “one of the most influential English theologians of the seventeenth century”[8].

2. Writing the *Mathematicall Magick*

2.1 Wilkins’ itinerary

It is uncertain how the clergyman John Wilkins (1614-1672) first became infatuated with wondrous machines, but there are a few clues that can shed light on this curious passion. Jessica Wolfe (2004) has shown that there was a general surge of learned interest in machines and mechanics in early modern England, but in Wilkins’ case there are also particular autobiographical reasons. His father, Walter Wilkins, was a goldsmith fascinated by machines and perpetuum mobiles.[9] During his studies and tutorage at Magdalen Hall, Oxford, between 1627 and 1637, the college had only few members with interests in mixed mathematics and natural philosophy, but the recently established Savilian lectures in astronomy and geometry could have had an important impact on Wilkins, resulting in the anonymous publication of his first book on Copernican astronomy. *The Discovery of a World in the Moone*, which appeared in 1638, already displayed the erudite use of a wide array of sources that would later also characterize his *Mathematicall Magick*. Wilkins’ university time might also have been important for the *Mathematicall Magick* as he states in the dedication that he composed the book during his “spare houers in the University”. Many passages in the *Mathematicall Magick* are based on works published after his time at Oxford, however, so we should conclude that Wilkins developed much of the book between 1637 and 1648.[10]

In this difficult period, which encompasses the worst of the English civil war, Wilkins was able to steer a middle course and avoided political and religious troubles. After a few clerical positions with Puritan patrons, in 1644 Wilkins became chaplain to the Prince Palatine Charles Louis, a remarkable figure of religious and political consequence in England. A grandson of King James I of England, Charles Louis had spent much of the 1630s at the England court, hoping to enlist English support for regaining the Palatinate, the county his father had lost to the Catholic Imperial armies. An emblem of the protestant cause, Parliament had also long supported his family. Moving between the opposing parties and criticizing the increasing divisiveness, he was effectively sidelined, and became a patron of the arts and sciences at his residence at Whitehall.[11] The Palatine princes had a longstanding interest in wondrous machines. Charles Louis' father, the ‘Winter King’ of Bohemia, had employed the well-known engineer Salomon de Caus to build the famous machine garden in Heidelberg. His younger brother, Prince Rupert of the Rhine, a Royalist general and later member of the Royal Society, would become famous for his many technical inventions.[12] Wilkins, who must have found a congenial environment in Charles Louis’ household, would have had ample time for developing his mechanical

[8] Henry (2000, p. 889). On Wilkins' and his religious context, see also Shapiro (1991) and Feingold (2002)
[9] Shapiro (1968, p. 12).
[10] Aarsleff concludes from this that Wilkins must have spent much time on university matters in this later period, which is rather implausible.
[11] When he had come back to England in 1644 after a period spent on the continent, it was rumored that he had an eye on the English crown, and he became involved in intrigues and espionage. This might have aroused his interest in Wilkins' *Mercury, or, The Secret and Swift Messenger*, published in 1641, in which Wilkins developed many ideas related to cryptography. Note that in the early modern period, mechanics and cryptography were thought to be affinitive, because of their occult associations and because their special effects could be indicted as being of demonic provenance.
[12] In his famous *An essay upon projects* (1697), Daniel Defoe explicitly associates Wilkins' and Prince Rupert's projects of inventing machines.

interests, and dedicated the *Mathematicall Magick* to his new patron. When Charles Louis was restored to the Palatinate, Wilkins travelled to The Hague and Heidelberg, the location of the (by then destroyed) famous garden, getting to know foreign courts and their retinue of courtiers, engineers and inventors.

When in London, Wilkins also belonged to a group of young scholars who met at Gresham College to discuss recent developments in natural philosophy and mixed mathematics, avoiding political and religious topics. As John Wallis described it many years later, they also performed experiments on the vacuum, gravitation, and many other topics in mechanics and the 'New Philosophy' of Galileo and Bacon.[13] Although Wilkins became Warden of Wadham College with parliamentarian support in 1648, and eventually would marry Cromwell's sister, he continued to steer a middle course. His pragmatic latitudinarianism was also reflected in his theological and scientific views, in which he avoided factionalism and fostered collaboration and agreement. In particular, he attracted virtuosi from all persuasions, including Hooke, Wren, Ward and Wallis, to collaborate on mechanical and other experiments.[14]

Wilkins' personal itinerary may partly account for the complex structure of the *Mathematicall Magick*. Indeed, as we will show, the first and the second book have a rather distinct character, which is reflected in the different registers of wonder used. The first half of book one (called *Archimedes*) is more in line with traditional literature on the science of simple machines, referring mostly to classical and humanist literature. It is in the second book (called *Daedalus*), where Wilkins most clearly caters to the courtly taste of spectacular machines (as he would have encountered with the Prince Palatine), that we find most references to recent literature published after Wilkins' university years (e.g. Mersenne, Gassendi and Kircher).[15] This suggests that the book was written in different stages, with different concerns and audiences in mind, reinterpreting and adapting previous notes and ideas.[16] This does not make the book incoherent. Indeed, as we will show, the book's structure follows a clearly discernible logic, and it is possible to distinguish a progression in attitudes and concerns.

2.2 What is 'Mathematical Magic'?

Wilkins' *Mathematicall Magick* is most often characterized as either a 'popular science' treatise or a work of 'popularization', mainly relevant for its introduction of learned knowledge in a practical context and aimed at a general public.[17] This is to some extent confirmed by a statement on the title page: that its subject is "not before treated of in this language". Throughout the book, there are also numerous exhortations to men of wealth to invest more in mechanical innovation, so there is no doubt that Wilkins saw the promotion of the utilitarian benefits of mechanics as one of the goals of his treatise. This reading can only do full justice to the first half of the first book, however, in which learned mechanical knowledge is indeed translated in an accessible, non-formal idiom. Most of the

[13] Wallis (1696, clxii). We cannot be sure of the accuracy of Wallis' description, however.

[14] On Hooke and Wren in relation to Wilkins, see Bennett (1975; 1982; 2001), Bennett et.al. (2003), and Jaridine (2004). On Hooke and his experiments on human flight, see in particular Tkaczyk (2011), whose insightful conclusions about Hooke come close to our analysis of Wilkins', which confirms the close intellectual ties between them.

[15] Cf. e.g. Mersenne (1636; 1644a), Gassendi (1641), Kircher (1643). Note that the topics treated in the first book can also be associated with courtly culture at the time (Wolfe, 2004), but they appeal to rather different aspects of it.

[16] Just as Wilkins' position with Charles Louis might have been partly due to the specific topic of his *Mercury*, there is a tantalizing conjecture that the *Mathematicall Magick* can be read as an implicit signal that Wilkins had the intellectual tools to make true on some of the Rosicrucians' professed ambitions (Charles Louis was often associated with the fraternity). We cannot develop this hypothesis here, however.

[17] Shapiro (1968, p. 43), Aarsleff (1976, p. 363), Henry (2000, p. 890).

book – and especially the 'impossible machines' described – cannot be explained in such terms. Furthermore, the category of 'popular science', or 'popularization', introduces unwarranted anachronistic expectations concerning the goals and nature of a 'popular' treatment of a 'scientific' subject.

Wilkins also announces on his title page that the subject is "one of the most easie, pleasant, usefull, (and yet most neglected) part of mathematicks", bringing to mind titles such as the popular *Recreations Mathématiques*.[18] This book had recently been translated into English (in 1633) and presents a wide array of surprising tricks and gadgets. The category of 'mathematical recreations' has the advantage of being closer to a seventeenth century understanding, and it is possible to find other popular treatises that fit this label, such as Mersenne's *Questions inouies ou récréation des savants* from 1634.[19] Wilkins' book shows affinities with these works in its focus on inventive and spectacular applications of basic principles from mixed mathematics.[20] It is also clear that he was familiar with them: the Recréations Mathématiques are cited once, and part of his book's subject matter could have been directly inspired by Mersenne's book.[21] If we want to understand the appeal that a book such as Wilkins' could have had, it is thus important to take this recreational literature into account. There are also differences, though, that set Wilkins' book apart. Mathematical recreations are usually a haphazard collection of curious contrivances and problems.[22] In contrast, in the *Mathematicall Magick* there is a clear logic to the succession of chapters, as we will show. Furthermore, mathematical recreations usually derive their wonder from trickery or prestidigitation, playing with the ignorance of readers and spectators. In Wilkins' work, there is no trace to be found of trickery, neither does it play with illusion nor deception. As we will argue, the wonder in the *Mathematicall Magick* is tributary to very different sources.

Of course, the most obvious connection is with the tradition of mathematical magic itself.[23] Explaining his choice of title, in reference to Agrippa's *De Vanitate*, Wilkins writes that mathematical magic was the traditional name for the art of mechanical inventions.[24] The term mathematical magic was rather uncommon, however, and related terms such as artificial magic or thaumaturgy were also used.[25] Insofar as we can meaningfully speak of a genre, this is mainly due to the recurrence of lists of typical

[18] See e.g. Eamon (1996, pp. 308-309).
[19] The *Recréations Mathématiques* was first published in French in 1624, and had its first English publication in 1633. Afterwards it went through numerous editions. Heeffer (in preparation) provides an extended description and discussion.
[20] In the early modern period, mathematics included many instrumental practices, and mathematical recreations thus also included references to wondrous instruments and techniques (such as fireworks).
[21] See also Aarsleff (1976, p. 377, n. 36).
[22] In the case of the *Recréations Mathématiques* this character is probably to be explained partly by the circumstantial nature of its original publication (on this see Heeffer (in preparation)), but it shares its lack of overarching structure or apparent design with other works, such as Mersenne's.
[23] See Zetterberg (1976, 1980), Eamon (1983), Marr (2004), Stolzenberg (2001), Grafton (2005), Kang (2011, chapter 2), many of whom use Wilkins as a main example.
[24] Agrippa writes in chapter 43 "Of Mathematical Magick": "There are besides these, many other imitators of Nature, wise inquirers into hidden things, who without the help of natural Virtues and Efficacies, confidently undertake, onely by Mathematical learning, and the help of Celestial influences, to produce many miraculous Works, as walking and speaking Bodies; which notwithstanding are not the real Animal: such was the wooden Dove of Archytas, which flew; the Statues of Mercury, that talk'd; and the Brazen Head made by Albertus Magnus, which is said to have spoken." The quote is from the 1676 English translation of Agrippa's *The vanity of arts and sciences* (Agrippa 1676).
[25] Alsted (1630) divides magic into natural and mathematical magic. Del Rio (1600, I, 2) classifies magic by "*efficient cause*" and distinguishes between "Natural, Artificial, and Diabolic [magic] because all its effects are to be ascribed to the innate nature of things, or to human agency, or to the malice of an evil spirit." John Dee uses Thaumaturgy (Dee, 1570).

contrivances that straddle the boundaries of art and nature, such as flying doves and eagles made of wood or iron, speaking statues, and moving automata.[26] The ways in which these lists were introduced in texts differed rather widely, but the discourse surrounding them always put them into the context of the relation between the mathematical arts and magic. Indeed there had been a longstanding connection between mathematics and different kinds of magic or occult practices.[27] Mathematical magic also shared a lot with the more established tradition of natural magic, and was sometimes incorporated in it.[28] Natural magic brought about wondrous effects without the intervention of demonic aid, and much of it could be incorporated within attempts at forging a reformed natural philosophy.[29] But due to its association with demonic magic under the common denominator of magic, it was also treated with suspicion – not least in the period when Wilkins published his book, at the height of the witch craze.

What does ‘magic’ mean for Wilkins? In his *Mercury* (1641), Wilkins often referred to “Magick” or “Diabolicall Magick”. It was one of the categories that helped him to explain wondrous phenomena such as secret and swift communication: wondrous phenomena were either “Magick”, “Fabulous” or “Naturall and true” (*Mercury*, p. 145).[30] In his *Mathematicall Magick*, however, Wilkins ignores the demonic association of magic. He explains that he used the term magic in his title as an allusion to “vulgar opinion, which doth commonly attribute all such strange operations unto the power of Magick” (*Mathematicall Magick*, To the reader).[31] Commentators see this as a sign that Wilkins’ choice of title was intended ironically, as his treatise goes on to show that these operations can actually be explained purely mechanically.[32] If he wanted to get rid of magical associations, however, why choose a title that only perpetuates the confusion?[33] And how are we to understand the fact that Evelyn, who could hardly be associated with “vulgar opinion”, could nonetheless unproblematically refer to Wilkins’ own collection of “artificial, mathematical, and magical curiosities”? Dismissing the demonic interpretation of magic as a “vulgar error” was moreover part and parcel of the natural magic tradition itself. So why not take Wilkins at his own word when he explains on his title page that mathematical magic treats of “The wonders that may be performed by mechanicall geometry”, indicating that what is magical about the treatise is its topic of wondrous operations? After all, one dominant meaning of ‘magic’ in the seventeenth century was precisely the enquiry into the wondrous, or the production of wondrous effects.[34] This wonder often referred to what goes beyond the understanding of the vulgar, but it was also used in a more general sense. Indeed, immediately after having stated that vulgar opinion “doth commonly attribute all such strange operations unto the power of Magick”, Wilkins also reports that for that reason “the Ancients did name this art *Θαυματοποιητική*, or *Mirandorum Effectrix*”.

But even granting the above, is Wilkins not ironical when he suggests transparent mechanical explanations for these wondrous effects? Is he not evacuating the remaining sense of the magical along

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[26] For an analysis of the lists of typical mechanical wonders, see Chapter 2 in Kang (2011).
[27] See e.g. Neal (1999) for the connection between mathematics and the occult.
[28] See e.g. Della Porta (1589), who treated wonders caused by mixed mathematics as part of natural magic.
[29] Henry (2008) contains a discussion of this process of incorporation.
[30] For the early modern categories available to explain wonders, see e.g. Vermeir (2009).
[31] Wilkins uses the term magic only two more times, referring to traditional stories (relating to Simon Magus and to Saint Augustine) in which the term magic was well established.
[32] Sawday (2007, p. 120); Kang (2011, p. 97).
[33] See Zetterberg 1980 for the lament that the mathematicians’ own rhetoric played a crucial part in what he calls the “mistaking” of mathematics for magic.
[34] The Jesuit Gaspar Schott (1659, 1:18), for instance, defined magic as “whatever is marvelous and goes beyond the sense and comprehension of the common man.” Cf. Vermeir (2009).

the lines of Stevin's famous "wonder en is gheen wonder"?[35] In what follows we will show that such arguments (which can be linked with a more general disenchantment thesis) are a bit too quick. A careful reading of the text shows that there are still good reasons to categorize it as mathematical *magic*, because the whole discourse remains organized around wonder as a *non-reducible* aspect of mechanical knowledge and practice. Knowing the mechanical reasons behind the operation of machines does not automatically remove wonder as a proper response.

3. Archimedes: Proportioning wonder

3.1 Pseudo-Aristotle and the multiplication of power

The *Mathematicall Magick* is divided into two books, *Archimedes, or, Mechanicall Powers*, which deals with the mechanical multiplication of power, and *Daedalus, or, Mechanicall Motions*, which treats of automata. The general structure of the work is significant. The first nine chapters of the first book explain the basic principles of mechanics and identify the six mechanical faculties (the balance, the lever, the wheel, the pulley, the wedge and the screw), faithfully following Heron, Pappus and their Renaissance heirs. On the whole, these chapters stay close to the models provided by sixteenth century writers of the so-called 'renaissance of mathematics' who were engaged in forging a synthesis of the ancient sources known to them.[36] Wilkins also follows them in claiming that these mechanical disciplines "overcome, and advance nature" (p. 3), and that by this art "nature is commanded against her own law" (p. 10).[37] Given Wilkins' own indication that he wants to treat the wonders that may be performed by mechanical geometry, one would expect that the wonderful character of this feat would be stressed. After all, the 'wonder' that machines were able to overcome nature was very often commented upon in the literature drawn upon by Wilkins; an idea that can be traced back to the example set by the *Mechanical Problems*, a work attributed to Aristotle at the time.[38]

The preface of the pseudo-Aristotelian *Mechanical Problems* starts with a phrase that would become classic: "Remarkable things occur in accordance with nature, the cause of which is unknown, and others occur contrary to nature, which are produced by art for the benefit of mankind".[39] It is important to notice that the author of the *Mechanical Problems* introduces two different sources of wonder: firstly, we can be in wonder because we are ignorant of the cause of things that happen naturally, but secondly, some artificial phenomena seem to go against nature and are intrinsically wonderful. Indeed, the latter kind of wonder is provoked when the smaller wins from the bigger, as happens in the case of the lever, where a small force is able to move a big weight, which goes against the nature of things. Pseudo-Aristotle then continues with a quotation from Antiphon, which we also

[35] This line of reasoning brings e.g. Anthony Grafton to conclude that Wilkins' use of the terminology of magic "had no organic connection to magic in the traditional sense" (Grafton 2005, p. 45).
[36] Rose (1975), Laird (1986), Van Dyck (2006). The first 9 chapters are indebted most of all to Guidobaldo del Monte (1577), as can be seen e.g. by a comparison of the illustrations (as was already noticed by Aarsleff 1976, p. 366).
[37] Guidobaldo del Monte, e.g. had stated that "mechanics … operates against nature, or rather in emulation of its laws" (Del Monte 1577, p. 2 of unnumbered preface; on "emulation" as carrying ideas of both rivalry and imitation, see Van Dyck 2013, p. 19). Festa & Roux 2001 (242-244) collect many other instances.
[38] Festa & Roux (2001).
[39] In the translation of W.S. Hett (with one modification: rendering "technè" by art rather than skill) in Aristotle, (1933, p. 331).

find on the title page of Wilkins' *Mathematicall Magick*: "We by art gain mastery over things in which we are conquered by nature".[40]

Surprisingly, Wilkins nowhere refers to this passage from the *Mechanical Problems* in the opening chapters of his book, in which a very wide array of authors and texts is cited. His discussion of the mechanical faculties is down to earth, and there is hardly any mention of wonder. Only from the tenth chapter onwards, where Wilkins discusses the magnificent works of ancients, the rhetoric of wonder is introduced. Some of the ancient buildings mentioned in historical literature (such as Solomon's temple or the Colossus of Rhodes) would "seem almost incredible" to people from our times, since they are "so mightily disproportionable to human strength". Wilkins explains that it is nevertheless "easie to conceive the truth and ground" (p. 61) of these monumental "wonders" (p. 63), as they were erected with the help of the mechanical principles that he has just expounded. Wilkins thus seems to introduce a nice example of the second kind of wonder in which art overcomes our natural limitations. At the end of the chapter he also refers to the much discussed moving of the Vatican obelisk in 1586 to convince the readers that such "strange" feats (p. 78) should not be thought of as beyond the reach of their own times. As Wilkins explains in the eleventh chapter, all that is missing are the right kind of motives and available financial means that would spur on the further "reduction" of these theoretical principles into "remarkable" action.

In chapter 12, the wonderful nature of mechanics is amplified by the discussion of the "strange assertions" of Archimedes, such as the claim that he could move the whole world if only he found a fixed point to stand (FIGURE 1). As Wilkins recounts, this was so much "above the vulgar apprehension or belief" that the king of Syracuse had to install a law obliging people to believe "what ever Archimedes would affirm" (p. 80). It is clear that we are now moving toward a different realm: such a law would certainly not have been necessary concerning the magnificent monuments discussed in the earlier chapter: their truth would have been all too easy to see for the people living in antiquity.[41] It is thus not insignificant that Wilkins goes on to state that he will demonstrate the "geometrical" truth of Archimedes' claim. The kind of wonder we are dealing with here is actually moving us beyond the classes of phenomena as identified in the pseudo-Aristotelian preface, as it no longer concerns things that occur (either according to or against nature), but things that ideally *could* occur. Wilkins explains that the mathematical proportions discussed in the first nine chapters do imply that all of the mechanical faculties can be of *infinite* power: any conceivable weight can be moved with e.g. a lever, by making the lever arm long enough. Indeed, he calls chapter 14 "Concerning the infinite strength of Wheels, Pulleys, and Screws, that it is possible by the multiplication of these (...) to perform the greatest labour with the least power". To drive home his point, Wilkins explains in the next chapters "how to pull a man above ground with a single hair" or how to pull up an oak only with the strength of a straw (FIGURE 2), involving himself in calculations of enormous numbers that can remind the reader of the number games of the mathematical recreations.[42] Wilkins' rhetoric of wonder reaches its provisional apotheosis in the conclusion of chapter 14: "So that there is no work impossible to these contrivances, but there may be as much acted by this art, as can be fancied by imagination" (p. 102). The wonder of mechanics has truly become infinite.

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[40] Ibid.

[41] This anecdote about the king of Syracuse is told by Proclus, and repeated in Dee's *Preface*. The king proclaims this law only after that Archimedes has shown that he can indeed move very great weights with little force, so it is not completely dissociated from practical backing; as Wilkins expresses it: "his acts were somewhat answerable thereunto [the boast of moving the whole earth]" (p. 80).

[42] Many of the contrivances and calculations are inspired by Stevin (1605) (the Latin translation of both his "Art of weighing" and "Practice of weighing" from 1585) and Mersenne (1644b). Below we will comment on some significant differences in the presentations of Wilkins and his two predecessors.

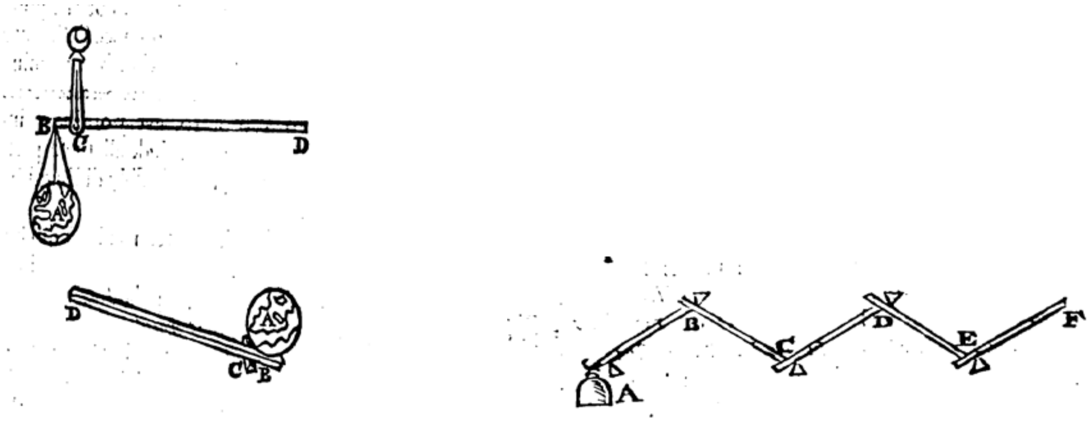

FIGURE 1: Wilkins' illustrations of Archimedes' idea to lift the earth and of the multiplication of force by the combination of levers (p. 81 and 84).

3.2 The multiplication of wonder

The ensuing chapter 15 brings a dramatic shift in perspective. Immediately after having stated that it is possible to do anything with machines, it is now announced that "a man shall be exposed to many absurd mistakes, in attempting of those things, which are either in themselves impossible, or else not to be performed with such means as are applyed unto them" (p. 103). Everything seemed possible, but as it now turns out, there are limits to mechanics. Although with a lever you can in principle lift an infinite weight, you will also need infinite time to do so. That is why so many inventions fail, "because the artificers many times doe forget to allow so much time for the working of their engine" (p. 103). The fact that the advantage gained in power is always lost in distance over which the power has to move (and thus in time spent) was a crucial principle in mechanical practice, and follows immediately from the mathematical proportions characterizing the operation of machines. Wilkins implicitly follows Mersenne's presentation of Galileo's manuscript treatise *Le mecaniche* in linking this principle with limits imposed by a providential nature.[43] But whereas Mersenne had only stressed the wisdom exhibited in this compensation between power and distance that symbolized "equity & perpetual justice" (Mersenne 1634b, p. 2 of unnumbered preface), Wilkins directly connects this with our status as created (and fallen) beings. He writes: "The wisdome of Providence hath so confined these human arts" because without these limits "the works of nature would be then too much subjected to the power of art: and men might be thereby incouraged (with the builders of *Babell,* or the rebel Gyants) to such bold designes as would not become a created being." (p. 104)

In his presentation Wilkins has separated this compensation principle from his initial treatment of the mechanical faculties and their use in the multiplication power, and he plays this to dramatic effect. Mathematically, however, these principles directly imply each other. For this reason, Galileo had begun his *Le mecaniche* by immediately stressing the crucial importance of the compensation principle. He made clear that it imposed clear limits on what is possible with the mechanical faculties,

[43] The link between a neglect of the principle and failed promises by incompetent (or malevolent) artisans had already been made by Galileo (see Mersenne 1634b, pp. 1-2; see also Galileo 1960). Salomon de Caus had also made the same link in very similar terms in the dedication of his *Les Raisons des Forces Mouvantes*, published while in the service of Frederick V, the father of Wilkins' patron (de Caus 1615). In his own preface "To the Reader", Wilkins had also stressed that the lecture of his book might help Gentlemen to "more easily avoid the delusions of any cheating Impostor".

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disabusing everybody of false hopes from the very start.[44] Wilkins, in contrast, explicitly kindles the hopes of his readers before these intrinsic limits are exposed. Something similar is true about Wilkins' presentation of Archimedes' promise to move the earth. As noticed, his presentation of the different devices that could bring about such effect is closely modeled on Stevin and Mersenne. There is one crucial difference, though. Both predecessors do not fail to notice immediately that the motion of the earth brought about would be insensible, because the distances moved have to be in the inverse proportion of that of the weight of the earth to the power used (Stevin 1605, p. 107; Mersenne 1644b, p. 16, pp. 42-3). Wilkins again holds this limitation in suspense for a number of chapters before he brings it up. What is more, he immediately exploits it to reinstall the sense of wonder that might have disappeared after the exposure of the severe limits on possible mechanical effects, which imply that man's overcoming of his limitations is itself severely limited in a mathematically determinate way.[45] Wilkins uses precisely Stevin's and Mersenne's calculations about the extreme slowness of the effected motion of the earth to show "that it is possible to contrive such an artificiall motion, as shall be of slownesse proportionable to the swiftenesse of the heavens", which idea he presents as "a pretty subtility" (p. 110) and as a "wonder … no less admirable" (p. 114) than the infinity of force treated earlier.

FIGURE 2: "Possible" machine for uprooting an enormous oak (Wilkins explicitly makes the judgement of "possibility" in the title of chapter 14). (p. 98.)

We already noticed how Wilkins was transposing the wonderful nature of mechanics towards the abstract mathematical realm in his discussion of Archimedes. This move is now reinforced: we are not only dealing with phenomena that are only theoretically possible, it is also stressed that if these

44 Galileo even explicitly states that an indefinite multiplication of power is "impossible to accomplish with any machine imagined or imaginable" (Galileo 1960, p. 148). Notice the stark contrast with Wilkins' claim at the end of his chapter 14.

45 E.g. Galileo had used this principle to argue that it is actually not true that in mechanics one can move a great load with a smaller power, since the power actually exerted has to be taken over the whole distance over which it moves. He concludes that art cannot overcome nature. This obviously undercuts the second cause for wonder identified in the pseudo-Aristotelian *Mechanical Problems.* This is a nice exemplification of the attitude expressed in Stevin's famous slogan that wonder is no wonder. As we now see, this is not the route taken by Wilkins.

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phenomena were to be realized, they would still be unobservable. At the same time, Wilkins' presentation of the thought experiments depends upon a striking appeal to the reader's visual imagination, as is made clear by the accompanying illustrations (FIGURE 2). Uprooting an oak with only a straw is clearly only a theoretical possibility, as it would take an infinite amount of time, but if it were realized, the dramatic effect of a falling oak would highlight the wonderful spectacle. Notwithstanding this playful presentation, Wilkins stresses that "our senses being very incompetent judges" (p. 115), we should abandon them in favor of mathematical reasoning when dealing with such incredibly slow motions. Only mathematics can show that the effects are "real" (p. 116).[46]

After treating extremely slow motion, Wilkins moves his attention to extremely swift motion. He first discusses real life examples of catapults and ballista, taken from the literature of war engineering.[47] But the very last chapter of the first book returns to the category of abstract, mathematical wonders. Wilkins inquires whether it is possible to make a machine that would move as swiftly as the "supposed motion" of the heavens. Here we have the mechanical art replicating one of the most admirable facts of nature that would have seemed completely beyond the reach of mankind.[48] This is reminiscent of Archimedes' construction of a mechanical model imitating the heavenly motions, which was another reason for his renown in the Renaissance. Indeed, following both Cicero and the famous epigram of Claudianus,[49] many authors used this to comment upon man's ability to imitate or even equal God's act of creation through the mechanical art.[50] But Wilkins is careful enough to state immediately that his "quaere is not to be understood of any reall and experimentall, but only notionall, and Geometrical contrivance" (p. 142). This is the first time that Wilkins comments upon the fact that the feats that are theoretically possible cannot be put into practice (even with infinite time) because of material hindrances. Indeed, he remarks that "a materiall substance is altogether incapable of so great a celerity" (p. 141). The wonder is provoked by an unrealizable thought experiment, but Wilkins again

[46] Mersenne stated that only angels of God can perceive these motions (Mersenne 1644b, p. 16). Wilkins' position would then imply that mathematics allows us to understand what only God or Angels can perceive. We will come back to this in section 5.2.

[47] Wilkins again compares the ancients and the moderns (who have gunpowder), and in this instance concludes that the machines of the ancients were better. Wilkins prefers mechanical inventions over gunpowder and considers them cheaper.

[48] Wilkins was a convinced Copernican, and had already published his *Discovery* in 1638 and *Discourse* in 1640 defending different aspects of the Copernican view. Strictly speaking, the extremely swift motion of the heavens is thus no fact, hence his reference to the "supposed motion", but this need not matter that much for the rhetorical effect that Wilkins wants to achieve. Whether the earth moves or the sphere of the stars, the motion in any case needs to be incredibly swift.

[49] Wilkins quotes Claudianus' epigram in the second book of the *Mathematicall Magick* (pp. 164-5). The epigram reads, in a contemporary translation by Henry Vaughan (1621- 1695): "When Jove a heav'n of small glass did behold, / He smil'd, and to the gods these words he told. / Comes then the power of man's art to this? / In a frail orb my work new acted is, / The poles' decrees, the fate of things, God's laws, / Down by his art old Archimedes draws. / Spirits inclos'd the sev'ral stars attend, / And orderly the living work they bend. / A feigned Zodiac measures out the year, / Ev'ry new month a false moon doth appear. / And now bold industry is proud, it can / Wheel round its world, and rule the stars by man. / Why at Salmoneus' thunder do I stand? / Nature is rivall'd by a single hand." Vaughan (1904, Volume II, p. 238).

[50] Cicero: "For when Archimedes fastened on a globe the movements of moon, sun and five wandering stars, he, just like Plato's God who built the world in the *Timaeus*, made one revolution of the sphere control several movements utterly unlike in slowness and speed. Now if in this world of ours phenomena cannot take place without the act of God, neither could Archimedes have reproduced the same movements upon a globe without divine genius." *Tusculan Disputations*, Book I, Section XXV. Guidobaldo del Monte, e.g., uses Archimedes' planetarium imitating the motion of the heavens as an occasion to state that "God willed that in mechanics [Archimedes] should be a unique ideal which all students of that subject might keep before them as model for imitation." He then goes on by obliquely referring to Claudianus' epigram "So does his hand imitate nature that nature herself is thought to have imitated his hand". (Del Monte 1577, p. 5 of unnumbered preface; tranlation taken from Drake & Drabkin 1969, p. 243).

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goes as far as printing an image of the necessarily imaginary machine (FIGURE 3). Here, Wilkins' machine explicitly becomes a mathematical recreation played out purely in abstracto.

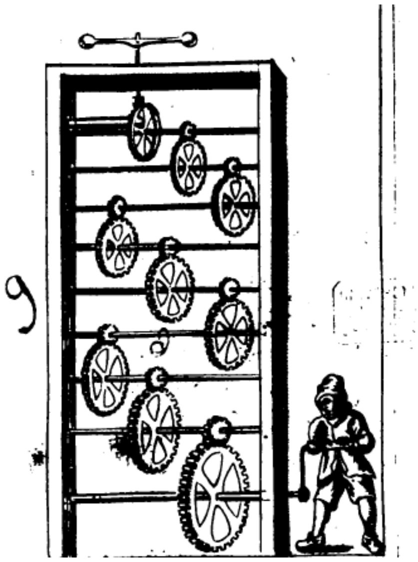

FIGURE 3: Unrealizable machine, "geometrically possible", for creating infinite swiftness. (p.143.)

4. Daedalus: The flight of wonder

4.1 Possibility and subtlety

The second book of the *Mathematicall Magick* is called *Daedalus*, after the mythical inventor of many automata as well as of human flight. The book treats of automata, that is, of machines that move out of themselves, such as a clock, or are moved by an external inanimate agent, such as a watermill powered by a stream.[51] Wilkins explains that automata are the kind of machines that are of most use and pleasure. Automata can be particularly useful: "And it is a wonderfull thing to consider, how much mens labours might be eased and contracted in sundry particulars, if such as were well skilled in the principles and practises of these Mechanicall experiments, would but thoroughly apply their studies unto the inlargement of such inventions." (p. 148) Wilkins decides to focus especially on those machines that are "most eminent for their rarity and subtilty" (pp. 145-6), however. As we will see, these automata are not useful in a direct and down to earth utilitarian sense, like the machines proposed by the members of the contemporary Hartlib circle. Instead, Wilkins' machines seemed to embody a promise of unthought-of of possibilities, profit and wonder. Even more than the first book, Wilkins caters to a public of gentlemanly readers and a court culture of wonder and recreation, but he also tries to inspire inventors and projectors.[52]

This book is structured around a different kind of wonder than the book called *Archimedes*. Wilkins quickly skips over the practical and down to earth automata such as water mills and clocks, and chooses to focus on curiosities, such as a sailing chariot or a submarine. These are paradoxical machines, because they seem to mix contraries: a sailing boat for travel on land instead of on water or

[51] Marr (2004, p. 215) notes that Wilkins is one of the first authors to explicitly make analytical distinctions in different kinds of automata.

[52] For more context and an ingenious analysis of the wonder evoked by automata during the Renaissance, see Marr (2006).

a boat that travels *under* instead of *on* the water seem to defy the order of things. The title of the second book, *Daedalus*, evokes maybe the pinnacle of such a paradoxical machine: the wonder of human flight. Flight was a contemporary symbol for the *impossible*: Icarus is always in mind when Daedalus is evoked. Wilkins himself considered the myth of Daedalus a fiction, claiming that he did not escape by flying away, but rather by inventing the sails for a sailboat (pp. 198-9).[53] Nevertheless, Wilkins thought that it should be possible to conduct successful trials of human flight. An important structuring element of the second book of the *Mathematicall Magick* is exactly such a play with impossibility, possibility and probability, and the progression of machines discussed in *Daedalus* corresponds to an increasing implausibility.[54]

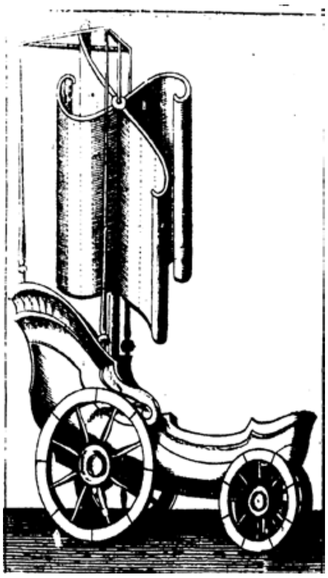

FIGURE 4: Wilkins' improvement of Stevin's sailing chariot "with movable sails" (p. 160).

After having cited some well-attested automata in the first chapter, the second chapter treats of Stevin's sailing chariot (FIGURE 4). Wilkins comments on some contemporary sources that had described it: "these relations did at the first seem unto me, (and perhaps will so to others) somewhat strange & incredible"; but, he continues, he has "heard them frequently attested from the particular eye-sight & experience of such eminent persons" (p. 157). It is immediately clear that the second book will have to follow a different logic than the first one, as Wilkins can no longer fall back on some well-established mathematical framework to directly distinguish the possible from the impossible (a role played in the first book by the law of the lever and the compensation principle respectively). A few chapters after the sailing chariot, Wilkins discusses the submarine, of which he states that the feasibility is "beyond all question, because it hath been already experimented here in England by Cornelius Dreble" (pp. 178-9). Still later chapters treat of flying automata, of human flight, and finally, of diverse kinds of perpetual motions. Not only the structure of the second book as a whole follows a progression towards the more implausible; also at the end of each chapter, Wilkins verges into the more incredible and the fictional. At the end of the submarine chapter, for instance, Wilkins

[53] This claim might seem surprising, given that Wilkins clearly thinks human flight should be feasible. Yet, one recurring message of Wilkins' book is that the moderns would be able to surpass the ancients, if they were only properly spurred into action. By implicating that the ancients did not achieve human flight, this is kept as one of the domains where the moderns can still excel.

[54] For the history of notions of probability, also in relation to Wilkins, see esp. Shapiro (1983, 1991). See also Aït-Touati (2011, p. 56-62) on gradations of probability and credibility in Wilkins' account of flight.

goes into much detail on how whole colonies could live in submarines, and even raise children who would never have seen land or sky.

Still, the machines in the *Mathematicall Magick* are not just fictional devices, functioning only on the page of a book. For Wilkins, the possibility to actually realize these machines is important. In certain passages, he inveighs against speculation and against the limited nature of notional contrivances. He emphasizes experiments, and especially in book 2, he stresses the material realization of machines and the making of concrete and practical trials.[55] This highlights the importance of the real possibility to create machines materially, indicating that the stakes are very different than in the book *Archimedes*. As mentioned, Wilkins' referred to machines that were actually made and demonstrated in his own time, such as Stevin's chariot or Drebbel's submarine, and everyone knew about them. Furthermore, Wilkins himself made some of the machines he described, or he was at least involved in their construction. Wilkins devised a machine to measure distance travelled (p. 163) after an account from Vitruvius, for instance. We know from Nehemiah Grew's *Catalogue and description of the natural and artificial rarities belonging to the Royal Society and preserved at Gresham Colledge* that Wilkins donated such a machine to the Royal Society. The entry refers to it as a "way-wiser", and describes it as "very manageable. It hath five Indexes pointing to so many different Measures, sc. Perches, Furlongs, Miles, Tens of Miles, and Hundreds of Miles; and turn'd about with as many Wheels. Made to Work in a Coach."[56] Other donations of machines and instruments by Wilkins include a hearing aide ("octocoustick") and an anamorphosis ("catoptrick paint"). As we saw in the opening of the paper, when Evelyn visited Wilkins in 1654, he was shown many such instruments, including the way-wiser and maybe the most emblematic instrument from the mathematical magic tradition, the talking head.

Given that Wilkins constructed, tried to construct or initiated experiments on some of the machines he described in the *Mathematicall Magick*, it is clear that the question what could or could not be realized was important to him. It seems that in his book Wilkins was primarily interested in those machines that were located at the borderline between the possible and the impossible. Some machines could in principle be realized, according to him, but there were huge obstacles and difficulties to be overcome. Human flight presented such an exemplary challenge. He distinguished four kinds of human flight: aided by angels or demons, aided by large birds, by attaching wings on the human body, and by constructing a flying chariot.[57] He was especially intrigued by the last way, which, he writes, "seems unto me altogether as probable, and much more usefull then any of the rest." (pp. 209-210). The main obstacles to be overcome for constructing such a flying chariot were its considerable weight and the lack of strength to launch it (see Book 2, chapter 8). Yet, it was clear that enormous birds like condors or rucks can fly, so weight need not be an insurmountable obstacle. Mechanical principles teach us that strength has to be proportionate to weight in order to fly, but mechanics also gives us the tools for increasing strength artificially. Wilkins follows a suggestion of Mersenne (1634a, p. 2) in opting for a machine based on springs (pp. 209-210; p. 221), but the exact design would only be found as a result

[55] There are subtle differences of meaning in Wilkins' text. The term "experiment" is a general category that can be applied to abstract ideas, and is used throughout the *Mathematicall Magick*. In contrast, the term "trial" is used almost exclusively in the second book (*Daedalus*), where it signifies an experiment, actually performed with material machines.
[56] Grew (1685, pp. 360-1).
[57] Wilkins follows up on an earlier discussion that he had added in 1640 to the second edition of his *Discourse*, where he had already discussed the possibility of flight to the moon. There he had primarily focused on the natural philosophical issues suggesting that a body would no longer be heavy once it moved beyond the earth's atmosphere, thus suggesting that it would move very easily and swiftly. etc. But he had already referred to Archytas' wooden dove and Regiomantus' wooden eagle to suggest that there were "good grounds" to believe that also the problem of how to launch the flying machines would not be too difficult a matter (pp. 238-9).

of repeated experiments, in which the artificer "must be carefull to observe the various proportions betwixt the strength of the spring, the heavinesse of the body, the breadth of the wings, the swiftnesse of the motion, &c." (p. 223) There is evidence that Hooke engaged in experiments trying out some of Wilkins' suggestions during his time with Wilkins at Wadham College.[58]

Wilkins is fascinated by such difficult challenges, because the more difficult the challenge, the more wonderful the result, if the difficulty were to be solved. He uses the typical Renaissance term "subtlety" to refer to the difficulties presented by his most wondrous machines. 'Subtilitas' referred to ingenuity, intricacy, smallness and precision, and could have positive as well as negative connotations, from the well-wrought and wonderful to the artificial and excessive.[59] Girolamo Cardano was the most famous author promoting the concept, applying it to all kinds of artifices, including political and mechanical.[60] Wilkins was a diligent student of Cardano's account of machines, and he used subtlety almost exclusively in a similarly positive vein. For him, subtlety signified the difficulties to be overcome with mechanical ingenuity, as well as the results of this ingenuity. It is what makes a machine "excellent", "eminent" and "noble", and it is a continuous source of fascination. Early in the second book, Wilkins gives us some criteria for the "eminence" of automata, and they can reliably be read as markers of subtility in construction (chapter 3, pp. 168-172). Lasting motion is the first criterion. Simplicity of composition is a second criterion, as unnecessary parts show the lack of skill and ignorance of the artificer. Thirdly, a machine that combines a variety of uses is the more wonderful. Finally, the smallness of the machine increases the wonder. Wilkins gives the example of an automatic iron spider, fulfilling most of these criteria, as especially remarkable and the result of "wunderfull art".

4.2 Perpetual subtlety

The first criterion of subtlety clearly points towards perpetual motion as one of the paradigmatic examples of "eminent" automata. Its special character is made clear by Wilkins' lengthy discussion of subterraneous or perpetual lamps, a topic of which he states that although it does not properly belong to mechanical geometry, the "subtilty and curiosity of it" justifies its inclusion (pp. 232-233). The perpetuum mobile is for Wilkins a limiting case, which presents a special kind of difficulty and again a different kind of wonder. It is at the extreme end of the spectrum that evolves from certainty over probability and possibility to impossibility. It is enlightening to look at the progression of chapter titles to assess Wilkins' changing appreciation of the possibility of machines. It is always the most wondrous machines, at the limit of the credible, which are qualified with the label "possible" (i.e. non-realizable but still not to be excluded from the realm of sensible discourse). In particular, he calls "possible" the machine that pulls up an oak with a hair (Book 1, chapter 14) and the machines that make almost infinitely slow or swift motions (Book 1, chapters 16 and 20), i.e. machines that are only possible in a "geometrical" sense. Also the submarine and the flying automata (Book 2, chapters 5 and 6) are "possible" machines because they they do not contradict the principles of mechanics even if they present almost insurmountable difficulties. The perpetuum mobile, however, is a class apart, and

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[58] "I contriv'd and made many trials about the Art of flying and moving very swiftly on the Land and Water, of which I shew'd several Designs to *Mr. Wilkins* then *Warden of Wadham College*, and at the same time made a Module, which, by the help of Springs and Wings, rais'd and sustain'd itself in the Air; but finding by my own trials, and afterwards by calculation, that the muscles of a Mans Body were not sufficient to do any thing considerable of that kind, I apply'd my Mind to contrive a way to make artificial Muscles, divers designs whereof I shew'd also at the same time to Dr. Wilkins, but was in many of my Trials frustrated of my expectations." (Cited in Jardine 2004, p. 112.) Note that not only flying but also moving very swiftly on land and water are mentioned, suggesting that something akin to Stevin's chariot might have also been put to the test.

[59] See e.g. Wolfe (2004, pp. 11-14 and passim).

[60] See e.g. Mclean (1983).

the perpetuum is never explicitly called "possible" by Wilkins.[61] In the title of chapter 14, only a *seeming* probability is announced. This brings an important inversion in the second book, not unlike the reversal we noticed in the first book. With respect to the other automata, Wilkins had tried to argue that their perceived implausibility stood in contrast to their mechanical possibility. Here it is the perceived plausibility that does not square with what appears to be their mechanical impossibility. The perpetual motion deceives by its *seeming* facility, while the difficulty is real (chapter 9). At this point, subtlety for the first time takes on its association with deception, since the problem presents itself as easy while in fact it is insurmountable: "There being no enquiry that does more entice with the probability, and deceive with the subtilty" (p. 226).

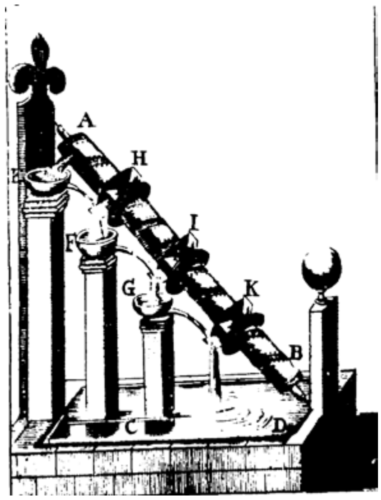

FIGURE 5: Wilkins' illustration of a gravitational perpetual motion machine, in which an Archimedean screw pulls up the water, while the gravity of the falling water continues to move the screw (p. 286).

In a sequence of chapters closing the second book, Wilkins evaluates the probability of some concrete proposals for perpetuum mobiles. He sees three main categories: alchemical, magnetic, and gravitational (pp. 226-7) (FIGURE 5). In all cases he will try to gauge how the "conjectures" fare when "brought to triall", by putting the speculations into practice (p. 225). This is the only safeguard against vain hopes delivered by our imagination: "Any one who hath beene versed in these experiments must needs acknowledge that hee hath been often deceived in his strongest confidence; when the imagination hath contrived the whole frame of such an instrument, and conceives that the event must infallibly answer its hopes; yet then, does it strangely deceive in the proof, and discovers to us some defect, which we did not before take notice of." (p. 225) With respect to many alchemical proposals, putting them to the test immediately poses a problem, as their descriptions are too obscure (p. 228). Nevertheless, Wilkins tries to gauge two specific proposals in a bit more detail. Of the first (taken from the *Recreations Mathématiques*) he states: "I cannot say anything from experience against this; but me thinks it does not seem very probable" (p. 228), adducing some general considerations suggesting that very violent processes cannot be expected to be perpetual. Of the second (ascribed to Cornelius Drebble) he states: "What strange things may be done by such extractions, I know not, and therefore dare not condemn this relation as impossible; but me thinks it sounds rather like a chymicall dream then a Philosophicall truth." (p. 230) In both cases his skepticism is hardly veiled, but the care with which he avoids calling it "impossible" is also notable.

[61] This is in contrast to Sawday (2007, p. 120), who claims that Wilkins believed a perpetual motion might be achieved.

On balance, the magnetic perpetuum mobile seems to be the most promising case according to Wilkins. He does not mention any trials, but notes some theoretical problems with the conception of what he sees as the "most likely invention" (p. 258). He concludes by stating that "though these kind of [magnetic] qualities seem most conducible unto [perpetual motion], and perhaps hereafter it may be contrived from them" (pp. 262-3). The gravitational proposals present maybe the most interesting cases, because they most clearly illustrate the imaginative appeal that such contrivances can have. Indeed, Wilkins states that he himself did "conclude them to be infallible" "til experience had discovered their defect and insufficiency" (pp. 264-5). Wilkins interprets all these experiences and explains why the particular proposals cannot work, because in each case the necessary disequilibrium cannot be maintained indefinitely. It is only after having discussed a number of particular gravitational devices in considerable detail that Wilkins reveals in the very last pages of his book that there is a more general reason why none of the proposed devices could ever work. The principle that suddenly puts a limit on what can be achieved with a mechanical machine is the very same one that already played a very similar role in the first book. Indeed, the compensation principle can be seen to express the idea that the centre of gravity of a connected system cannot rise out of itself.[62] The passage in which Wilkins introduces this shift in perspective deserves to be quoted in full:

> I would be loath to discourage the enquiry of any ingenious artificer, by denying the possibility of effecting [a perpetuum mobile] with any of these Mechanicall helps; But yet (I conceive) if those principles which concern the slownesse of the power in comparison to the greatnesse of the weight, were rightly understood, and throughly considered, they would make this experiment to seem (if not altogether impossible, yet) much more difficult then otherwise perhaps it will appear. However, the inquiring after it, cannot but deserve our endeavours, as being one of the most noble amongst al these Mechanical subtilities. And (…) though we doe not attaine to the effecting of this particular, yet our searching after it may discover so many other excellent subtilities, as shall abundantly recompense the labour of our enquiry. (pp. 292-3)

Notice again the careful wording in which Wilkins simultaneously makes clear that there are scant hopes of success, but stays clear of explicitly calling the hoped for contrivances impossible. It is also clear that he sees the possible gains of the search for a perpetual motion to consist not so much in the attaining of it, but in the general stimulation of mechanical curiosity in aspiring virtuosi. It is not without reason that he had introduced the perpetuum mobile as a chaste whore, a *Casta metetrix*, "because it allures many, but admits none" (p. 226). In the introductory chapters of the first book, he had quoted Eustathius on a possible etymology for the word "Mechanick", as deriving from "παρά μή χαίνειν (saith Eustathius) *quia hiscere non sinit*, because these arts are so full of pleasant variety, that they admit not either of sloth or wearinesse" (p. 8). The search for the perpetuum mobile is itself perpetual and impossible to realize. The perpetuum mobile thus stands as a symbol for the defining characteristic of mechanics as Wilkins understands it.

In the first book Wilkins had introduced the compensation principle as a consequence of the limits imposed on created beings by the "wisdome of providence". It now turns out that it is this same principle that makes the finding of a perpetual motion "much more difficult then otherwise perhaps it will appear". But as he goes on to state in the very last words of his book, this is only just: "The justice of providence having so contrived it, that the pleasure which there is in the successe of such inventions, should be proportioned to the great difficulty and labour of their inquiry" (pp. 294-5). The

[62] The latter idea is generally known as Torricelli's principle. Torricelli did formulate it as a generalization of the compensation principle as given in Galileo's *Mecaniche.*

reward for the actual construction of a perpetuum mobile would thus be an infinite pleasure, as it would imply the final overcoming of our status as fallen beings.[63] But since this search will never be completed, there is never a time for sloth or weariness of any kind.

5. Mechanical Wonders in a Providential Cosmos

5.1 Archimedean and Daedalean wonders in the *Mathematicall Magick*

The overall structure of Wilkins' *Mathematicall Magick* has been carefully crafted to gradually instill different kinds of wonder in his readers. We began by recalling pseudo-Aristotle's twofold delineation of wonder in the opening passage of the *Mechanical Problems*, which for many writers in the early modern period provided the language in which to reflect on the relation between mechanics and the presence or absence of wonder. The first kind of Aristotelian wonder is wonder caused by ignorance, a kind of wonder Aristotle himself also referred to in the Metaphysics.[64] Wilkins usually referred to this kind of wonder as “strangeness”, and even if Wilkins does not discuss this Aristotelian or Pseudo-Aristotelian wonder, we can find references to strangeness interspersed abundantly throughout the text.[65] Explicit references to the second kind of Pseudo-Aristotelian wonder, of art overcoming nature, are also relatively sparse in the *Mathematicall Magick*, although the prominent mention of Antiphon’s statement (“We by art gain mastery over things in which we are conquered by nature”) on the title page suggests that the whole book can be placed under its aegis. Indeed, on a first level the *Mathematicall Magick* can be read as one long panegyric on art’s almost unlimited possibilities. The structure of both the first and the second book is characterized by a progression towards more and more extreme effects: in the first book this is epitomized by Archimedes’ claim to be able to move the whole world, in the second book by the Daedalean ambition of human flight. Both the figures of Archimedes and Daedalus are striking emblems of human inventiveness and skillfulness.

We already pointed out how Archimedes was given an almost divine status and was upheld as an example of man’s ability to imitate or even equal God’s act of creation through the mechanical art. Wilkins introduces the figure of Daedalus with a similar end in mind. In Greek *Daidalos* (δαίδαλος) means “cunning worker”, and *daidala* referred to (among other things) finely crafted objects (Morris 1992, pp. 3-35). Accordingly, the automata that are the topic of Wilkins’ second book all testify to the artificer’s imaginative and dexterous skill that is responsible for their wonderful subtlety. If we have a closer look at some of the criteria that Wilkins introduced to measure this skill, it becomes clear that the most skillfull artificer must be God himself. The creation of perpetual motion was often seen as the

[63] In the very first chapter of the first book, Wilkins had already explicitly stated that the “artificiall experiments” of mechanics were “(as it were) but so many Essays, whereby men doe naturally attempt to restore themselves from the first generall curse inflicted upon their labours” (p. 2).

[64] For Aristotle (*Metaphysics*, A.2), wonder caused by ignorance initiated inquiry and eventually makes place for science and wisdom. He writes "a man who is puzzled and wonders thinks himself ignorant (…) they philosophized order to escape from ignorance (…). For all men begin, as we said, by wondering that things are as they are, as they do about self-moving marionettes, or about the solstices or the incommensurability of the diagonal of a square with the side; for it seems wonderful to all who have not yet seen the reason, that there is a thing which cannot be measured even by the smallest unit. But we must end in the contrary [science or wisdom] and, according to the proverb, the better state, as is the case in these instances too when men learn the cause; for there is nothing which would surprise a geometer so much as if the diagonal turned out to be commensurable."

[65] Whereas ‘wonder’ and ‘wonderful’ taken together occur 15 times in the text, ‘strange’ and ‘strangeness’ have 27 occurrences.

prerogative of a divine being,[66] as is also seen by Wilkins' implicit association of the attainment of a perpetual motion with the overcoming of our status as fallen beings. Similarly, variety, the third criterion of subtlety in construction, plays a crucial role in the picture painted of God's Providence in Wilkins' *A Discourse on the Beauty of Providence*, which was published in 1649, one year after the *Mathematicall Magick*. Commenting on the inscrutable ways of Providence, which manages to put "the *worst* action of man to the *best* advantage of man", Wilkins states: "Such depths of policy, which all the subtiltie of men or Angels, was not able to *contrive*, no nor to suspect, πολυποίκιλτοςφία, as the Apostle calls it, Ephes. 3. 10. *Interchangeable wisdom*, of *curious variety*, as the word signifies." (*Discourse*, p. 57, emphases in original.) There is no doubt that the cosmos is an infinitely subtle contrivance, and that mechanics is a properly divine art.[67] As the opening chapter of the *Mathematicall Magick* had already explained: "Curious variety" is the "natural end" of mathematics when it is put into "mechanicall practice" (p. 7).[68]

In the fifth chapter of the first book of the *Mathematicall Magick*, Wilkins comments on the classical topos of the hand as the "instrument of instruments", which Galen himself had already linked with reason, as the "art of arts".[69] Wilkins states that "as the soul of man doth bear in it the image of the divine wisdome and providence, so this part of the body [the hand] seems in some sort to represent the omnipotency of God, whilest it is able to perform such various and wonderfull effects by the help of this art [mechanics]." (p. 30) This throws further light on the division of the *Mathematicall Magick* in its two books: Archimedes and Daedalus can be understood to exemplify complementary aspects of man's likeness to God, respectively reason and skill.[70] As we pointed out, the Archimedean wonders of the first book have become explicitly mathematical in nature – they are purely "notionall", wonders of the mind – whereas the Daedalean wonders of the second book, due to dexterous skill, should be materially realizable for them to be counted as truly wonderful.[71]

5.2 Senecan and Plinian wonder in a providential cosmos

As reflected in the structural reversals characterizing both books, the *Mathematicall Magick* is also a treatise on the *limits* inherent to human art. There is still an infinite distance separating human art from properly divine art. The mathematical proportions that allow for an infinite power simultaneously impose limits on what can be truly achieved. As we have seen, Wilkins transforms these limits, usually perceived as a restraint on wonder, into a striking new cause of wonder, giving the first book its distinctive character. After all, the presence of these limits implies that the potentially infinite

[66] See e.g. De Caus who is explicit about the fact that a truly perpetual motion can impossibly be created by mortal men (De Caus 1615, p. 18).

[67] Wilkins states as much in the opening of his "To the Reader" that opens the *Mathematicall Magick*, where he states that "a divine power and wisdome might be discerned even in those common arts", such as mechanics.

[68] Smallness (the third criterion of subtlety) also plays a role in describing the "eminence" of Providence's contrivances: "they that have experimented the use of Microscopes, can tell, how in the parts of the most minute creatures, there may be discerned such gildings and embroideries, and such curious varietie as another would scarce believe. Why 'tis so in the works of Providence, there are very many passages of frequent daily occurrence, whose excellent contrivance doth not fall under our sense or observation." (pp. 60-1)

[69] Galen (1968, p. 71).

[70] This should not be seen as an exclusive disjunction. The figures of Archimedes and Daedalus are traditionally associated with both aspects (e.g., as quoted in footnote 50, Guidobaldo del Monte explicitly referred to Archimedes' semi-divine "hand"); for the changing image of Archimedes in the period, see Laird (1991), and Wolfe (2004, pp. 50-54).

[71] It is striking that *reason* was not explicitly referred to as an absolute limiting factor for the perpetual motion machines. They are described in book *Daedalus*, however, where not reason but experience is emphasized. Nevertheless, when experience shows that a perpetuum was fallacious, Wilkins also gives reasons and calculations (p. 271).

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multiplication of power is doubled by another infinity of slowness: "so that besides the wonder which there is in the force of these Mechanical motions, the extream slownesse of them is no lesse admirable." (p. 114). This second kind of wonder is in its turn doubly connected with our position in a providential cosmos. On the one hand, according to Wilkins, these limits reflect our position as created beings dependent of a transcendent and providential order. On the other hand, the latter insight in itself is cause for wonder. Remember how the infinite multiplication of power is only possible in an infinite time: even if Archimedes could have found a fixed place outside our world, the resulting motion would have been insensible; or as Mersenne commented: only an Angel or God could perceive the resulting motion (Mersenne 1644b, p. 16). Wilkins, however, goes at lengths to stress that mathematical reasoning also allows *us* to understand the reality of this effect. This helps better identify the precise sense of the wonder involved in the infinitely slow motions: our mathematical science allows us to 'perceive' exactly the infinity separating us from what would be a properly divine vision.

It is in this context that Wilkins stressed that we should not put undue trust in our senses as they are "very incompetent judges" (p. 115); or as he goes on, they are "extreamly disproportioned for comprehending the whole compasse and latitude of things" (p. 116). Yet, as we now have seen, the science of mechanics simultaneously teaches that we are not doomed to remain completely dependent on them. Wilkins comments that this same fact is also testified by the microscope, which shows that "there may be some *organicall* bodies, as much less then ours, as the earth is bigger" (p. 115). The relativity of man's position in a providential cosmos was also one of the running themes of Wilkins' contemporaneous *A Discourse Concerning the Beauty of Providence* (1649). In that context Wilkins again referred to microscopic observations as a striking illustration thereof.[72] He makes clear that it follows that we should not presume to be in a position to judge God's plans: "If there be a commonwealth amongst Ants and Bees (as some Naturalists say there is) 't would make a man smile to think, that they should take upon them the censure of State matters amongst us men: and yet here the disproportion is finite, whereas betwixt God and man 'tis infinite." (*Discourse*, pp. 94-5) This is a hardly veiled reference to Seneca's *Naturales Questiones*, where the rhetorical question was already asked: "What difference is there between us and the ants except the insignificant size of a tiny body?" (Seneca, *Nat. Qu.* I, Pref. 10).[73] Seneca was approvingly quoted at the end of Wilkins' sermon as one the Stoicks that have "many excellent passages" for moral edification (*Discourse*, p. 129), and a quote from Seneca's *Naturales Quaestiones* has already served as the motto to Wilkins' *A Discourse Concerning a New Planet* (1640).[74] Indeed both Wilkins' general discussion of Copernican astronomy and his imaginative account of possible travel to the moon can be placed in a wider Senecan context, in which the search for astronomical knowledge is intrinsically linked with the moral effects of the accompanying shift in perspective that for the first time allows us to properly appreciate the providential ordering in the cosmos and our position in it.[75]

[72] Cf. the quote in footnote 51.
[73] In the translation of T.H. Corcoran in Seneca (1971, p. 9).
[74] "Quid tibi inquis ista proderunt? Si nihil aliud, hoc certè, sciam omnia hic angusta esse." The original reads in English: "You say: 'What good will these things do you?' If nothing else, certainly this: having measured God I will know that all else is petty." (Seneca, *Nat. Qu.* I, Pref. 16, 1971, pp. 14-5). Wilkins left out the reference to measuring God, which is rather problematic from a Christian point of view.
[75] In the second book of the *Mathematicall Magick*, there is a passage with striking affinities to the *Discourse concerning a New World*. In the latter, he narrates how the earth looks like, when seen from the moon; in the former, he imagines that children are born in submarines and live there in colonies without ever having set foot ashore. "Severall Colonies may thus inhabit, having their children born and bred up without the knowledge of land, who could not chuse but be amazed with strange conceits upon the discovery of this upper world." This presents a similar change of perspective that can lie at the basis of wonder, amazement and admiration. Kaoukji

When we depend too much on our untutored senses, we restrict ourselves to our contingent perspective on creation, and are in constant danger of using the former as the measure for the latter. The wonder evoked by the thought experiments of the first book of the *Mathematicall Magick* can be called Senecan wonder as it can be understood as a further exercise in the overcoming of that limited perspective. There are many things that may look ‘strange’ to us, but we can come understand that they are nevertheless as much part of the creation as familiar things are. The mathematical science of mechanics allows us to explore and imaginatively transcend our position in the cosmos, not unlike the role played by astronomy in Wilkins' *Discourse Concerning a New Planet.*

This Senecan wonder has to be carefully distinguished from the first-order wonder that arises when we are merely confronted with strange or uncommon events, i.e. events that we do not understand. As Wilkins states in his *Discourse Concerning the Beauty of Providence*, in such cases we should not “marvell”, and “Be not transported with wonder or impatience, or unbelief, as if the Providence of God were regardlesse or negligent” (*Discourse*, Preface to the Reader). It is exactly this uneducated sense of wonder, which is “not so much in the things themselves, as in our mistake of them” (*Dicourse*, p. 81) that needs to be placed in a larger perspective. For Wilkins, one should go beyond this kind of wonder, to arrive at a position in which we can only properly admire the order of the divine plan; a position in which one realizes “that in all these obscure administrations, (which seem unto us so full of casuall, negligent, promiscuous events) there is an admirable, (though unsearchable) contrivance” (*Discourse*, Preface to the reader). It is not insignificant to note Wilkins’ terminology here. The world is conceived of as a large contrivance or machine, which we only partially understand and which remains unsearchable, but which produces all kinds of incredible events. Not just common wonder but true admiration is the proper response to this machine, which is the blueprint of divine providence. Also in referring to the infinite slowness of motions, which is the consequence of the compensation principle, Wilkins by exception uses the term “admirable”, which indeed means that this principle is inscribed in God’s plan.[76]

The many paradoxical contrivances discussed in the second book of the *Mathematicall Magick* play a similar role, but in a different way. Using a traditional juxtaposition, we can say that Wilkins explores here a Plinian rather than a Senecan wonder.[77] A focus on the extraordinary as well as an interest in the physicality of things is typical of Plinian wonder, which promotes what has been called a “terrestrial curiosity”.[78] This is in contrast to a Senecan attention to rational consideration and contemplation, the study of the heavens, and the wonder provoked by the *logos* of nature. Wilkins’ extraordinary machines in *Daedalus* are somewhat akin to the Plinian monsters and curiosities, which also seem to defy the order of things, and are similarly located at the precarious borderline between reality and fiction, between the possible and the impossible. Wilkins method of trying out the machines also forces him to focus on the physical world, even in its more mundane aspects. (Indeed, one of the questions he tries to answer is how to get food into a submarine, and how to dispose of excrements.) Furthermore, the variety of nature is an important cause of Plinian wonder. This corresponds to Wilkins’ arts “so full of pleasant variety”, and the open-endedness of his research project, which encourages ever new extraordinary inventions. For both Wilkins and Pliny, looking at

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& Jardine (2010) and Aït-Touati (2005, 2010, 2011) comment on further aspects involved in Wilkins’ and Francis Godwin's metaphorical ascent to the moon.

[76] This is one of the very few occurrences of “admirable” in the *Mathematicall Magick*, besides one reference to “admirable skill” (p. 119) and one to “the most famous and admirable” war machines built by Archimedes (p. 120).

[77] For more context on Pliny and wonder (also in opposition to Seneca), see e.g. Labhardt 1960, Beagon 2011, Jalobeanu 2012. Whereas Seneca figures prominently in Wilkins’ own texts, Pliny is only mentioned in passing.

[78] See Beagon (2011, p. 75), who speaks of “sub-lunar curiositas”.

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the minutiae of the actual world, and being engaged with it actively, as well as trying to overcome many practical and material limits - activities admitting of neither “sloth or wearinesse” - allows a variety of new wonders to come up, which encourages further research.[79]

Similarly to Senecan wonder, which Wilkins explored in book one of the *Mathematicall Magick*, this Plinian wonder, evoked by material objects explored in book two, has the effect of shifting our limited perspective. The seemingly possible becomes impossible and the seemingly impossible possible. This comes out most clearly in a passage where Wilkins discusses some of the objections that have been leveled against the possibility of human flight. Here he reacts against the fact that such “strange inventions” are “so generally derided by common opinion, being esteemed only as the dreams of a melancholy & distempered fancy”. He cites the learned example of the church father Eusebius: “Eusebius speaking with what necessity every things is confined by the laws of nature, and the decrees of providence, so that nothing can goe out of that way, unto which naturally it is designed; as a fish cannot reside on the land, nor man in the water, or aloft in the air, …” (p. 197). Wilkins explains that this is a prejudice, as if we would be in a position to judge what would “transgresse the bounds of nature” (ibid.). To put it differently, this prejudice assumes illegitimately that the decrees of providence would be transparent to us. But as Wilkins' *Discourse* makes clear, providence does not operate in that way. What at first sight comes across as bad or evil to us, can actually be something good. This is true for natural events as well as for artificial inventions, such as human flight. This kind of unexpected crossings of what we think are natural boundaries was indeed already the subject of Pliny’s *Historia Naturalis*. Many things that seem to transgress the bounds of nature are possible and good, and they happen in accordance to God's hidden providential order. Indeed, Pliny's statement “How many things are judged impossible before they actually occur?” (Pliny, *Historia Naturales* 7.6) could have served as a fine motto to the second book of the *Mathematicall Magick*.

5.3 Wonder, art, and nature

By now we are in a better position to understand why Wilkins would be relatively silent on the pseudo-Aristotelian circumscription of wonder. Most importantly, the latter starts from a stable and relatively transparent notion of the nature of things, against which deviations can then be measured. The wonder that interests Wilkins is one that destabilizes such an idea. Despite their differences, both Senecan and Plinian wonder make us realize that our everyday experience of the world is very limited, and should not be taken to offer ready access to what really lies in the nature of things as created by a provident God. At the same time, art does provide a privileged starting point for an inquiry into this withdrawn nature. After all, we are created in the likeness of God, who is explicitly depicted as an infinitely skillful artisan. Surely, as with any subtle artisan, the outward operations with which we are confronted in ordinary experience do not immediately reflect the contrivance actually underlying them.

The *Mathematicall Magick* seems to have been written to foster an attitude towards mechanical wonders, and by extension towards ‘strange’ operations in general, that allows one to overcome pernicious prejudices concerning our place in the world. But this overcoming is not supposed to result in a "Stoic" disengaged position. On the contrary, Senecan and Plinian wonder spur us on to ever

[79] One of the Plinian wonders (from the *Natural History*) that Wilkins actually constructed, together with Wren, was a beehive with glass panels, which allowed observation of the bees. (It is rather fitting that while Pliny doesn’t play a prominent role in Wilkins’ texts, he did provide a model for one of his material constructions.) For Hartlib, this beehive also signified a model of pious industry and good husbandry. See Hartlib, *The reformed common-wealth of bees*, esp. the letter by Wren p. 50-52. When Evelyn visited Wilkins in 1654, he was given one such beehive that had impressed him a lot.

further explorations. Firstly, "if all the events of Providence be so wisely contrived, 't is certainly then our duty to consider and to take notice of them" (*Discourse*, p. 72).[80] Secondly, since this contrivance at the same time is "unsearchable", we should not expect to actually achieve the point of having unraveled it, the distance between us and God always remaining infinite. This is the lesson expressed by Wilkins in the final passages of the *Mathematicall Magick*, where he discusses perpetual motion machines.

The open-ended character of our investigations into nature shows that what is most important is the process of exploration itself. At the same time, it is anchored in the secure knowledge that our world at its base is a true "kosmos", that is, a "beautiful World" (*Discourse,* p. 105). In the *Mathematicall Magick* the double movement pivots around the compensation principle between speed and weight. As a constraint imposed upon us by God, it symbolizes our fallen nature, which in turn implies that progress depends on continued work and inquiry. The Antiphon quote on the title page, "We by art gain mastery over things in which we are conquered by nature", must thus be read in a thoroughly Christianized context, where "conquered by nature" can also signify "conquered by our own nature". By actually exposing the limits under which we must labor, it also points towards the fact that we can indeed gain deeper insight in our position in the world, and God's providential plan.[81]

6. Conclusion

At first, John Wilkins' *Mathematicall Magick* seems like a chaotic *Wunderkammer* or a set of *récréations mathématiques*, full of artificial wonders meant to stun his readers. In fact, there is a structure behind the progression of the two books, *Archimedes* and *Daedalus*, which make up the *Mathematicall Magick*. The order of the book can partly be explained by Wilkins' personal itinerary. The first chapters of *Archimedes* corresponds most closely to the interests that he would have fostered at university, where he was a student and tutor between 1627 and 1637, while the marvels described in the *Daedalus* better fit the court culture he was part of, just before the publication of the book in 1648. Later, at Wadham College, he would be actually involved, together with his associates, in building machines and in creating the artificial *Wunderkammer* visited by Evelyn.

The title of Wilkins' book, "Mathematical magic", refers to the wonders that can be generated by means of theoretical and practical mathematics. Wonder has many functions for Wilkins, however, and we can read the book as ordered around these different kinds of wonder. The context of the book is the long textual tradition on machines and automata that started with the pseudo-Aristotelian *Mechanical Problems*. In this work, two kinds of "Aristotelian wonder" are stressed: the wonder experienced by the ignorant in the face of phenomena they don't understand; and the wonder of machines that are able to overcome nature. These 'Aristotelian wonders' are present in Wilkins' work

[80] In one striking passage in the *Discourse*, Wilkins even invites his readers to consider engaging in "experimental divinitie": "If a man were but well read in the story and various passages of his life, he might be able to make an experimentall divinitie of his own. He that is observant of Gods former dealings and dispensations towards him, may be thence furnished with a rich treasury of experience against all future conditions." (pp. 60-61)

[81] Hans Aarsleff already pointed out the importance of Wilkins' concern with the curses inflicted upon man as a result of the fall, as it provides a unifying theme to his treatment of language in the *Mercury* and labor in the *Mathematicall Magick* (Aarsleff 1976, p. 365).

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(see for instance his title page), but in contrast to his contemporaries, he does not pay much attention to it.

In the *Mathematicall Magick*, Wilkins takes this reversal of nature by artifice to its extreme, hence creating other kinds of wonder. As a result, he presents many unrealizable machines. In *Archimedes*, he explores the limits of the mechanical principles, taking them nearly to infinity. This is part of an abstract intellectual game, which would deliver infinite powers of speeds. These machines produce a distinct kind of wonder, which can aptly be called 'Archimedean wonder'. In *Daedalus*, Wilkins explores paradoxical machines that seem impossible to realize, such as *Daedalean* machines which allow humans to fly. Nevertheless, the focus here is on the possibility, plausibility and impossibility of material realization. Such machines, which presuppose incredible skills for overcoming countless subtle problems, provoke a 'Daedalean wonder'. Both Archimedean and Daedalean machines overcome the ordinary course of nature, but in different ways. Importantly, we react with wonder to such machines, not because we are ignorant of its causes, but because its conception or realization by far exceeds our expectations of what could be humanly achievable.[82]

Wilkins knows that many impossible machines can be dreamt up by an unbounded imagination. Yet the wonder these machines generate is at the very most the result of a surprise, of a pleasing fiction (p. 109, 195-6, 225). In contrast, the possibility and impossibility of Wilkins' machines are grounded in reason or experience, which pose limits on the imagination. On the one hand, Archimedean wonder is based on reason, on the principles of mechanics. This wonder is provoked by abstract machines: mathematical constructions which often cannot be realized in practice, and even if they would be realized, their effects would often be imperceptible. Nevertheless, mathematics shows the (relative) 'possibility' of these machines and can show that these effects are real even if they are imperceptible. On the other hand, Daedalean wonder is caused by the skill, experience and subtlety of the inventor or technician. This wonder is the result of the concrete trials of practical mathematics.[83] Even if the inventive imagination should be controlled by reason and experience, it should not be stymied, as is clear from Wilkins' discussion of perpetuum mobiles. Invention should not be dismissed as "dreams of a melancholy & distempered fancy" (p. 197). The imagination of the ingenious needs to be nurtured, and what could be a better incentive than the pursuit of impossible instruments such as perpetual motions, which will keep the generation of new inventions going.

Wilkins' near-impossible technologies also have a religious function. Wilkins after all was a clergyman, and there are interesting parallels between his scientific, technical and religious writings. Wilkins did not aim to build "religious machines", of course, but his writings on machines could also be legitimized by their relevance for religious practice and experience, especially in terms of the wonder, admiration and reflection they evoked. We have argued that book one of the *Mathematicall Magick*, evokes a 'Senecan wonder', which allows the reader to see the deeper laws of nature, for instance in the compensation principle. This principle sets limits on our ambitions, and highlights that man remains a fallen creature, notwithstanding his creative and inventive capacities. These limits are good, however, and part of God's providential plan. Crucially, by means of mathematics, we can understand this and marvel at it. Book two is characterized by a 'Plinean wonder', for the variety of marvelous artifices and the possibility to upend the normal boundaries of nature. These machines are like the monsters in a cabinet of natural history, and they stress that we do not know the deep workings

[82] What sets apart this Archimedean and Daedalean wonder from the second kind of Aristotelian wonder is the passage to the limit of human achievement.

[83] The distinction between Archimedean and Daedalean wonder corresponds to the contrast Wilkins draws between "rational" and "chirurgical" mechanics, between the abstract understanding of mechanical principles and the practicalities of constructing machines (cf. *Mathematicall Magick*, p. 9).

of providence. Some machines seem impossible, but are possible to construct in practice. Other machines seem possible, but are impossible to realize. Our ignorance in this respect can only be overcome by experience and practical action. In both cases, an important religious function of these (seemingly) impossible machines is the undermining of our prejudices about art and nature, about providence and the creation.

This article presents a detailed study of a neglected work by the early modern English virtuoso John Wilkins, but it has also broader relevance. It presents a case-study in the intertwinement of early modern magic, machines and curiosities, and in the changing conceptions of art and nature. It also inquires into the little studied relation between technology and religion. The most direct result is the development of a typology of wonder, however. Despite the sustained attention on wonder in the recent historiography of philosophy and the sciences, 'wonder' is too often treated as a monolithic category that presents the same problems in different contexts. In this paper, we have shown that it is important to distinguish between six kinds of wonder in order to come to grips with one early modern treatise. This typology of wonder could be the first step in a more refined understanding of the diverse registers of early modern wonder, which in its turn can shed light on many central aspects of early modern culture.

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