GALILEO'S ABANDONED PROJECT ON ACOUSTIC INSTRUMENTS AT THE MEDICI COURT

Matteo Valleriani
Max Planck Institute for the History of Science

Galileo's old friend, the painter and mathematician Ludovico Cardi da Cigoli, wrote from Rome on 24 February 1613 about a rumour that was circulating: someone in Padua had invented an instrument able to "greatly multiply the sense of hearing".[1] Da Cigoli asked Galileo for more details. A full five months earlier Galileo's former pupil Daniello Antonini had informed Galileo that Paolo Aproino, another former pupil, had produced something "miraculous" in Treviso near Venice.[2] These two events mark the period, 1612–13, when new developments were taking place in the field of acoustics. With epistolary guidance from Galileo, Paolo Aproino was constructing an ear trumpet.

Ear trumpets did not first appear at the beginning of the seventeenth century. If the ear trumpet is seen as an enlargement of the ear auricle to improve hearing, then this instrument is as old as the practice of cupping a hand to the ear, or of using perforated seashells with various pipes to extend their range. Thus, to find out why Galileo and Aproino's ear trumpet was considered to be such a novel and even miraculous device is quite a challenge. If the entire seventeenth century is considered, then an investigation becomes even more intriguing, for this period embraces a wealth of inventors of the ear trumpet.

At the beginning of the seventeenth century, the ear trumpet was considered to be a product of human art in the Aristotelian sense and thus treated as either the completion of what nature had left unfinished — for instance, a relatively deaf human ear — or as the result of a construction process guided by the principle of imitation of nature.[3] By the end of the century, however, the ear trumpet had come to be seen as a mechanical instrument. Its creators ceased to investigate it from the perspective of natural philosophy or to associate it with any natural product.[4] The emergence of a new interpretation of the acoustic instrument is immediately connected with the seventeenth-century conflict between two different conceptions of sound: the Aristotelian, based on the concept of sensible quality and violent motion, and the mechanical, based on the analogy between optics and acoustics.

Galileo and Aproino's project in acoustics is directly connected to this conflict. Although the project was a success from a technological point of view — Aproino devised a very efficient ear trumpet — they decided to abandon it. To understand why this happened, a brief survey of the history of the ear trumpet will be given in the following. This will show how investigators shifted the instrument from the realm of traditional natural philosophy into the framework of modern mechanics, with the explicit intent to disregard any investigations concerned with the nature of sound and, especially, to focus only on the technical efficiency of the instrument. Parallel to this process of reconfiguration of the acoustic instrument, it will be shown how the Aristotelian conception of sound came to be renounced in favour of a new mechanical interpretation. Finally, Galileo and Aproino's project will be analysed in the context of the dominant conception of sound in the early seventeenth century. And to understand why in the end Galileo and Aproino abandoned the project, the institutional role of the court in scientific practice will be considered. The paper closes with the question of why so many seventeenth-century figures considered themselves to be the first to invent the ear trumpet. This analysis contributes to the understanding of the concept of novelty applied to early modern technology.

Translations of the relevant sources are appended at the end of the paper.

IMITATION OF NATURE[5]

No doubt, ear trumpets have been in use since time immemorial.[6] According to Harald Feldmann,[7] Archigenes the famous Roman doctor suggested to Emperor Trajanus, who was hard of hearing, that he use a *tuba* placed close to the ear. Moreover, funnel-shaped objects of bronze with spiral tubes at the narrow end, found close to Pompeii, are thought to have been ear trumpets.[8]

However, the relevant context for Galileo and Aproino's work begins at the end of the sixteenth century, specifically in Giovan Battista della Porta's pre-modern perspective on the ear trumpet.

In 1589 della Porta published *Magiae naturalis*.[9] The fifth chapter of the twentieth and final volume, dedicated to miscellaneous subjects, deals with the ear trumpet and della Porta's aim to determine its most efficient shape and design.[10] With the title *Quomodo instrumentum fieri possit, quo longe audiamus*, della Porta first stated that this kind of instrument shows some analogy to the telescope.[11] He goes on to suggest that the most appropriate shape could be found by imitating nature; first conches and then the hearing systems of various animals are taken into consideration but, in the end, it is the hearing system of the hare that prevails. The ultimate shape is circular and wide with two turns of the cochlea, arranged in such a way as to avoid sound entering linearly into the ear because only when it enters the path of the circumference of the cochlea can it be perceived as "multiplied, as in the case of an echo".[12]

Clearly, della Porta conceptualized the instrument as an imitation of nature, explain-ing its functioning in relation to how nature deals with sound. Della Porta was thus satisfied with a phenomenological description: sound is perceived to be "multiplied" in the ear as it must do in the hare's ear.

In the history of acoustic devices, and especially of ear trumpets, della Porta's contribution is considered, if at all, a mere curiosity. Generally the history begins with Jean Leurechon's 1624 publication, the *Récréation mathématique*,[13] thus completely ignoring what took place between della Porta's and Leurechon's publications, namely Galileo and Aproino's project.The *Mathematical recreations* is a collection of 'problems'[14] related and updated to the modern results of all fields of the scientific research of the time. Problem 59

— *How to make an instrument to help hearing, as* Galileus *made to help the sight?* — is concerned with the ear trumpet and, once again, with the determination of its most efficient design:

... its well knowne that long trunks or pipes make one heare well farre off ...: And it is a generall principle, that pipes do greatly help to strengthen the activities of naturall causes: we see that fire contracted in a pipe, burnes 4 or 5 foot high ...: the rupture or violence of water issuing out of a fontaine, shewes us that water being contracted into a pipe, causeth a violence in its passage. The glasses of *Galileus* makes us see how usefull pipes or trunkes are to make the light and species more visible.... It is said that a Prince of *Italy* hath a faire hall, in which he can with facility heare distinctly the discourses of those which walk in the adjacent Gardens, which is by certain vessels and pipes that answer from the Garden to the Hall ...: and in these times amongst many noble personages, the new kinde of trunkes are used to help the hearing, being made of silver, copper, or other resounding materiall; in funnell-wise putting the widest end to him which speaketh, to the end to contract the voice, that so by the pipe applied to the eare it may be more uniform and lesse in danger to dissipate the voice, and so consequently more fortified.[15]

Leurechon's text clearly considers the ear trumpet as a modern instrument, though it also makes clear that by the beginning of the seventeenth century it was already widely diffused. Leurechon described the instrument as being able to strengthen the natural causes, as a sort of completion of what nature usually does. Among the examples given, he focused on the analogy between the "pipe to hear" and the pipe "as Galileus made to help the sight". According to Leurechon, moreover, the ear trumpet works because the sound resonates on the instrument's internal surfaces and so becomes "more uniform"; it does not "dissipate" and — what is more important for the present argument — it is "fortified". The shape he proposed is that of a funnel and therefore presumably circular.

Francis Bacon also mentioned the ear trumpet as an instrument already known in the new era. In his *Sylva sylvarum*, written in 1623 but published posthumously in 1627, Bacon suggested:

for the *Helpe* of the *Hearing*, (and I conceive it likely to succeed,) to make an *Instrument* like a *Funnell*; The narrow part whereof may be of the Bignesse of the Hole of the *Eare*; And the Broader End much larger, like at *Bell* at the Skirts; And the length halfe a foot, or more. And let the narrow End off it be set close to the *Eare*: And marke whether any *Sound*, abroad in the open Aire, will not be heard distinctly, from further distance, than without that Instrument; being (as it were) an *Eare-Spectacle*. And I have heard there is in *Spaine*, an *Instrument* in use to be set to the *Eare*, that *helpeth* somewhat those that are Thicke of Hearing.[16]

Apparently, Bacon neither made nor tested such an instrument and thus made no attempt to explain how it functioned. The shape of Bacon's ear trumpet is also funnel-like and therefore presumably also circular. Like della Porta and Leurechon, Bacon stressed the analogy between the ear trumpet and the telescope.

Bacon's, Leurechon's and della Porta's conceptions of the ear trumpet show some fundamentally common aspects. First of all, they did not discuss the nature of sound in direct connection with the explanation of the functioning of the instrument. They had no need to do so. On the basis of the analogy to the telescope, emphasized by all three authors, the ear trumpet does not influence the sound source and does not *increase* the sound, just as the telescope does not change the stars observed or the light they produce.[17] Following the principle of the imitation of nature, the sound is made but perceived differently by different natural hearing systems. In accordance with Aristotle's definition of technology, the ear trumpet is an instrument that naturally belongs to the human equipment as the tool naturally belongs to the human hand.[18]

THE TWO CONCEPTIONS OF SOUND IN THE SEVENTEENTH CENTURY

During the seventeenth century two contrasting conceptions of sound were in evidence: the ancient Aristotelian conception of sound as a peculiar sensible quality and/or as a violent motion, and the modern conception based on the application of the rules of optics to acoustics. The latter sought an understanding of how sound moves, but not what it is.

According to Aristotle, sound is a sensible quality which basically means that its existence is fundamentally conceived as a relation connecting the perceiving entity and the object (or phenomenon) of nature from which it originates. Colour and flavour, for example, are sensible qualities too. In *De anima*, Aristotle explained that sensible qualities are active only if the sense faculty is active as well. Such a relation between sensible quality and sense faculty is defined by Aristotle in such a way that in the end, they cannot be sharply distinguished from each other: they are one and the same,[19] both located in the sense faculty[20] and able to be simultaneously preserved or destroyed.[21] Sound, however, is a peculiar secondary quality. While odours, flavours, colours etc. are features of the objects, sound is not. *Objects do not have sound, they make it*.

This definition led Aristotle to investigate the question of whether and how sound is transported from the object to the sense faculty. In *De anima*, he also described his conception of this issue:

> For just as that which produces local movement causes a change extending to a certain point, and that which gave an impulse causes another to produce a new impulse so that the movement traverses a medium, the first mover impelling without being impelled, the last moved being impelled without impelling, while the medium (or media, for there are many) is both.[22]

In conclusion, Aristotle had a relatively confused conception of sound, as Ganson Todd Stuart found:

> [this difference] shows that sound in activity in III, 2 [of *De anima*] is a result of action of the faculty of hearing, while sound in activity in II, 8 [of *De anima*] is a result of action on air by a thing struck.[23]

If only the source of a sound is considered, then sound is defined in such a way that it could exist also without the hearing faculty, as if it were simply one of the perceptible consequences of violent motion in the same way as a cannon ball flies independently of the place it will strike.

In conclusion, whether sound is a sensible quality or whether it is a peculiar sort of violent motion acting on the medium air, it cannot be increased *per defnitionem* . In the first case, sound is conceived as a feature of the object and exists together with the hearing faculty. Only a different object can produce a different sound and only a different hearing system can perceive a different sound. The latter is the case of the ear trumpet, considered as a modification of the hearing system. This is how nature works and for this reason, the search for the most efficient ear trumpet consists in a comparative analysis among the natural hearing systems or other natural products, for example, seashells. If sound is considered to be transported through the air fol-lowing a violent movement, then it cannot be increased either, for to re-establish the natural state this can only slowly decrease until it reaches a state of rest:

We are forced, therefore, to suppose that the prime mover [the blow] conveys to the air (or water, or other such intermediary as is naturally capable both of moving and conveying motion) a power of conveying motion, but that this power is not exhausted when the intermediary ceases to be moved itself. Thus the intermedi-ary will cease to be moved itself as soon as the prime mover ceases to move it, but will still be able to move something else. Thus this something else will be put in motion after the prime mover's action has ceased, and will itself continue the series. The end of it all will approach as the motive power conveyed to each successive secondary agent wanes, till at last there comes one which can only move its neighbour without being able to convey motive force to it.[24]

According to this view, the principle by which trumpets work is discussed in Pseudo-Aristotle's *On things heard*:

Voices appear to come to us from the places in which they are produced, but we hear them only when they fall in our hearing. For the air, pushed aside by the blow, is carried continuously up to a point, and then little by little penetrates farther and by this we distinguish all sounds — both those which occur at a distance and those which are near to us. This is evident; for when a man takes a pitcher or a pipe or a trumpet, and putting it near another man for hearing purposes talks through it, all the sounds seem to be near the hearing because the travelling air is not scattered, but the voice is equally protected by the surrounding vessel.[25]

Pseudo-Aristotle's example shows only how a trumpet can be used to avoid scat-tering the air that transports the sound. However, it does not explain what happens when the source of the sound is placed at a certain distance from the ear trumpet. In this case the air would scatter and the trumpet would be able to catch only part of it, but could still give the impression of improving hearing. How does this happen?During the seventeenth century another, different theoretical approach to the same issue developed. In 1620 Giuseppe Biancani demonstrated geometrically how an echo can be created using the concave surface of a section of a sphere.[26] Biancani did not discover this himself: he simply approached a phenomenon that had been common knowledge for centuries among mirror makers and mathematicians involved in practical matters. The same effect is described, for example, in Ausonio's *Theorica speculi concavi sphaerici*, a sixteenth-century Venetian manuscript of practical character which describes the characteristics of spherical mirrors.[27] What was new in Biancani's approach was that he dealt with sound by adopting the geometric rules used to describe the phenomenon of the reflection of light — known from the field of optics — as if sound were constituted of rays.

In 1636 Marin Mersenne published his *Harmonie universelle*.[28] It is this work that conclusively shifted the focus to a mechanical conception that abandoned Aristotle's definition of sound as a sensible quality and that exploited extensively the possibility of applying the rules of optics to describe and explain acoustic phenomena.[29] Mersenne approached the topic in the first paragraph of the first page of the first book:

> ... one finds many persons, who believe that the sound is nothing, if it is not heard ..., I think that the sound is not less real before it is heard....[30]

Mersenne therefore defined sound as a "movement of the air, external or internal, which can be heard".[31]

Focusing solely on the mechanical aspects, Mersenne was finally able to describe how sound can be "fortified" without relying on the hearing faculty. He analysed phenomena of resonance and concluded that several factors determine how "strong" a sound is. The first factor is obviously the strength of the blow: the stronger the blow, the greater the quantity of air set in motion. The second factor is concerned with the quantity of air involved in the hearing experience. Mersenne introduces, prob-ably for the first time, the need to quantify the volume of air within which acoustic phenomena take place. This enables a shift from an absolute concept of motion of air to a relative quantification of moved air that is within a certain given volume. Third, and more relevant for the present argument, is the correspondence between the intensity of the sound and the relation between the number of blows in a certain quantity of air.[32] Although Mersenne did not consider acoustic instruments like the ear trumpet, his mechanical conception of sound could easily be applied to furnish an explanation of how such instruments work.[33]

Two years later, in 1638, Galileo's *Discorsi e dimostrazioni matematiche intorno à due nuove scienze*[34] was published. Without entering the issue of the nature of sound, Galileo clearly endorsed Mersenne's conception of sound as a movement.[35]

The second half of the seventeenth century witnessed the definitive abandonment of the Aristotelian doctrine in favour of an approach aiming simply to find the physi-cal laws ruling the movement of sound. The most relevant step in this direction, that is, towards the foundation of modern acoustics, is probably represented by Pierre Gassendi's discovery that sound always moves with constant velocity in air and this independently of the strength of the blow that causes it. The description of his tests and of his results, written in *Syntagma philosophicum*, was published in 1658, three years after his death.[36] This was a crucial claim. If Mersenne's work signalled the end of the use of the Aristotelian notion of sensible quality to describe the nature of sound, then Gassendi's discovery supplanted the Aristotelian mechanical interpreta-tion of sound movement as a sort of violent motion.

Gassendi's experiments and subsequent discovery vividly impressed the members of the Accademia del Cimento, founded in Florence in 1657 and dissolved just ten years later.[37] Many of its members were ex-pupils of Galileo, who was considered to be the Accademia's spiritual father. The work of the Accademia consisted in undertaking experiments and measurements mainly within the frameworks of thermometry, barom-etry and pneumatics. It was at the Accademia del Cimento, for example, that the idea of creating a network to investigate meteorological phenomena was first developed and realized.[38] Experiments set up by its members could be either newly conceived or repetitions and tests of experiments previously undertaken by other scholars. A great number of these dealt with the "movements of sound", as documented in manu-scripts now preserved at the Biblioteca Nazionale Centrale of Florence. However, the members of the Accademia published only a selection of their results, in 1666 through the work of Lorenzo Magalotti, the secretary.[39] These include the description of the experiments set up in order to prove Gassendi's discovery, and others aiming to extend the range of validity of that result. For example, they investigated whether the velocity of sound remains constant in air, even in the presence of strong wind, and independently of the direction of the movement of sound.[40]

One member of the Accademia was Vincenzo Viviani, the last of Galileo's pupils. He explored the behaviour of sound, both in general[41] and in reference to acoustic instruments, such as the ear trumpet. As Favaro reported,[42] in a folder of documents entitled "miscellaneous of experiences accomplished and to be accomplished", there is a folio where an "instrument for hearing" is drawn by Viviani's hand (Figure 1).[43] This drawing of the ear trumpet shows the longitudinal section of a parabolic curve and depicts sound rays converging to focus at the small opening.[44]

THE EAR TRUMPET DURING THE SECOND HALF OF THE SEVENTEENTH CENTURY

During the mid-seventeenth century, the Jesuit Athanasius Kircher carried out most of the investigations undertaken on acoustic instruments like the ear trumpet.[45] His work perfectly mirrors the theoretically unresolved situation of the mid-seventeenth century. The second volume of Kircher's 1650 *Musurgia universalis*[46] is dedicated to harmony, acoustics, musical instruments and acoustic devices, with a long section explaining how sound propagates in a medium. Accepting completely the analogy between optics and acoustics promoted by Mersenne in 1636, Kircher showed how sound follows straight lines that propagate while maintaining the shape of the sound source: if the sound source is shaped like a cone, for example, the sound lines con-tinue in the medium retaining the same conical shape (Figure 2). On the basis of his investigations about the behaviour of reflected sound lines, Kircher found that the most efficient way to "let the sound obtain the most force"[47] is by means of a spiral

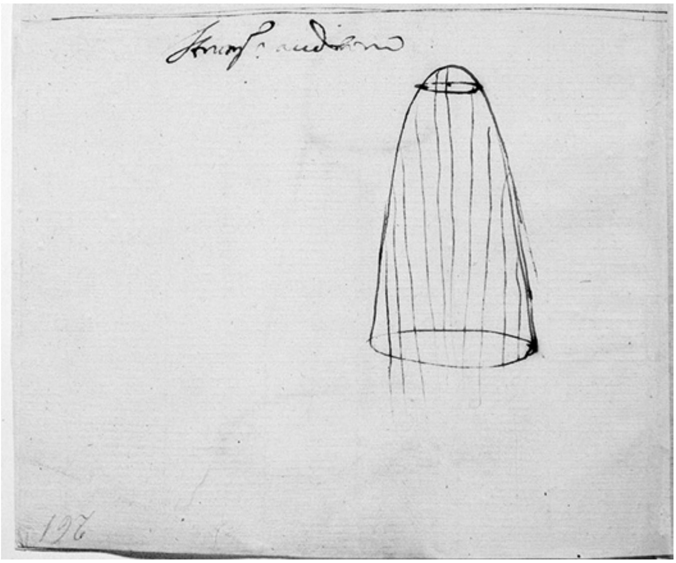

FIG. 1. Vincenzo Viviani's representation of sound rays through a parabolic cone. BNCF, Mss Galileiani, Cimento, iv, car. 261.

trumpet, since this facilitates the longest pipe in the smallest space. This trumpet, moreover, had to be shaped internally like a cochlea (Figure 3). Kircher seems to have considered the ear trumpet shaped internally as a cochlea as the most efficient to "fortify" the sound because its rays are reflected most frequently within this object than in any other. In this sense Kircher seems to have assumed Mersenne's conception in its entirety. However, in the end, he explained the efficiency of his instrument by associating it with the best ones shaped by nature, therefore assigning

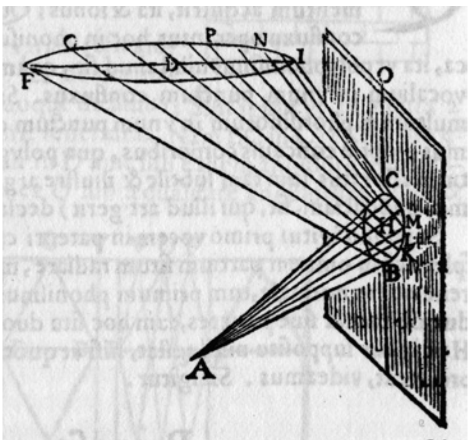

FIG. 2. Reflection of a cone of sound rays. From Athanasius Kircher, *Musurgia universalis sive ars magna consoni et dissoni* (Rome, 1650), ii, 255.

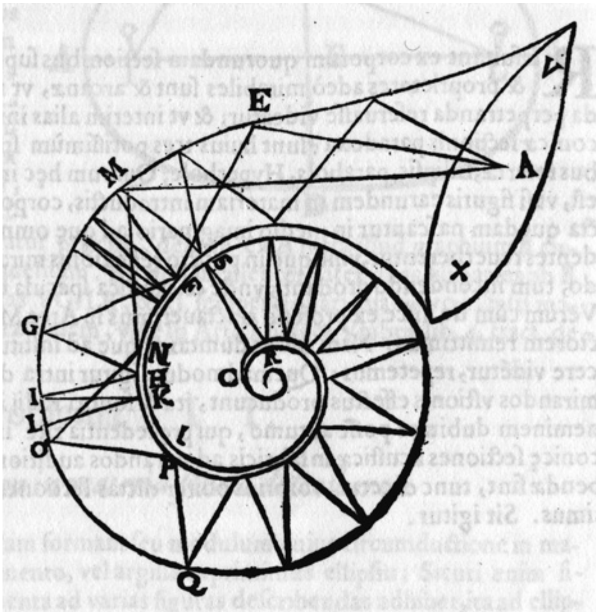

FIG. 3. Spiral ear trumpet, shaped internally like a cochlea. The sound source is at point A. From Athanasius Kircher, *Musurgia universalis sive ars magna consoni et dissoni* (Rome, 1650), ii, 277.

once again epistemological value to the principle of imitation of nature based, in the case of sound, on the Aristotelian conception of sensible quality. In his *Phonurgia nova*, published in 1673, Kircher similarly suggested imitating nature in order to find the most efficient shape for an ear trumpet and, like della Porta, concluded with the idea of imitating the hare's ear: long, elliptical and shaped internally like a cochlea (Figure 4).[48]

By the time Kircher had published *Phonurgia* in 1673 the situation had changed radically. In 1670, the mathematician and inventor Sir Samuel Morland[49] began to set up experiments in London with speaking trumpets of different shapes, sizes and materials. One year later he published an essay entitled *Tuba stentoro-phonica*,[50] where, besides indicating of the workshop where the reader could buy such instruments, he described them and the experiments he accomplished with each of them. Some of these tests, for instance those devoted to researching the lines following the outgoing sound, were made with a speaking trumpet whose longitudinal curve was parabolic. This trumpet, moreover, was made of glass (Figure 5). Morland's work deliberately concentrates on the speaking trumpet and its possible applications, although in the very beginning the author admitted that not only was he heard by several persons at a considerable distance, but that "they likewise were heard by me [him]".[51] As at the time speaking and ear trumpets were considered to work on the basis of the same principles, Morland's words might mean that the same instrument could be used both as a speaking trumpet and as an ear trumpet, simply by holding it

FIG. 4. Athanasius Kircher's realizations of speaking/ear trumpets by imitation of the hearing organ of the hare. From Athanasius Kircher, Athanasii Kircheri Phonurgia nova, sive, Conjugium mechanico-physicum artis & natvra paranympha phonosophia concinnatum (Campidona, 1673), 160.

to the ear.[52] What makes Morland's work particularly interesting is that he absolutely refused to enter into the discussion of the nature of sound:

I shall not here engage myself in any tedious Philosophical Discourse touching the Nature of *sounds*, forasmuch as I believe it equally mysterious with that of *Light* and *Colours*, and consequently too fine and too subtil a thing for humane reason and understanding to comprehend.[53]

In 1672 Morland sent a description of his trumpet to both the Royal Society of

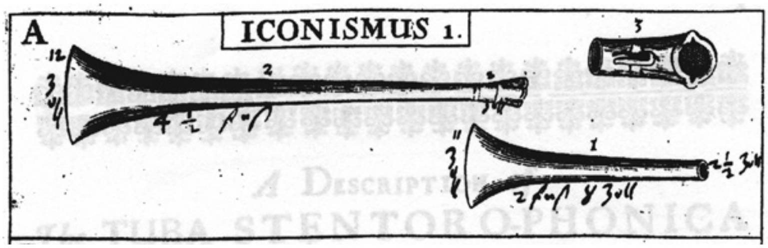

FIG. 5. The first set of trumpets used by Samuel Morland for experimenting on the motion of outgoing sound. From Samuel Morland, Tuba stentoro-phonica (London, 1671), Cover.

London and the Académie des Sciences in Paris, hoping to find out whether it could be further improved. In May of the same year, in fact, Laurent Cassegrain de Chartres, whose name is preserved in the Cassegrain telescope, published a letter in *Journal des sçavans* where he suggested abandoning the parabolic curve and instead making an instrument with a hyperbolic longitudinal section which would improve the ear trumpet (Figure 6).[54] As Frederick Hunt pointed out, according to the acoustic theory at the time, this is the most efficient shape that could have been suggested.[55]
Cassegrain's 1672 trumpet follows a hyperbolic curve in its longitudinal dimension and its inner surface is bare. From a technical point of view, this shape was the best one achieved during the seventeenth century. But Galileo and Aproino had already achieved exactly the same result in 1613.

THE SOCIAL BACKGROUND OF GALILEO AND APROINO'S PROJECT

Paolo Aproino had been a pupil of Galileo in Padua.[56] His interests lay primarily in the study of geometry, a subject on which he frequently deliberated in his rich correspondence with Galileo and Daniello Antonini,[57] a good friend of Fulgenzo Micanzio and assistant to Paolo Sarpi.[58]
Paolo Aproino wrote to Galileo on July 27, 1613 in the following terms:

... I decided to write to You about the history of the observations I have made until now concerning the topic of bringing sound closer, so that you can have an instrument made (because it does not make any sense to send it to you already assembled, since it is very easy and I do not have anyone here who can serve me by decorating it) to demonstrate in front of those *murmurers*, because your proposal on this topic should neither be scorned nor considered to be in vain.[59]

The idea of constructing an instrument to "bring sound closer" was Galileo's. When Galileo negotiated his return to Florence from Padua in 1610 with Belisario Vinta, the State Secretary of the Grand Duke, he announced his intention to write a work whose title would have been *De sono et voce*.[60] It is likely that Galileo then assigned the task to research this subject to his pupil Aproino, possibly also to avoid

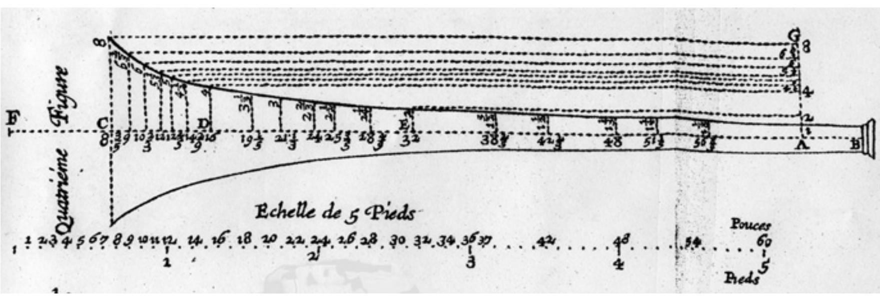

FIG. 6. Hyperbolic ear trumpet drawn by Cassegrain de Chartres. From Laurent Cassegrain de Chartres, "Report of a letter received from N. Cassegrain de Chartres", Journal des scavans, 1672, supplement (2 May 1672), 131.

involving the “murmurers”, at least during the first stage of research. Another sentence by Aproino may clarify the problem:

> ... once I became infatuated with the novelty of the thing, I told several friends that I had heard about some people wanting to increase sound. I told them this in order to check their reaction and also to discover whether they knew of someone else who had observed this detail. Although some believed the problem to be worthy of speculation, most *derided the problem and considered this task impos-sible*. Therefore, I decided to consider the nature of sound and its differences.[61]

Aproino and Galileo did not consider the ear trumpet to be a device one could apply in the case of hearing impairments; they considered it an instrument to “bring sound closer” or to “increase” it. As will be shown in the following, it might have been this approach that led to unease at court and Aproino to be derided by his culti-vated friends and acquaintances. Moreover, they considered their own project to be a novelty, as if no one had ever used an ear trumpet before.

In a letter dated 26 January 1613, written by Aproino and addressed to Galileo, the former pupil thanked Galileo grandiloquently for having introduced him and his work to the Court of Florence.[62] In fact, Galileo had presented the project, at court as one that was carried out by his pupil. He intended to organize a journey to Florence for an official demonstration of the instrument to be staged by its maker, and for the submission of a tract on its characteristics, to be dedicated to an illustrious personage at court. Most likely, Aproino intended to deliver both of these items to the Medici on the occasion of his visit. In May of the same year, however, Aproino’s brother died and the work to “reduce [the instrument] to perfection” had to be postponed.[63] In June, Aproino was still hoping to improve the “auditory instrument” and was also ready to write about its functioning, but his duties kept him from the project. At this time Aproino had an ear trumpet with which sound could be perceived as being ampli-fied four times.[64] However, he was convinced that it could be improved much more and had several “designs” in mind which required “new experiments”. Moreover, the instrument exhibited a certain ground noise, especially at the beginning of each word. Aproino also remarked that the instrument was more efficient in increasing the voice than any other kinds of sound. At the end of July, finally, Aproino sent Galileo a complete summary of the work and of the results he had accomplished, but no instrument and no official treatise. He invited Galileo to continue the project alone, as he had meanwhile secured a clerical position and therefore was no longer able to pursue this project.

Aproino’s last letter to Galileo presents a first rough draft of the treatise he would have had to write. It contains, first of all, the occasion that supposedly gave him the idea for the instrument; second, the literature he consulted; third, the experiments undertaken to study the geometrical characteristics of the trumpet so as to obtain the most efficient shape; fourth, an analysis of the materials suitable for making such an instrument; and fifth and last, a written procedure for making the instrument so that Galileo could have it made directly in Florence.[65]

Aproino related that he came upon the idea of amplifying sound during a beach vacation, when he read *History* by Guillaume Rondolet,[66] a sixteenth-century physician. In this book,[67] Aproino found not only descriptions of the seashells that he casually found on the beach, but also indications of the relation between seashells and their potential function as ear trumpets, for example, in the section entitled *buccinum*, known today as *nautilus*.[68] Rondolet described a seashell called *turbine aurito*, which is precisely the seashell from which, as Aproino told Galileo, his idea of increasing sound had originated. Aproino set to work at once. He cut off the smaller end of the seashell and immediately determined that an almost natural ear trumpet could be obtained in this way.[69] Once he recognized that he could hear sounds that were impossible to perceive without the “aurita”, as he called it, an effect which greatly surprised him,[70] he thought it might be possible to achieve the same effect artificially:

For this [study] I had, as a main fundament, some ideas that I remember learning from Your Lordship. Additionally, Boethius accompanied me while learning the actual state of the art. Sometimes that gentleman of Maurolicus made me aware of some details and Vitrivius of some further details, in that chapter where he speaks about the resounding of scenes, although, to tell the truth, what has been said so far is really very little, and this is mostly misunderstood and partly wrong and far removed from the experiments.[71]

Boethius’s work, *De institutione musica*,[72] was recognized as the undisputed author-ity on matters of music theory. The first of the five books that make up Boethius’s work is concerned with theoretical topics such as the nature of sound, its propagation and the mathematical division of pitch space, consonance, scale forms and systems. In particular, Boethius accepted Aristotle’s conception of sound as produced by a bow and propagated in a medium like a decreasing violent motion. Boethius added that the way sound propagates resembles the system of concentric waves caused by a stone falling in water, the only difference being that sound waves are spherical and not merely two-dimensional.[73] No acoustic device, however, is taken into considera-tion throughout the entire tract.

Maurolicus was a sixteenth-century engineer-scientist who worked predominantly on mathematics, astronomy and optics.[74] In his *Opuscola mathematica* published in 1575,[75] Maurolicus included a text dedicated to sound and music,[76] to which Aproino eventually referred in his letter to Galileo. In this text, after unreservedly adopting Boethius’s view on the nature of sound and its propagation, Maurolicus briefly considered the effect of sound bows propagating in a medium as they enter a pipe. In this passage,[77] which refers to speaking trumpets, he stated that the motion of the sound changes direction (*reciproco*) and begins to tremble (*tremebundo*), so that a reverberation occurs. What exactly Maurolicus meant with the word ‘reverberation’ in connection with the trembling effect is unfortunately never explained, although it was apparently clear enough to rouse Aproino’s interest.

In Vitruvius’s *De architectura*, Aproino’s third source, long passages are dedicated to devices and architectural arrangements able to improve acoustics, that is, to amplify sound.[78] The most important of these devices were known as *vasa*, the function of which was to amplify the voices of actors in the Roman theatre and which remained in use throughout the Middle Ages.[79]

The fourth author quoted by Aproino is Galileo himself, from whom Aproino apparently took "some ideas", although exactly what these were is impossible to determine. This body of knowledge, which included Galileo's teaching on this subject as well, was, however, "far removed from the experiments", as Aproino himself stated.

THE TECHNICAL ASPECTS OF THE PROJECT

After performing a first set of tests using several instruments made of different materials and of different sizes, and with different kinds of internal spirals, Aproino obtained an ear trumpet made of balsa, in the shape of a cone with an opening of fifteen degrees, one span long, equipped with three internal spirals that started from the smallest opening but did not touch each other. Together with Antonini, he performed several experiments on this trumpet and concluded "that the sound came closer by one-third of the distance",[80] that is, as if the source of the sound were located only one-third as far as the actual distance between its source and the hearer.

Once Aproino had acknowledged that Antonini and another of his friends concurred with his conclusion, he built another, larger trumpet and performed tests in order to find the relations between the size and the effect of the instrument. The second trumpet was two spans long and had six internal spirals, arranged in the same way as in the first instrument, but its opening was about twenty-five degrees wide.[81] Because of the difficulty of building six internal spiral revolutions, Aproino decided to build another trumpet of the same dimensions but, instead of six revolutions, he used six concentric cones inserted into each other. In this case Aproino claimed that the effect was even better. Aproino continued by building the last trumpet of this second set of instruments with the same dimensions as the second and third, and with a conical shape, but these were left bare inside. The conclusion taken from this second set of tests was that the bare and hollow trumpet was the worst, and that the effect of the trumpet increased with size, according to a certain as yet undetermined proportion.

To decipher the terms of this proportion, Aproino elaborated a "very excellent way of measuring these trifles". The new method, which is unfortunately unknown, obliged him completely to reinterpret the results of the second set of tests. As mentioned, the very first trumpet, some details of which Aproino related to Galileo, was considered to be imperfect because of the ground noise perceived by the ear. In fact, all the trumpets of the second set exhibited the same problem. With these instruments, therefore, the perception of sound was greatly distorted because of the impression of increased effect caused by the ground noise. Thanks to the new method, Aproino came to the conclusion that the ear trumpet one span long and with three spiral turns brought the sound closer not one-third, but two-thirds of the distance between the user of the instrument and the sound source, and so its effect was smaller. The second trumpet, twice as long as the first and with six spiral turns, instead of "very close", brought the sound to half the distance. The third trumpet, with the same dimensions as the second but equipped with concentric cones, showed the same effect as the second and, finally, the fourth, the simple cone, was just as efficient as the second and third, but with a decreased intensity of the ground noise effect. The complicated internal spirals, therefore, could be identified as the direct cause of the ground noise and the bare and hollow trumpet as the most efficient.

In conclusion, Aproino moved on from the spirals of the seashells, that is, from a trumpet conceived on the basis of the principle of the imitation of nature, to an instrument whose characteristics were determined in sole accordance with the results of systematically performed tests.[82]

THE INSTRUMENT'S EFFICIENCY, SHAPE AND BUILDING METHOD

Once he had realized that the internal surface of the ear trumpet should be bare, Aproino performed tests to establish a relation between the size and the effect of the instrument. To Galileo, Aproino reported only the conclusions:

... that of two cones with equal bases, the one of greater height brings [sound] closer and likewise conveys more ground noise; and of two cones of equal height, the one with a greater base brings [sound] closer, and produces less ground noise. Thus, although, as I say, bringing sound closer follows the ratio of the base and of the height, nevertheless it [bringing sound closer] does not follow one and the other with the same ratio, but with another one much smaller than the ratios [of height and base]. [Therefore,] if one [unit] of height or of base gives one [unit] of increase, two [units] of base or of height will give much less than two [units] of increase.[83]

Thus, the efficiency of the ear trumpet depended on the height and on the size of the base — the angle of the opening — of the instrument. Whether increased height caused more efficiency than an increased base is not stated. The ground noise depended more on the height than on the dimension of the base. The increase in efficiency was not linearly proportional to the increase in the dimensions of height and base. This final statement means that:

... for this increase in sound, there is a limit, and perhaps not so far [from the dimensions I have now], through which, as concerns the figure, no instrument, though endlessly increased, can arrive.[84]

Aproino concludes his report by suggesting that Galileo have an instrument made with a hyperbolic shape, although he did not know whether this was really the most efficient shape, but "it works very well". He also sent a drawing representing the method (Figure 7) of making a hyperbolic mould in order to check the curvature of the instrument, a method highly reminiscent of the art of trumpet-makers.[85]

After having explained how to obtain the hyperbolic shape to produce a mould to control the curvature of the instrument — an explanation that Aproino did not want to give in great detail because Galileo "will perhaps find a better alternative to

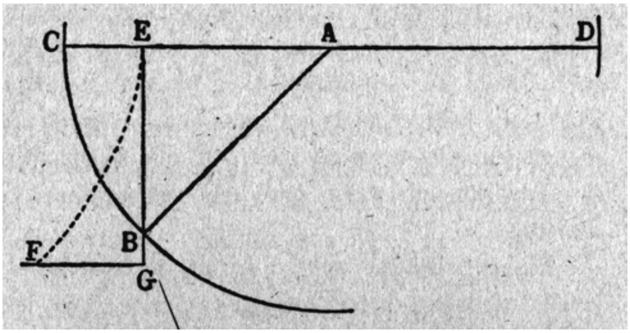

FIG. 7. Aproino's illustration of a method to build a hyperbolic mould to check the final longitudinal curvature of the ear trumpet. From Paolo Aproino to Galileo, 27 July 1613, in Galileo Galilei and Antonio Favaro, Le opere di Galileo Galilei, 4th edn (20 vols, Florence, 1968), xi, 543.

facilitate the work" — Aproino dedicated some thoughts to the materials of which the ear trumpet should be made. The more rigid the material, the more efficiently the instrument would work, and, although Aproino always worked with balsa wood, he strongly believed that any kind of metal or, above all, glass, could improve the instrument's efficiency.

IT WORKS BUT ...

Aproino's trumpet was exactly like Cassegrain's: hyperbolic and bare inside, that is, without spirals, turns or concentric cones. As mentioned, Cassegrain's trumpet represents the best technical result achieved during the seventeenth century in this field, and it was achieved on the basis of the work of Samuel Morland. Remarkably, the exact same output had been achieved fifty-nine years earlier by Aproino.

Galileo and Aproino's project was cancelled. This was due in no small part to chance events: Aproino's brother died, and he himself secured a new and "permanent position" in the clergy which may have reduced his efforts to conclude the project. However, if one considers that Galileo in a letter to the secretary of the Medici in 1610 had already promised such a work, and had informed the court about his pupil's progress in 1613, it seems improbable that this sudden change of attitude towards the project can be adequately explained by the changes in Aproino's circumstances. Aproino and Galileo had achieved an excellent technical result and even the treatise describing it was almost complete, as Aproino's last letter shows. At this stage Galileo would have been able to finish the project very easily by himself. He had a wealth of artisans at the court of Florence to help him and enough pupils to shape the treatise properly. The authorship would not have posed a problem either, since Aproino had asked Galileo explicitly to continue the project without him.

In his letter of 1 June 1613, which is translated in the last section of this work, Aproino tried to convince Galileo that the project was dangerous and that he should present it discreetly. Aproino was clearly intimidated and, as described earlier, had tested the reactions of his educated friends and acquaintances. Moreover, Galileo had reported on the opposition that this project had met with at court.

By drawing on the few sources available, some cautious speculations can be made about Galileo's possible opponents at court. Given the time, Aproino's acquaintances and Galileo's opponents were most likely people who considered sound according to the Aristotelian doctrine, possibly as a sensible quality. Galileo and Aproino had no appropriate theoretical apparatus at hand to explain what they had done with the ear trumpet, and especially to explain how they had developed it. Rather than observing the hearing apparatus of animals or considering other natural forms like the seashell, Aproino used geometry and in particular applied conical sections. This was a method usually employed in the field of optics. From a theoretical point of view, Galileo and Aproino described the functioning of the instrument either as "increase in sound" or as "bringing sound closer". But they had no notion of sound to explain the physi-cal meaning of such expressions. The problem was twofold. First, the expressions used by Galileo and Aproino were nonsensical within the Aristotelian framework. Second, the Aristotelian conception of sound, through the lack of consistency seen above, was an elaborated and historically well-established conception. It was used to describe a great deal of phenomena and was well integrated in the theoretical structure of the sensible qualities described in *De anima*. Considering Galileo's precarious involvement in the animated debate on floating bodies at the same court,[86] which had been concluded just one year earlier, he might have concealed the authorship of the acoustic instrument, or at least postponed its presentation at court. A function-ing ear trumpet, geometrically conceived and built by Paolo Aproino in Treviso to "increase the sound" and not to help the hard of hearing, would not have stood up to the potential philosophical dispute at the Florentine court of 1613.

The court system would have allowed alternative approaches. Galileo could have avoided a philosophical dispute by simply pointing to the fact that the instrument worked. After all, this is how he presented the telescope in several Italian cities.[87] He could even have made tests with the hard of hearing to show just how efficient his trumpet was.[88] Presenting a technical device as a gift but without furnishing any theoretical explanation would have been engineer-like behaviour. While Galileo did have a strong profile as an engineer that he himself brought from Padua,[89] it was precisely this profile that he sought to change by moving to the Florentine court in 1610 and insisting on the title of Philosopher. Somewhere between this engineer-like behaviour and a full immersion in philosophical disputes, there were other options available. For instance, he could have kept the discussion on a phenomenological and rather descriptive level. Nevertheless, although the scientific practice at court allowed different strategies to be undertaken, the few sources at disposal seem to indicate that Galileo intended to present the instrument in a way that would make it impossible to avoid such a dispute. Aproino concludes his last letter:

Although this instrument will certainly arouse and at least in part meet those great expectations that originate from the fact that this was your idea, in my opinion it should also be shown as a thing with heavy consequences among the philosophers, and not only as an object for a prince.[90]

Galileo might have turned his attention to acoustic devices before 1610, when he was still working in Padua as a practical mathematician. Because of the increas-ing diffusion of contemporary architectonic solutions, which made more and more use of “surprising [acoustic] effects”, such as those used in the Boboli Gardens of Florence, or in Salomon de Caus’s Palace Gardens in Heidelberg, engineers like Galileo naturally focused their attention on such contrivances. Aproino’s study of the Vitruvian *vasa* seems to corroborate this hypothesis. Although Aproino and Galileo foreshadowed the results later obtained by Morland and Cassegrain, their theoretical background in this field in 1613 could not have bridged the gap between acoustic devices in the fields of architecture, engineering and medicine, and the natural philosophers and engineer-scientists,[91] since the new mechanics of sound was not yet at their disposal. In conclusion, if this speculation is correct, Galileo and Aproino’s project can be considered as an attempt to include ideas and objects rooted in the practical knowledge of their time in the scientific debate of natural philosophy by climbing the social ladder at court. Given the scientific context of Florence in 1613, the steps of that ladder were too numerous for Aproino’s ear trumpet and thus Galileo abandoned the project.

NOVELTY AND RE-CONFIGURATION

On the basis of this interpretation of Aproino’s work, the apparent historical curiosity of the continuously invented ear trumpet can be investigated. As mentioned, Aproino considered his work a novelty. Towards the end of the century Samuel Morland and Cassegrain de Chartres, too, claimed to have invented the speaking/ear trumpet. Also della Porta and even Athanasius Kircher thought they were presenting something new when writing about the ear trumpet.

For Morland and Cassegrain the novelty lay in the geometric shape according to which they thought the instrument had to be built. At that time the instrument was already well known. Research on the most efficient shape obviously continued after their work and many different geometrical shapes were suggested.[92] Before them, Athanasius Kircher suggested not only imitating the most efficient hearing organs of living beings, but also that the most efficient shape could be elliptical, that is, a conical section. Kircher’s ear trumpet therefore was new in two senses. On the one hand, like Morland’s and Cassegrain’s trumpets, it should have a particular geometrical shape; on the other hand, the instrument should be built to imitate an object found in nature. Della Porta considered his ear trumpet new because he believed he was the first to suggest making it with a shape similar to that of a hare’s ear. In the end, Aproino began by looking for the most suitable seashell shape and ended by suggesting a conical section as the most efficient shape for the instrument. Unlike Kircher, Aproino could not rely on a systematic work on acoustics that showed how rules and theorems, originally developed within the framework of optics, could be applied. Aproino did not consider his last ear trumpet a novelty because it was con-

ceived within a new theoretical or even philosophical context. Basically, Aproino considered his instrument to be new because he had no framework to make sense of the novelty of the method and of the path he followed in developing it. He consciously abandoned the ancient framework and developed a method of investigation appropriate for a new theoretical framework as yet unattained. It was the new geometry-oriented method of investigation that caused him to consider his instrument a novelty. It could have been the lack of a framework for such a method of investigation that caused his friends to consider this trumpet to be miraculous, that is, for which no rational explanation was possible.
In a sense, all of these figures were inventors, that is, they proposed novelties. The actual meaning of novelty, however, changes dramatically in reference to their works. The originality of Aproino and Galileo's case is that they produced a new apparatus for which they had no explanation. Clearly, their work can be seen within the frame of the process of reconfiguration in which the instrument is taken from one framework and placed in another. Their own work, as well as the work of other contemporary engineer-scientists, contributed to such reconfiguration processes and to the emergence of a new theoretical framework in acoustics.[93]

CORRESPONDENCE

(a) Paolo Aproino to Galileo in Florence. Treviso, 1 June 1613

Most Illustrious and Excellent Lord, my Very Cultivated Master
I finally received the penultimate letter that Your Lordship sent me on 16 April
with Your considerations on the sunspots. [The letter] was then brought to me one and a half months later, on the last Tuesday of Pentecost, by means of a farmer sent by a certain Father Tomaso of St Georgio Maggior of Venice, who is rector here in the countryside, eight miles away, at one of their estates called Monestier.
Your considerations are a very great pleasure to me, not only because they come from You and because they are what they are (I cannot speak more magnificently about them), but also because I have been waiting for them for some time and because they are very appropriate to me. Thanks to the greatness of their concepts, they will probably free my heart a little from the great sadness which oppresses me. I there-fore thank you endlessly for them, as much as I can, and after I have devoured them during these last two days, I will now enjoy them slowly.
I am also dubious and jealous concerning Lord Danielle [Antonini], as Your Lordship is, for I asked him [to write] more than twice, but never received any letter. Tomorrow, since the mail carriage passes through Friuli, I will try again. I believe that the old trouble of his house keeps him away from us. Moreover, there are problems in that city so that his brother might not yet have been able to deliver the message.
For what concerns the acoustic instrument, I am about to apply my mind to it or, more accurately, my hand. Although I have many designs in mind to improve it, they however require new experiments, and therefore I do not want to work on such [designs] too much as this would take a long time. Your Lordship should recognize that

all your projects turn out with such splendour that You will certainly not be completely satisfied with this one. It is sufficient that one makes what has been said: to show that a sound, caught with an artificial instrument, reaches the ear 4 times louder than when it is heard naturally. By showing this, which is what I wrote to you, not only will rational men have no chance to doubt, but they will also have more [material] to speculate about the nature of sound, more than what has been speculated upon until now. It is true, however, that on this subject there are no immediate demonstrations to convince without difficulties also those who want to stay on the boundary between ignorance and obstinacy. I can tell you the following: When I was outside, 4 miles away, I heard and recognized the sound of the city bells although they are not loud. Without the instrument, one can only hear faintly one or two of the biggest bells during the winter. The others cannot be heard and recognized. Concerning the music too, it seems to me that there is something subtle to speculate about as, when one is far away, the parts can be heard in a perfect blend of consonance, and the instrument allows the voices to be heard more vividly, as if they were closer. As Your Lordship certainly observed, the distance decreases the voices but increases the sweetness of the consonance. As any other thing, also this instrument has its problems. One of them is represented by a little whirl. From this it follows that the words, at the beginning of their articulations, do not seem to be closer and that they then follow the proportion of the increase which they naturally make according to the essence of the sound. However, since such an accident does not follow from the instrument itself, as turbid sight does not follow from lenses, I hope to eliminate it trying with various experiments and with that patience and precision that this subject requires, which is made of *minimis naturae*.
Finally, it does not matter if one speaks from so far away that I miss half of the words: with this instrument I will understand all of them. Your Lordship knows, however, that most people consider these issues as if it were possible to do everything imaginable, as if one decreases the merits of Your divine telescope because, with it, it is not possible to clearly observe an object placed in a dark position, as certain people believed should happen. Therefore, I believe that one should be moderate while giving occasion to instil these sorts of concepts to such men in such a way that the facts best correspond to what they imagine. Please, remind them always that you do not want them to listen to the harmony of the sky, in the same way as You let them see it with the eye. It is true, however, that — if one wants to be impertinent — a thin tablet stops the telescope, whereas this acoustic device could pass through walls. Having touched upon the subject of miracles, I devotedly kiss your hands from here and remind you of your devoted servant, as I am obliged to be for ever.

Treviso, 1 June 1613.
Of Your Most Illustrious and Excellent Lordship
I would like to know whether a certain Lord Georgio Muschietti is at those courts.

But I absolutely do not want to disturb Your Lordship.

Very Obligated Servant
Paolo Aproino

This text was published on page 20 of the article "Galileo's abandoned project on acoustic instruments at the Medici Court."

[Addressed to:] The Most Illustrious and Excellent Lord, my Lord and Very Cultivated Master
The Lord Galileo Galilei.
Florence.

(b) Paolo Aproino to Galileo in Florence. Treviso, 27 July 1613

Most Illustrious and Excellent Lord, My Very Cultivated Master
In recent days, I received from Lord Gianfrancesco Sagredo the letter Your Most Excellent Lordship sent on the 13th of the current month and, apart from this one, I have not received any other from you, probably since one month. I am sorry it is not possible to set oneself deadlines when philosophizing, as Your Lordship knows, since, as soon as one succeeds in understanding one particular, then and only then does one also realize that there are other details that require investigation. Since this is the way of the world, one may only change in accordance with it. I decided to write to You about the history of the observations I have made until now concerning the topic of bringing sound closer, so that you can have an instrument made (because it does not make any sense to send it to you already assembled, since it is very easy and I do not have anyone here who can serve me by decorating it) to demonstrate in front of those murmurers, because your proposal on this topic should neither be scorned nor considered to be in vain.
The speculation originated from this: one day I was observing certain shells that I had collected on a trip to the sea last year, [bringing] together with [me] the *History* of these things by Guglielmo Rondeletio.[94] On finding the one he calls *aurita*, on a whim I drilled the bottom of a very large turbinate I had and placed it close to my ear in order to attempt some experiments. Indeed, it turned out that I had the impression of hearing my voice become much louder, although now that my ear is accustomed to louder impressions, it seems to me that its effect is very small, or non-existent. However, since that small increase took place along a great whirl, it [the increase] seemed remarkable and I took it into consideration. Then, once I became infatuated with the novelty of the thing, I told several friends that I had heard about some people wanting to increase sound. I told them this in order to check their reaction and also to discover whether they knew of someone else who had observed this detail. Although some believed the problem to be worthy of speculation, most derided the problem and considered this task impossible. Therefore, I decided to consider the nature of sound and its differences. For this [study] I had, as a main fundament, some ideas that I remember learning from Your Lordship. Additionally, Boethius accompanied me while learning the actual state of the art. Sometimes that gentleman of Maurolicus made me aware of some details and Vitruvius of some further details, in that chapter where he speaks about the resounding of scenes, although, to tell the truth, what has been said so far is really very little, and this is mostly misunderstood and partly wrong and far removed from the experiments. Who knows whether this eminent part of philosophy, so close to us, abandoned and neglected by everyone, will one day be elevated and enhanced!

Assembling on it [the instrument] some indices of truth, I have carried out many experiments and also built some instruments, wound as spirals in different ways, of different materials, corresponding, as I said, to the shade of truth which seemed to enlighten me, and sometimes also at whim. When, eight months ago, Lord Danielle passed through, I had made a cone, constructed of balsa, about one palm in height, which perhaps widened up to 15 degrees and truncated close to the top, but in such a way that it fit comfortably in the ear. Once assembled, I made three other spiral-like rotations within that conical surface [starting] from the hole at the top [down] to the base and in such a way that these did not touch each other. This was the instrument that Lord Danielle saw and experimented with. He made many marvellous things [with it] and remained so impressed that he wanted to mention it to Your Lordship, as you remember. He argued, as a friend of mine and as I also did before, that the sound came closer by one-third of the distance, or even less, while the other characteristics remained the same. Then we took a long and continuous holiday without thinking of it and some weeks ago, to reassure Your Lordship, I resumed the speculation.

Hence, I first built a cone of double the height of the above-mentioned one, with six spiral rotations and with a greater opening, of perhaps eight or ten degrees [more than the opening of the previous one], to experiment on a greater scale and to make the differences more perceptible. Then I made another one like this, but instead of the coils [which are] rather difficult to manufacture, I placed six further, gradually smaller, cones into each other in such a way that they were separated from each other. This procedure seemed to turn out rather better than the first one, and not vice versa. I also made a simple cone of the same size, which, although it did not show further difficulties, seemed to be less useful than the others. But willing to learn these differences in greater detail, I applied my mind a little more and found a very excellent way of measuring these trifles. This [experience] enabled me to see how judgements made superficially about things, although they are made with consideration, are far from what is deeply integrated into the nature of the things themselves. In short, I first recognized a great mistake I had made, as other people had. This [mistake] is that the cone, which seemed to us to bring sound to only one-third of the distance, does not even reach two-thirds. The other larger cone, which seemed to bring it [sound] very close, is now recognized as the one that does not really bring it [sound] closer than half the distance and the stronger [impression] is a false alchemy because of the whirl, unworthy and completely unnecessary, which I should have known, for I remember writing to Your Lordship about this. When I listened to someone reading, the articulation did not correspond to the closeness which seemed to be in the sound. Moreover, because of this same mysterious whirl, another very important deception with no minor consequences appears in the same way. Those many cones, one in another, seem to bring it [sound] closer than a simple cone, equal to the largest of them. Nevertheless the truth is different because the many cones perform just as the simple cone, with the difference that those dull more (because of the whirl) than the simple one does, and this is where the mistake originated.

Hence, with these obstacles removed and the subject made easier and clearer, then I clarified some things without difficulties, among which it will suffice to say to Your

Lordship these two things about the figure: that of two cones with equal bases, the one of greater height brings [sound] closer and likewise conveys more ground noise; and of two cones of equal height, the one with a greater base brings [sound] closer, and produces less ground noise. Thus, although, as I say, bringing sound closer follows the ratio of the base and of the height, nevertheless it [bringing sound closer] does not follow one and the other with the same ratio, but with another one much smaller than the ratios [of height and base]. [Therefore,] if one [unit] of height or of base gives one [unit] of increase, two [units] of base or of height will give much less than two [units] of increase. How much smaller then the mentioned ratios are and how much they differ from each other I do not need to tell extensively, nor am I able to state it in detail now. It is sufficient that I consider as a truth that, for this increase in sound, there is a limit, and perhaps not so far [from the dimensions I have now], through which, as concerns the figure, no instrument, though endlessly increased, can arrive. On the basis of the mentioned experiments, I arrived at the form of an instrument which Your Lordship will have built, that is hyperbolic, described in the following way and with the following measurements, although I do not say that it is the best that can be done, but only that it works very well. Take the straight line AB about three spans long, and, with the centre A, described around the distance AB the circle BCD, whose arch BC is about fifty degrees, [Figure 7] and draw the diameter CAD, and from the point B the [line] BE falls at right angles to [the line] AC; and take three small nails made with a hole in their shaft and drive these into the points D, A, C, so that the holes of the nails are close to the plane of the above-mentioned lines. Thread through the hole of nail A two strings, one of which passes through nail D and the other through C, and then join them at the point E to a mobile pencil in such a way that the mentioned knot in that pencil cannot slip. Hence, display these two strings in this way, so that they remain moderately taut, with the two strings running an equal distance from nail A, move the pencil from point E to part B with dexterity, so that the two strings, which tend towards the points D and C, always remain equally taut, so that it will describe the curved line EF, which is a hyperbole, as is possible to demonstrate from the LI [proposition] of the third [book] of Apollonius, and AE is half the base and AB is the asymptote. Now, extend EB to G, so that EG is slightly shorter than three spans, and from the point G draw GF to form right angles, which meet the hyperbola at F. Take the plan FGEF, intended as rotating around the axis GE, so that GF describes a circle and the hyperbole EF a hyperbolic surface, which is being sought. Hence, one will cut this pattern on a table, which is used by the master as a mould to make the instrument, which then has to be cropped with the measurement of the mould so that it fits very comfortably into the ear. However, I do not need [to describe it] longer to Your Very Excellent Lordship, because You will perhaps find a better alternative to facilitate the work. I only say to you, in reference to the material, that I worked with balsa. Nevertheless, silver would be better (although without a great difference) and You have only to take care of the assembly, of the rigidness of the body and of the smoothness of the surface. I also know that, in addition to these materials, there are a lot of others which produce the effect, among which one can even list a bag of paper, but for this purpose glass will perhaps be the most useful material of all.

I have taken too long and am occupying Your Lordship, to whom it is enough to give hints, whereas to other people it can only be said with long descriptions and by proposing manifest experiments and demonstrations founded on them, which make the truth known and then relate the probable adjudgement to the subjective one of the people. I am sorry I have not been able to send you the perfected object, which I would have delivered, if I had had the possibility to stay for ten more days at the villa working with balsa in order to find the above-mentioned ratios, and [the pos-sibility to stay] ten [days] at Murano to have glass objects made, in whose rigidity I have more faith than in any other material (if one does not add any new particular for speculation in reference to this issue). It is sufficient that the above-described instrument will give so good a proof that, I can say to You, it will gag, if not the emulators who are malicious and persistent, at least the ignorant people who too uninhibitedly persuade themselves that sound is one of those things that are not affected by devices.

I will receive therefore this favour from Your Most Excellent Lordship, that is, that You are delighted in taking with good mind these four little things that I am writing to you now and, in exchange for the fact that I freely speculated about this topic, partly stimulated by my intelligence, but partly also by a respect that I have for you, you will take the trouble to have the instrument made. Although this instrument will certainly arouse and at least in part meet those great expectations that originate from the fact that this was your idea, in my opinion, it should also be shown as a thing with major consequences among the philosophers, and not only as an object for a prince. With this, always reminding you that I am a very obligated servant, I reverently kiss your hand.

From Treviso, 27 July 1613.
Very Affected and Obligated Servant of Your Most Illustrious and Excellent Lordship
Paulo Aproino.
[Addressed to:] Most Illustrious and Excellent Lord, My Very Cultivated Lord and Master
Lord Galileo Galilei.
Florence.

ACKNOWLEDGEMENTS

This research was carried out at the Max Planck Institute for the History of Science of Berlin (Dept 1, directed by Jürgen Renn) and supported by the project *Transformations of Antiquity*, funded by the German Research Center (DFG), in which the Max Planck Institute for the History of Science also participates. The first results of this research were presented and discussed at a colloquium of Department II of the Max Planck Institute for the History of Science, directed by Lorraine Daston, at the end of 2008. I would like to thank the scholars of Dept II and Lorraine Daston for their helpful and constructive comments. Special thanks go also to Lindy Divarci, for her research in the literature.

REFERENCES

1. Ludovico Cardi da Cigoli to Galileo, 24 February 1613, in Galileo Galilei and Antonio Favaro, *Le opere di Galileo Galilei*, 4th edn (20 vols, Florence, 1968), xi, 484–5.

2. Daniello Antonini to Galileo, 1 October 1612, in Galileo and Favaro, *op. cit.* (ref. 1), xi, 406.

3. Aristotle, *The physics*, transl. by Philip H. Wicksteed and Francis M. Cornford (Cambridge, MA, 1934), in *Aristotle in twenty-three volumes*, iv–v, II, 8; 199 a 15–17. For an introduction to the Aristotelian concepts of art and nature, see Wolfgang Schadewaldt, *Die Begriffe 'Natur' und 'Technik' bei den Griechen*, *Hellas und Hesperien: Gesammelte Schriften zur Antike und Literatur* (Zürich, 1960), 907–19; Klaus Bartels, *Der Begriff Techne bei Aristoteles*, in Helmut Flashar and Konrad Gaiser (eds), *Synusia: Festgabe für Wolfgang Schadewaldt zum 15. März 1965* (Pfullingen, 1965), 275–87; and M. Schiefsky, *Art and nature in ancient mechanics*, in B. Bensaude-Vincent and W. Newman (eds), *The artificial and the natural: An evolving polarity* (Cambridge, MA, 2007), 67–108. For a critical approach to the view expressed by the previous authors, see Joachim Schummer, "Aristotle on technology and nature", *Philosophia naturalis*, xxxviii (2001), 105–20.

4. During the early modern period the conception of art as the completion or imitation of nature became less and less dominant and finally this process concluded with a more central relocation of the human being in the realm of nature. For an introduction to such encompassing cultural and philosophical changes, see Hans Blumenberg, "'Nachahmung der Natur': Zur Vorgeschichte der Idee des schöpferischen Menschen", *Studium generale*, x (1957), 266–82. This kind of process can also be analysed from the perspective of the process of 'transformation of ancient science' during the early modern period. The structure of this process is being analysed as part of a project funded by the German Research Center (DFG), *Transformations of Antiquity*. As in the case of this present work, the research carried out as part of such a project focuses on single material objects. For a study concerning the cantilever model and its relation to the process of emergence of the theory of resistance of materials, see Matteo Valleriani, "The transformation of Aristotle's *Mechanical Questions*: A bridge between the Italian Renaissance architects and Galileo's first New Science", *Annals of science*, lxvi (2009), 183–208. For studies concerning pneumatic devices, see Matteo Valleriani, *From condensation to compression: How Renaissance Italian engineers approached Hero's pneumatics*, in Hartmut Böhme, Christof Rapp, and Wolfgang Rösler (eds), *Übersetzung und Transformation* (Berlin, 2007), 333–54; and Matteo Valleriani, *Il ruolo della pneumatica antica durante il Rinascimento: L'esempio dell'organo idraulico nel giardino di Pratolino*, in Arturo Calzona and Daniela Lamberini (eds), *La civiltà delle acque dal Medioevo al Rinascimento* (2 vols, *Ingenium*, Florence, 2010), ii, 613–32.

5. Up until the appearance of electrical devices, no history of hearing instruments from Antiquity had been written, and for what concerns the modern developments of these instruments, some works, not originating in the field of the history of science, have been published on the basis of the strict relation between hearing instruments and deafness. The secondary literature at our disposal on this subject, therefore, results mostly from the collaboration between companies that produced and are producing these devices. Other quite isolated research has been undertaken by hospitals and academic departments for otorhinolaryngology, which are obviously not concerned with an investigation of the commercially irrelevant prehistory of the auricle. Classical books along this line of research are Michael C. Pollack, *Amplification for the hearing-impaired* (New York, 1975), and Kenneth Walter Berger, *Hearing aid: Operation and development* (Milan, 1974).

6. For a survey on ancient theories of sound, their relations to practical realizations and the experimental

method, see Frederick V. Hunt, *Origins in acoustics: The science of sound from Antiquity to the age of Newton* (New Haven and London, 1978), 9–42. Since the dominant conception of sound at the beginning of the sixteenth century was Aristotelian, this article will disregard all other ancient conceptions and focus only on the scientific work that took place during the seventeenth century.

7. Harald Feldmann, *Die geschichtliche Entwicklung der Hörprüfungsmethoden* (Stuttgart, 1960).

8. Berger, *op. cit.* (ref. 5), 8.

9. Giovan Battista della Porta, *Magiae naturalis libri XX* (Naples, 1589).

10. Della Porta, *op. cit.* (ref. 9), 296–7.

11. Della Porta, *op. cit.* (ref. 9), 269–70. See also Albert Van Helden, "The invention of the telescope", *Transactions of the American Philosophical Society*, lxvii/4 (1977), 1–67. Della Porta claimed the paternity of the invention of the telescope in 1609 by writing directly to Federico Cesi: Giovan Battista della Porta to Federico Cesi, 28 August 1609, in Galileo and Favaro, *op. cit.* (ref. 1), x, 201. In this letter, however, della Porta quotes the ninth chapter of his *De refractione optices parte libri nouem* (Naples, 1593). Della Porta was clearly mistaken and probably wanted to mention the eighth chapter, which deals with the rules governing the functioning of mirrors. Although this knowledge plays a relevant role in understanding the innovative technological process that led to the appearance of the telescope, della Porta in this work did not even mention the possibility of combining a concave and a convex lens. For more details, see Sven Dupré, *Die Ursprünge des Teleskops*, in Jürgen Renn, Jakob Staude and Matteo Valleriani (eds), *Galilei und die Anderen* (Heidelberg, 2009), 32–42. See also Vincent Ilardi, *Renaissance vision from spectacles to telescopes* (Philadelphia, 2007).

12. Della Porta, *op. cit.* (ref. 9), 297: "Forma igitur instrumenti auditus oportet sit ampla, & concava & aperta, & intus cochleata, duplici de causa. Prima si soni intus rectè serrentur, oblænderent sensum, secundo quia per cochleam circumferuntur, & allisa vox per aurium anfractus, moltiplicatur, ut de echo videmus."

13. Jean Leurechon (van Hetten Henrik), *Récréation mathématique: composée de plusieurs problémes plaisants et facétieux* (Pont-a-Mousson, 1624). In the following, the first English translation is used: Jean Leurechon (van Hetten Henrik), *Mathematical recreations* (London, 1663).

14. During the early modern period the term 'problem' was used to denote texts and arguments or to describe isolated natural phenomena or the functioning and building procedures of instruments; they were usually short and compact in form. The use of this term was certainly related to the structure of the well-known Aristotelian text *Mechanical problems*. The scientific meetings among the Jesuits, for example, were called meetings to "recite a problem". On various occasions, Galileo also announced his intention to write "collections of problems". For more details, see Matteo Valleriani, *Galileo engineer* (Dordrecht, 2010), 132.

15. Leurechon, *op. cit.* (ref. 13, 1663), 87–8.

16. Francis Bacon, *Sylva sylvarum or a natural history in ten centuries* (London, 1627), 73.

17. The analogy between the ear trumpet and the telescope is valid only to a certain extent within the Aristotelian framework, for sound is not produced by the objects from which it is dispersed, as light is produced by the stars: sound is produced by a blow between two bodies. As will be shown in the next section, the Aristotelian conception of the nature of sound is weakened by this difference.

18. An analysis of the relation between the human hand and the tools to be operated within the frame of activity defined in Aristotelian terms (such as *techné*) can be found in Bartels, *op. cit.* (ref. 3), 275–87.

19. Aristotle, *On the soul*, in W. S. Hett (ed.), *On the soul. Parva naturalia. On breath* (Cambridge, MA, 1936), in *Aristotle in twenty-three volumes*, viii, 8–203, III, 2; 425 b 27–9.

20. Aristotle, *On the soul* (ref. 19), III, 2; 426 a 5–8.

21. Aristotle, *On the soul* (ref. 19), III, 2; 426 a 16–20. For an introduction to Aristotle's theory of sensible

qualities, see Ganson Todd Stuart, “What’s wrong with the Aristotelian theory of sensible qualities?”, *Phronesis*, xlii (1997), 263–82.

22. Aristotle, *On the soul* (ref. 19), III, 12; 434 b 30–435 a 1.

23. Stuart. *op. cit.* (ref. 21), 273.

24. Aristotle, *The physics* (ref. 3), VIII, 10; 267 a 2–10.

25. Pseudo-Aristotle, *On things heard*, in George P. Goold, *Minor works* (Cambridge, MA, 1980), in *Aristotle in twenty-three volumes*, xiv, 50–79, pp. 57–9. This text is generally believed to have been written by Aristotle’s pupils. Because of the lack of a critical edition, the history of the transmission of this text is still unknown.

26. Giuseppe Biancani, *Sphaera mundi, seu Cosmographia demonstrativa ac facili methodo tradita* (Bologna, 1620), 432.

27. Ausonio’s own copy seems to be lost. However, it was copied several times between the end of the sixteenth and the beginning of the seventeenth century. Galileo, for example, prepared a copy between 1592 and 1601, which is now preserved at the Biblioteca Nazionale Centrale of Florence and published in Galileo and Favaro, *op. cit.* (ref. 1), iii, Parte seconda, 865–71. Giovanni Antonio Magini, a mathematician in Bologna, copied and published a slightly altered version of Ausonio’s manuscript in Giovanni Antonio Magini, *Theorica speculi concavi sphaerici* (Bologna, 1602) and, finally, discussed the same phenomenon more expansively in Giovanni Antonio Magini, *Breve instruttione sopra l’apparenze: et mirabili effetti dello specchio concavo sferico* (Bologna, 1611). For the relevance of Ausonio’s text, see also Sven Dupré, “Mathematical instruments and the theory of the concave spherical mirror: Galileo’s optics beyond art and science”, *Nuncius*, xv (2000), 551–88, and especially Sven Dupré, “Ausonio’s mirrors and Galileo’s lenses: The telescope of the sixteenth-century practical optical knowledge”, *Galilaeana*, ii (2005), 145–80.

28. Marin Mersenne, *Harmonie universelle contenant la théorie et la pratique de la music. Paris, 1636* (3 vols, Paris, 1986).

29. At the beginning of the seventeenth century, optics was undergoing a remarkable development. A relevant role in this process was played by the works of Kepler: Johannes Kepler, *Ad Vitellionem Paralipomena, quibus Astronomiae pars optica traditur; potissimum de artificiosa observatione et aestimatione diametrorum deliquiorumque Solis & Lunae* (Frankfurt, 1604), *Dissertatio cum Nuncio Sidereo* (Prague, 1610), and *Dioptrice* (Augsburg, 1611).

30. The original text reads: “... car il s’en trouue plusieurs qui croyent que le Son n’est rien, s’il n’est entendu ..., i’estime que le Son n’est pas moins reel deuant qu’il soit entendu....” Author’s translation. Mersenne, *op. cit.* (ref. 28), 1.

31. Author’s translation. The original text reads: “un mouuement de l’air exterieur ou interieur capable d’estre ouy.” Italics in the original. Mersenne, *op. cit.* (ref. 28), 2.

32. Mersenne explained his view on these aspects in Propositions VI and VII of the first book: *ibid.*, 11–14.

33. No early work on the functioning of musical instruments and, especially, about the way they amplify sound is known to date. Research based completely on primary sources is required, eventually investigating the practical knowledge in which Mersenne’s reflections are rooted.

34. Galileo Galilei, *Discorsi e dimostrazioni matematiche intorno à due nuove scienze* (Leiden, 1638). Reprinted in Galilei and Favaro, *op. cit.* (ref. 1), viii, 39–318.

35. Galileo had already briefly touched upon the issue of the nature of sound in 1623 in *Il saggiatore*. On this occasion, Galileo clearly refuted the Aristotelian conception of sound as a sensible quality and advanced the idea that sound, like heat, can be considered as movements in air. For more details, see Galileo Galilei, *Il saggiatore* (Rome, 1623), reprinted in Galileo and Favaro, *op. cit.* (ref. 1), vi, 197–372, pp. 346–50. In the first of the four Days of which the 1638 *Discorsi* is constituted, Galileo considered several acoustic phenomena, especially those related to vibration frequencies. He gave a compact exposition of the results of his experiments on the following topics

related to acoustics, listed here in modern terms: the relation of pitch to frequency, consonance and dissonance, the correspondence between frequency ratios and musical intervals, vibratory resonance, sympathetic vibrations, and the quantitative dependence of the frequency of vibration of a string on its length, diameter, density and tension. For Galileo's exposition, see Galileo and Favaro, *op. cit.* (ref. 1), viii, 141–50. On the relevance of Galileo's experiments to the history of acoustics, see Hunt, *op. cit.* (ref. 6), 80–2. Galileo's interest in harmonics and acoustics should not be dated to the time of the publication of the *Discorsi*. Particularly in reference to the correspondence between frequency ratios and musical intervals, Galileo's investigations had been reported by Galileo himself to Federico Cesi, patron of the Accademia dei Lincei, back in 1619. For more details, see for example, Federico Cesi to Giovanni Faber, 14 January 1619, in Galileo and Favaro, *op. cit.* (ref. 1), xii, 436.

36. "Quod spectat ad motum aëris ipsius à corpore usque sonante versùs aurem tendentis, id permirum est, quæcumque sit tandem sive vehementia, sive remissio, quo à sonante exagitatur, translationem eius per spatium esse semper æqui-velocem." From Pierre Gassendi, *Petri Gassendi Opera omnia* (Leiden, 1658; reprinted Stuttgart-Bad Cannstatt, 1964), i, 417–18 (*Petri Gassendi Syntagma philosophicum, Petri Gassendi Syntagmatis philosophici pars secunda, quae est phisica, Phisicae sectio prima de rebus naturae universe, Liber sextus de qualitatibus rerum, Caput X De sono*).

37. For an introduction to the work of the Accademia del Cimento, see W. E. Knowles Middleton, *The experimenters* (Baltimore and London, 1971), and Luciano Boschiero, *Experiment and natural philosophy in seventeenth-century Tuscany: The history of the Accademia del Cimento* (Dordrecht, 2007).

38. Lorraine Daston, "Unruly weather: Natural law confronts natural variability", in Lorraine Daston and Michael Stoilleis (eds), *Natural law and laws of nature in early modern Europe: Jurisprudence, theology, moral, and natural philosophy* (Farnham, 2008), 233–48.

39. In this present work the second edition is used: *Saggi di naturali esperienze*, 2nd edn (Florence, 1691). For the section dedicated to the movements of sound, see pp. 241–5.

40. *Ibid.*, 243–4.

41. For more details, see Boschiero, *op. cit.* (ref. 37), 52–5.

42. Antonio Favaro, *Amici e corrispondenti di Galileo* (3 vols, Florence, 1983), ii, 1043.

43. BNCF, Mss Galileiani, Cimento, iv, car. 261. See also Favaro, *op. cit.* (ref. 42), ii, 1043, ref. 1.

44. Favaro suggested that this investigation by Viviani was somehow related to or even inspired by the work of Aproino, Galileo's pupil and colleague. As will be shown, however, this is quite improbable, for in the end, Aproino suggested building the ear trumpet by using a hyperbolic curve on their longitudinal section, rather than a parabolic curve. Moreover, Aproino was a pupil of Galileo during his time in Padua, whereas Viviani was a pupil only towards the end of Galileo's life.

45. For an introduction to Athanasius Kircher's life and work, see Daniel Stolzenberg (ed.), *The great art of knowing: The baroque encyclopedia of Athanasius Kircher* (Stanford, 2001).

46. Athanasius Kircher, *Musurgia universalis sive ars magna consoni et dissoni* (Rome, 1650).

47. The original text reads: "... ita maximas quoque vires obtinet." From Kircher, *op. cit.* (ref. 46), ii, 277.

48. Athanasius Kircher, *Athanasii Kircheri Phonurgia nova, sive, Conjugium mechanico-physicum artis & natvra paranympha phonosophia concinnatum* (Campidona, 1673), 158.

49. An interesting biographical work on Samuel Morland is H. W. Dickinson, *Sir Samuel Morland: Diplomat and inventor, 1625–1695* (Cambridge, 1970).

50. Samuel Morland, *Tuba stentoro-phonica* (London, 1671).

51. Morland, *op. cit.* (ref. 50), 1.

52. Despite their similarity, speaking and ear trumpets work on the basis of different principles and Morland investigated the behaviour of sound lines only in reference to sound exiting the speaking trumpet. From the physical point of view, however, at the end of the seventeenth century the difference

between the ear and speaking trumpets was not yet recognized, as the theory of receivers in theoretical acoustics is relatively recent. For more details, see Leonhard Euler, *Leonhardi Euleri Commentationes mechanicae: ad theoriam corporum fuidorum pertinentes, volumen posterius*, in Clifford A. Truesdell, *Leonhardi Euleri Opera omnia* (77 vols, Leipzig, 1955), Section 2, Book 13, vol. ii, pp. XIXff.

53. Morland, *op. cit.* (ref. 50), 5, italics in original.

54. Laurent Cassegrain de Chartres, "Report of a letter received from N. Cassegrain de Chartres", *Journal des sçavans*, 1672, supplement, 2 May 1672, 124–31.

55. Hunt, *op. cit.* (ref. 6), 127–8.

56. Galileo testified to Aproino's affiliation to his school in the sixth chapter of his *Discorsi* (ref. 34). Galileo's *Discorsi* was originally conceived as being constituted of six sections, each of them defined as a Day (of discussion). The last two Days, however, were never completed and their manuscripts were first published by Antonio Favaro in Galileo and Favaro, *op. cit.* (ref. 1), viii, 319–46. At the beginning of the Sixth Day, Simplicio, one of the speakers in the dialogue, is said to be absent because it had been too difficult for him to understand the topics of the first five Days. Sagredo, another speaker, thus introduces Aproino as a new speaker, a person possibly equipped with a more acute mind.

57. Daniello Antonini is quoted at the beginning of the Sixth Day of the *Discorsi* as well.

58. Favaro, *op. cit.* (ref. 42), ii, 730.

59. Paolo Aproino to Galileo, 27 July 1613, in Galileo and Favaro, *op. cit.* (ref. 1), xi, 540–4, author's italics. The translation of the complete letter is appended below.

60. Galileo to Belisario Vinta, 7 May 1610, *ibid.*, x, 348–53, author's italics.

61. See ref. 59.

62. Paolo Aproino to Galileo, 26 January 1613, in Galileo and Favaro, *op. cit.* (ref. 1), xi, 470–1.

63. Paolo Aproino to Galileo, 25 May 1613, *ibid.*, xi, 513–14.

64. Paolo Aproino to Galileo, 1 June 1613, *ibid.*, xi, 517–19. The translation of the complete letter is appended below.

65. See ref. 59.

66. Guillaume Rondolet, *Universae aquatilium historiae pars altera, cum vero ipsorum imaginibus* (Leiden, 1555).

67. Rondolet's *History* was republished four years later as a sort of appendix to a much larger work by the same author: Guillaume Rondolet, *Libri de piscibus marinis* (Leiden, 1559). In the first part of this later work, which Aproino did not know, there is a chapter describing ears and explaining how they work. Rondolet stated that (i) the more rigid the flesh of which the ear is constituted, the more the sound resounds; (ii) the inside of the ear has revolutions which causes it to resemble the cochlea, so that the sound can resound better, as in the case of the echo; and (iii) those who have an impaired sense of hearing can be helped with the auricola built by imitating nature! For more details, see pp. 49–50 of his work.

68. Rondolet, *op. cit.* (ref. 66), 81–3. The *buccinum* is already mentioned by Pliny. In ancient times, the *bucina* was an instrument used during the classical Roman period. It was a trumpet employed during military campaigns, for example, or to mark the time intervals between day and night in Rome. Classical Latin literature contains many mentions of the *bucina*. One example is Ovid, *Metamorphoses*, 1.335. For Pliny's description of the *nautilus*, see Pliny and H. Rackam, *Natural history* (Cambridge, MA, 1952; reprinted 1983), iii, Book 9, 232–33.

69. According to Aproino's narration, he never thought of applying a cut seashell to help the hard of hearing.

70. Clearly, no one would have been surprised at this phenomenon during the seventeenth century and what Aproino wrote are clearly the rhetorical passages for an introduction to a treatise presenting the ear trumpet.

71. See ref. 59.

72. Boethius, *De institutione musica libri quinque*, in Gottfried Friedlein (ed.), *De institutione arithmetica libri duo. De institutione musica libri quinque* (Leipzig, 1867).

73. Boethius, *op. cit.* (ref. 72), esp. p. 200.

74. The first biography of Maurolicus appeared as early as 1613: Francesco Barone della Foresta, *Vita dell'Abbate del Parto D. Francesco* (Messina, 1613).

75. Franciscus Maurolicus, *Musicae traditiones*, *Opuscola mathematica* (Venice, 1575).

76. *Ibid*., 145–60.

77. It is very difficult to provide an unambiguous translation of Maurolicus's statement. The complete original sentence reads: "Quod in tibijs, tubis, atque cannis, aer flatu, aut follibus impulsus ac per foramina illisus, reciproco ac tremebundo motu, angustias laterum reverberans efficit." From Maurolicus, *op. cit.* (ref. 76), 146.

78. Marcus Pollio Vitruvius and Daniele Barbaro, *I dieci libri dell'architettura di M. Vitruvio* (Venice, 1567; reprinted Milan, 1997), 243–7.

79. Alfonso Pezzi, "Considerazioni sull'acustica delle sale" (Alma Mater Studiorum Università di Bologna, Facoltà d'Ingegneria, 2003). On the efficiency of Vitruvius's *vasa*, see Victor Desarnaulds, Yves Loerincik, and Antonio P. O. Carvalho, "Efficiency of 13th-century acoustic ceramic pots in two Swiss churches" (paper presented at the Noise-Con 2001, Portland Maine, 29–31 October 2001).

80. See ref. 59.

81. Aproino was not really sure about the opening of the second trumpet and indicated to Galileo that it was between 23 and 25 degrees.

82. It is likely that Aproino's story about Rondolet's book during his holiday is made up since it is known from other sources that the idea of providing the court with an ear trumpet was Galileo's. However, it is still relevant that Aproino intended to present his project as originating from investigations using current scientific methods that were based on the principle of imitation of nature. This principle, moreoever, is also reflected by the word Aproino uses for ground noise: *bucinamento*, which is clearly related to the Latin denotation of the *nautilus* and of the mentioned classic trumpet built to resemble it.

83. See ref. 59.

84. See ref. 59.

85. The textual description of the method is in *ibid.* For the art of the trumpet-makers, see Robert Barclay, *The art of the trumpet-maker: The materials, tools and techniques of the seventeenth and eighteenth centuries in Nuremberg* (Oxford, 1996).

86. The scientific and social aspects of the debate that ended with Galileo's publication of his *Floating bodies* in 1612 is analysed in Mario Biagioli, *Galileo courtier* (Chicago, 1993), and in William R. Shea, *Galileo's intellectual revolution: Middle period, 1610–1632* (New York, 1972).

87. Galileo promised but never gave a theoretical explanation of the functioning of the telescope. Instead he demonstrated to the greatest possible number of people that it worked. For more details, see Mario Biagioli, *Galileo's instruments of credit* (Chicago, 2006), 81ff.

88. For the normative aspects of the role of the court in the scientific practice of the Renaissance I thank the profound insights of an anonymous reviewer.

89. An extensive study of Galileo's profile as an engineer in Padua has been published in Valleriani, *op. cit.* (ref. 14).

90. See ref. 59.

91. For an in-depth study of Galileo as an engineer and engineer-scientist, see Valleriani, *op. cit.* (ref. 14); Matteo Valleriani, "Galileo in the role of the caster's assistant: The 1634 bell of the Torre del Mangia in Siena", *Galileana*, v (2008), 89–112; Matteo Valleriani, "A view on Galileo's 'Ricordi Autografi': Galileo practitioner in Padua", in Jose Montesinos and Carlos Solís (eds),

Largo campo di filosofare (La Orotava, 2001), 281–92; and Jürgen Renn and Matteo Valleriani, "Galileo and the challenge of the Arsenal", *Nuncius*, xvi (2001), 481–503.

92. In 1675, for example, Newton mentioned an ear trumpet that he considered longitudinally shaped with a gradual curvature compounded by the curve of a cone and the curve of a hyperbole. For more details, see Newton to Oldenburg, 30 November 1675, in Isaac Newton, *The correspondence of Isaac Newton* (7 vols, Cambridge, 1959–77), i, 359–60. From the end of the seventeenth century on, practical acoustics resulted more and more from the impressive development of applied theoretical acoustics after Newton's time. For a survey on the theoretical developments in acoustics during the eighteenth century, which touches upon the works of Daniel Bernoulli, Joseph Louis Lagrange and Leonhard Euler, see Leonhard Euler, *op. cit.* (ref. 52), pp. XIX–LXXII.

93. A similar result was achieved in the context of a study concerning the thermoscope. For more details, see Valleriani, *op. cit.* (ref. 14), 155–90.

94. Rondolet, *op. cit.* (ref. 66).

This text was published on page 31 of the article "Galileo's abandoned project on acoustic instruments at the Medici Court."