Brunelleschi's mirror, Alberti's window, and Galileo's 'perspective tube'

O espelho de Brunelleschi, a janela de Alberti e o 'tubo' de Galileu

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This essay argues that the advent of linear perspective, ca. 1425, when Filippo Brunelleschi painted a small panel of the Florentine Baptistery by applying the geometric rules of optical mirror reflection, was more than just an artistic event. Indeed, it subsequently had the most profound – and quite unanticipated – influence on the rise of modern science. Surely, by 1609, Galileo would not have understood what he saw when observing the moon through his newly invented optical telescope, then called the 'perspective tube,' had it not been for his training in perspective drawing. Yet, Brunelleschi's original dependence on the mirror two centuries earlier was intended not to reveal objective 'scientific' reality, but rather to reinforce Christian spiritual 'reality.' In 1435-6, Leon Battista Alberti, when codifying Brunelleschi's perspective in his famous "Treatise on Painting," substituted a gridded window for Brunelleschi's mirror, thus redirecting the purpose of perspective art away from revealing God's divine order as reflected on earth, to a more secular physical reality viewed directly in relation to human moral order.

KEYWORDS: linear perspective; Renaissance art; modern science.

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O presente ensaio defende que não foi somente um acontecimento artístico o advento da perspectiva linear (c. 1425), quando Filippo Brunelleschi ao pintar um pequeno painel no Batistério Florentino lançou mão das regras geométricas da reflexão em espelho ótico. Esse acontecimento veio a exercer uma profunda e inesperada influência no surgimento da ciência moderna. Com certeza, por volta de 1609, Galileu não teria compreendido o que via quando observava a lua através de seu recém-criado telescópio ótico, então chamado 'tubo de perspectiva', se não fosse sua familiaridade com o desenho em perspectiva. No entanto, a original dependência do espelho que Brunelleschi desenvolveu dois séculos antes não almejava revelar uma realidade 'científica' objetiva, mas sim reforçar a realidade espiritual cristã. Em 1435-36, Leon Battista Alberti, ao codificar a perspectiva de Brunelleschi em seu famoso "Tratado de pintura", substituiu o espelho de Brunelleschi por uma janela gradeada, assim redirecionando o propósito da arte da perspectiva, cujo intuito era não mais a revelação da ordem divina refletida na terra, mas sim de uma realidade física, mais secular, vista diretamente em sua relação com a ordem moral humana.

PALAVRAS-CHAVE: perspectiva linear; arte do Renascimento; ciência moderna.

Figure 1 is an illustration from a sixteenth-century manual on how to draw a simple picture in linear perspective. Figure 2 shows the twentieth-century rocket-powered Apollo spaceship preparing to drop its Eagle lander on the surface of the moon. In this essay, I argue that the construction of such complex mechanical devices, and even the possibility that the Eagle could stand on such an extraterrestrial body, could never have been realized without the humble artistic technique diagrammed in Figure 1. Indeed, linear perspective for painters, first conceived by the Italian artisan Filippo de Ser Brunelleschi in Florence (1377-1446), was one of the most decisive ideas in the history of Western technology and science as well as art. [1]

[1] This essay is actually itself an 'abstract' of a new book of the same name I am currently writing.

In the history of technology everywhere in the world, including the West, before the fifteenth century, mechanical apparatuses of whatever sort were never constructed from scale plans. Sometimes pictures were used, as in this quite non-perspective drawing from a fourteenth-century Islamic manuscript (Figure 3), but only to suggest the general purpose of the machine (a water pump) so that a skilled artisan, who already knew how to build such devices, could simply be reminded of what he was to construct, with little more than a glance at the image. In any case, it's obvious that the picture is hardly an accurate diagram-to-scale from which a three-dimensional working model could be fabricated.

Look now at Figures 4 and 5. The former is a drawing of a suction pump by an early fifteenth-century Italian engineer called Taccola (1381-ca.1453). He already knows about the new linear perspective, and his scale drawing could indeed be used in order to build from it a three-dimensional working model. But observe again: there's a flaw evident in this drawing. As the crank at the top turns, the rope that pulls the piston up and down must oscillate back and forth with every turn, causing the piston to rub each side of the circular wellhead until it is eventually bent into the shape of an oval, and thus cause the pump to loose suction and become dysfunctional!

What's interesting is that this pump never needed to be built in order to prove, at expensive cost, that it would indeed quickly fail. Taccola's successor, the great Italian engineer, architect, and painter, Francesco di Giorgio Martini (1439-1501), realized the flaw instantly, simply from studying this earlier drawing. Without even having to reconstruct a model of the old pump in order to test its oscillating action, he was able to redesign it with an ingenious, correcting improvement. Notice that the crank in his, the latter Figure 5, now has a rolling slip ring around it, and the piston rod has a loop in the top in which the slip ring can roll back and forth so the piston only goes straight up and down, and never wobbles, thus causing no damaging friction.[2]

[2] For more on the Italian (Sienese) engineers, Taccola and Francesco di Giorgio Martini, see my earlier book: Edgerton, 1991, p. 125-39.

Figure 1

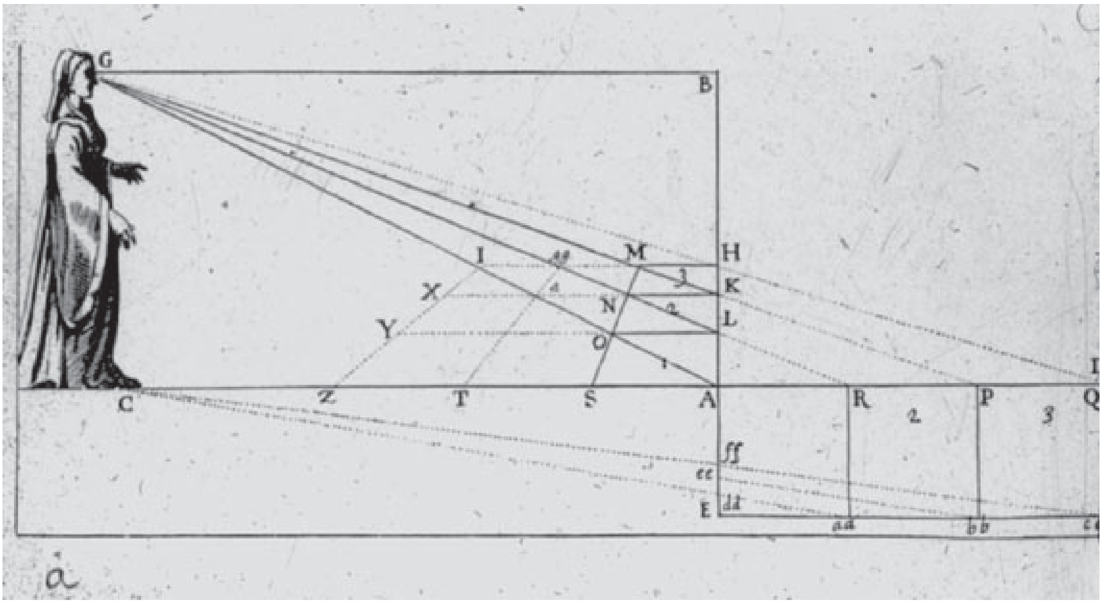


Figure 2

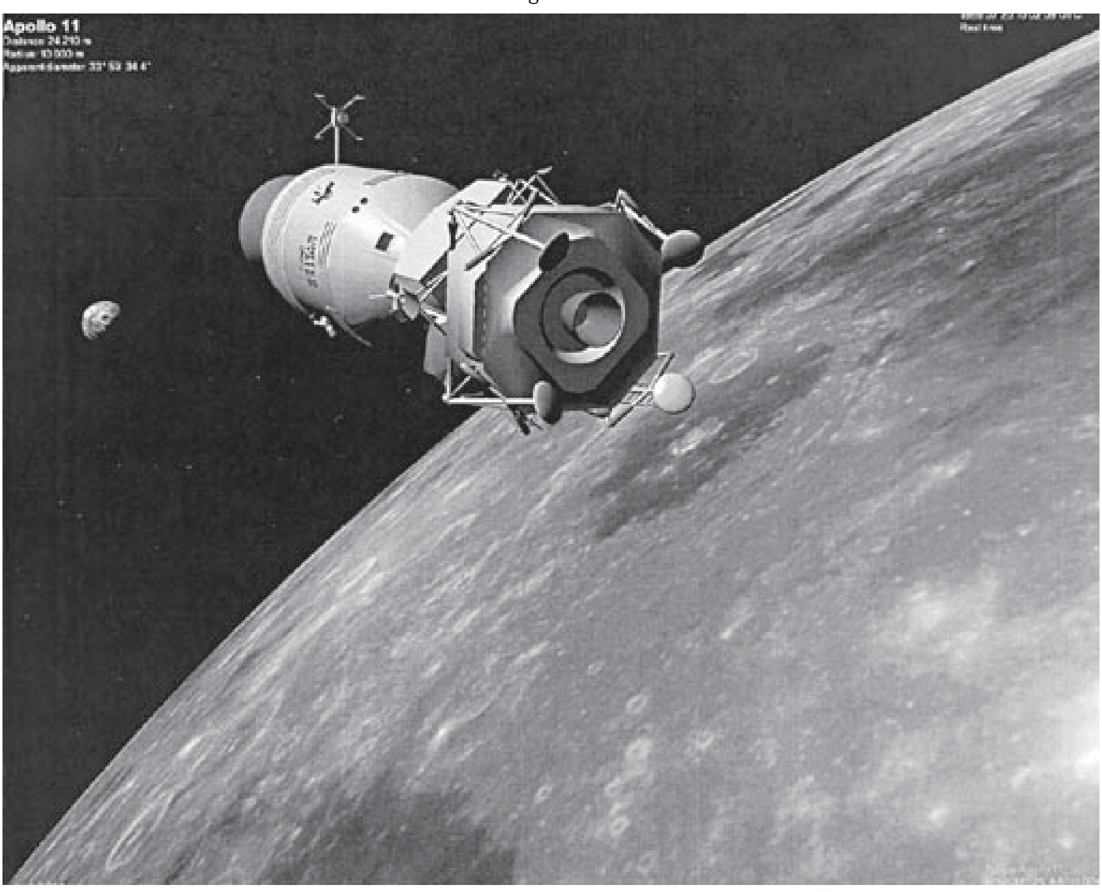


Figure 3

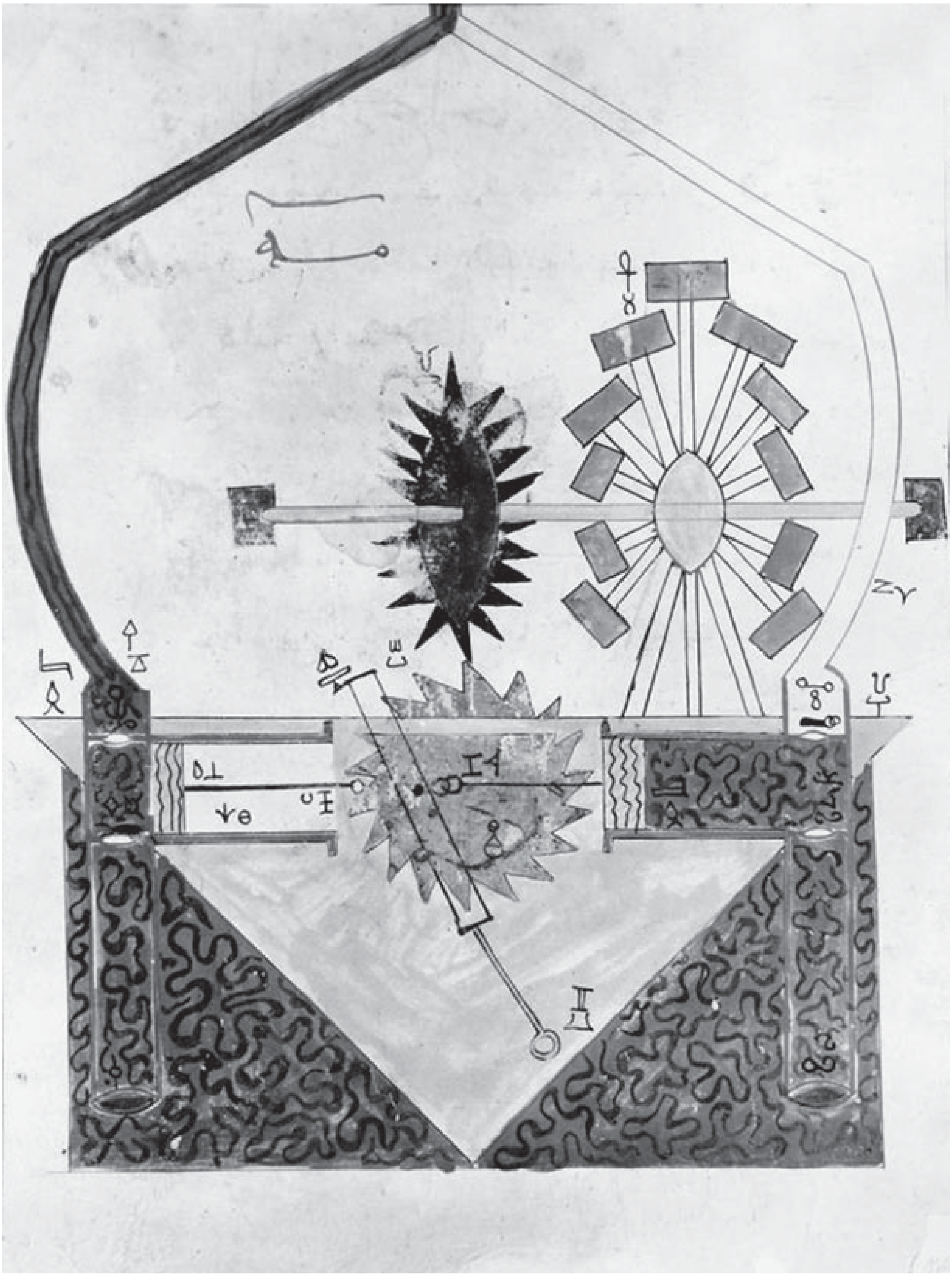


Figure 4

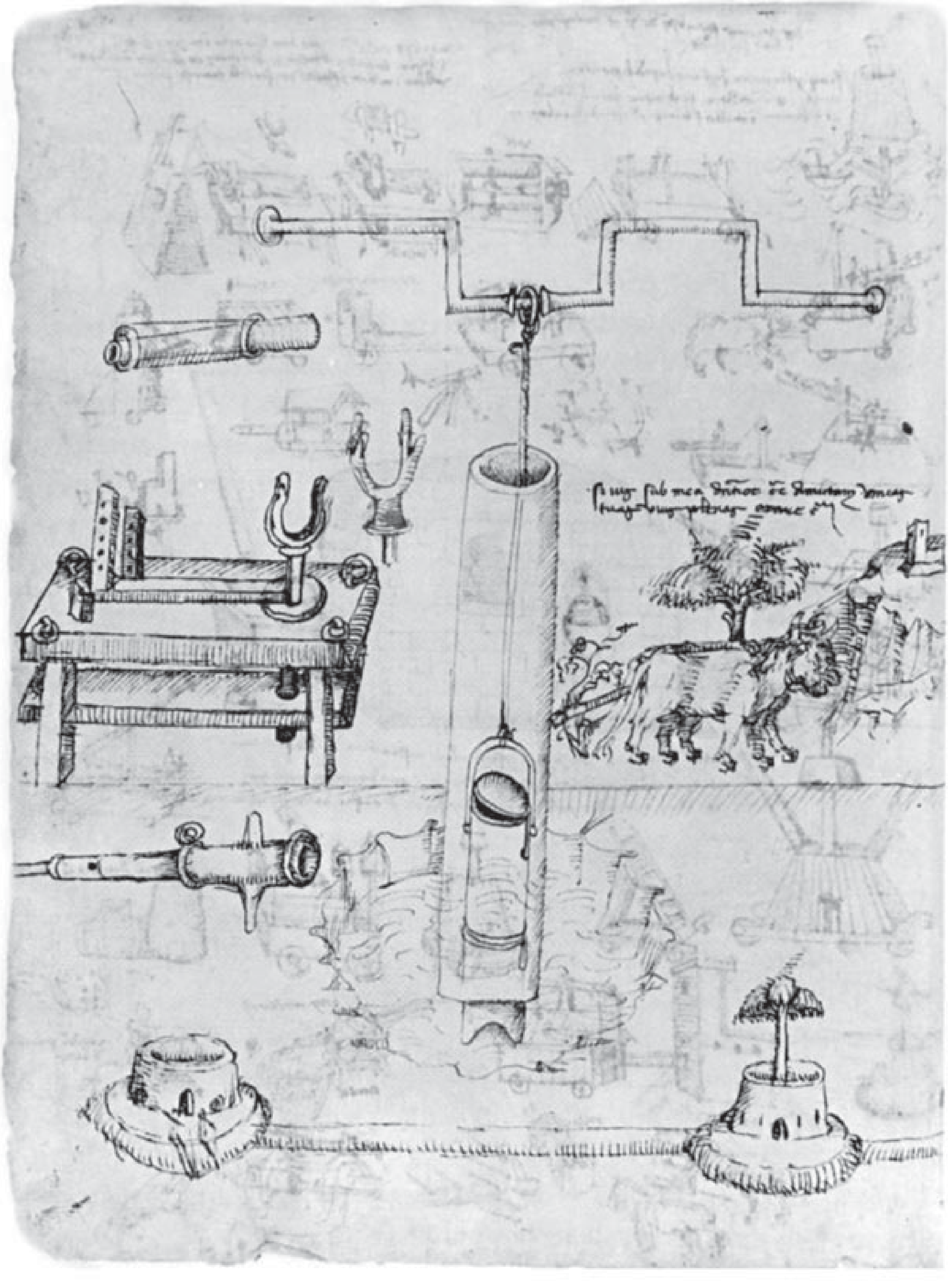
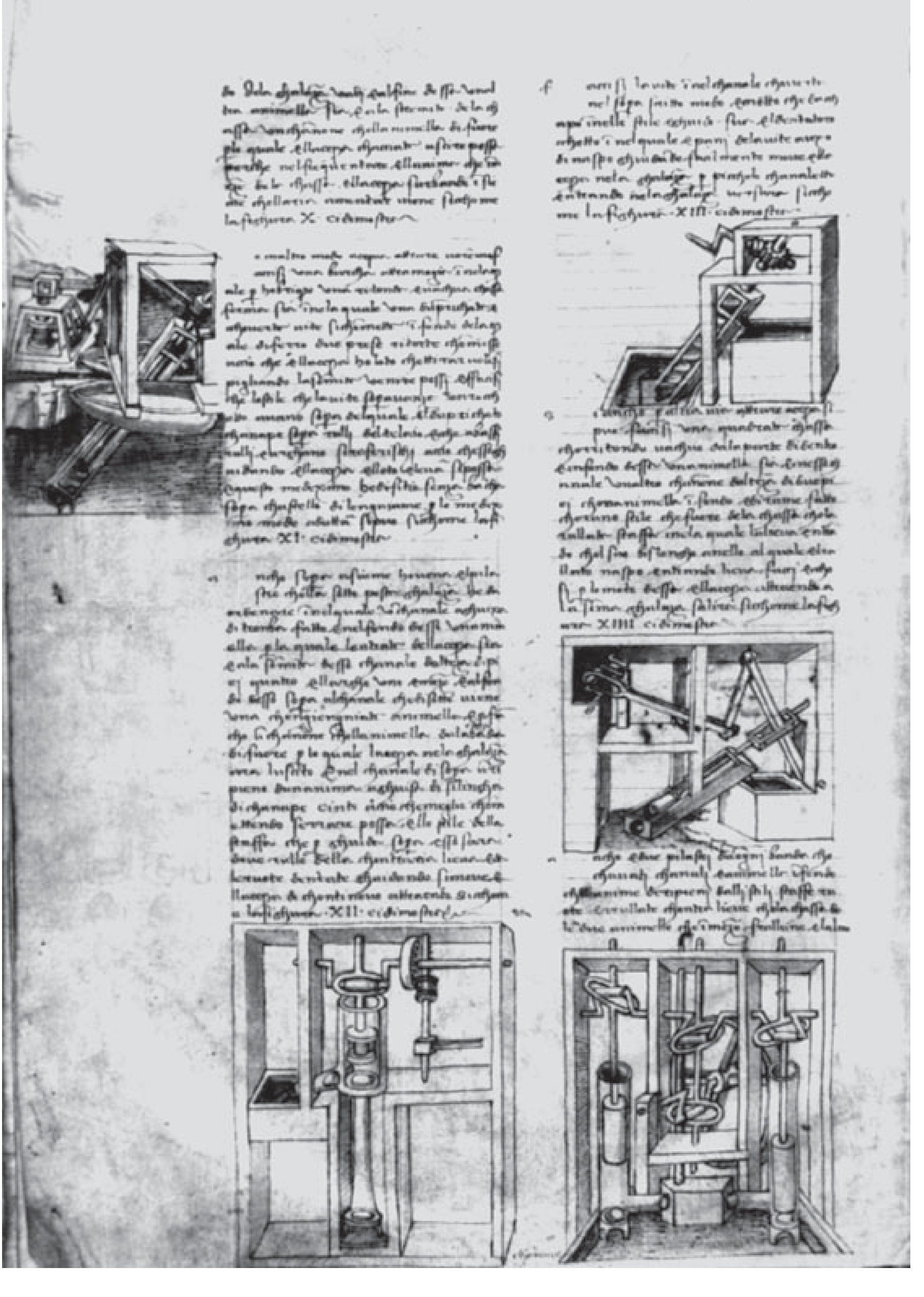


Figure 5



These simple drawings, dependent as they were on the draftsmen's knowledge of linear perspective to scale, indicate graphically what this unique Renaissance art technique bequeathed to modern technology, and even to modern science, as I shall show an amazing example of shortly. To repeat, linear perspective drawing to scale made it possible to invent, improve, and correct the most complex machinery without having to waste time and money building and testing actual three-dimensional models. No rocket ship to the moon could ever have been invented, let alone be built, without the humble heritage of Renaissance linear perspective.

The rest of my essay will now be devoted to how that remarkable and unexpected relationship came about. Indeed, as we shall now see, linear perspective was first devised with no such scientific application in mind, but solely to help solve a very medieval theological problem, the burgeoning feeling among many intellectuals of the late Middle Ages that the traditional styles of religious painting no longer inspired the faithful sufficiently, especially during a gloomy time when the Holy Mother Church was suffering a number of traumatic crises like the loss of Jerusalem and the failure of the Christian Crusades, the terrible Schism of Church itself, and the even more terrible onset of the Black Death in the fourteenth century. In these miserable times, many people thought that God had abandoned them. What was needed in order to restore the faith, many community leaders and churchmen felt, was to make people feel that God and his saints were once more immanent in their daily lives, and that people could see and touch them just as if they were actual life-size persons in the here and now. Even figuratively putting their fingers in Jesus' wounds – just as Saint Thomas did – in a famous Florentine statue, so illustrative of this famous Biblical proof (Figure 6), by the sculptor, Andrea del Verrocchio (ca.1435-1488), teacher of Leonardo da Vinci and whose surname, by the way, means 'True Eye.'

Figure 6

Ironically, the currently popular early fifteenth-century "International Style" of painting, even religious painting as displayed in churches, was anything but inspirational. It tended to be frivolous, gaudily colored and cluttered with sensual, hardly spiritual trivia, like this well-known altarpiece by Gentile da Fabriano (ca.1370-1427), painted in 1423 (Figure 7). No less than the Dominican archbishop of Florence, Fra Antonino Pierozzi (1389-1459), later canonized as Saint Antonine, spoke out in a public sermon against such painters whose art he disclaimed because they showed "oddities, which do not serve to excite devotion, but laughter and vanity, such as monkeys and dogs chasing hares, and the like, or vain adornment of clothing." [3]

Of great interest is that Antonino frequently laced his sermons with references to a newly arrived science in Italy, actually an old Greek science related to Euclidian geometry, called όπτική in Greek or *perspectiva* in Latin: the study of how light rays travel in straight lines but always fanning out pyramidally from the light source, and how the eye receives these rays and thus sees. After the rise of Islam in the seventh century, this science, now forgotten in the West, was re-discovered and expanded upon by the Arabs. Only after the slow re-conquest of Moorish Spain and Sicily, beginning in the eleventh century, did Western Christians learn of it once

[3] Antonine, *Sancti Antonini Summa Theologica* (facsimile of Verona, 1740 edition), Graz (Akademische Druck u. Verlagsanstalt), Graz, 1959, 4 vols. This Latin original of this text is found in v. 3, Titulus 8, Chapter 4, Column 322. See also the further discussion of this passage by Creighton Gilbert, 1959, p. 75-87.

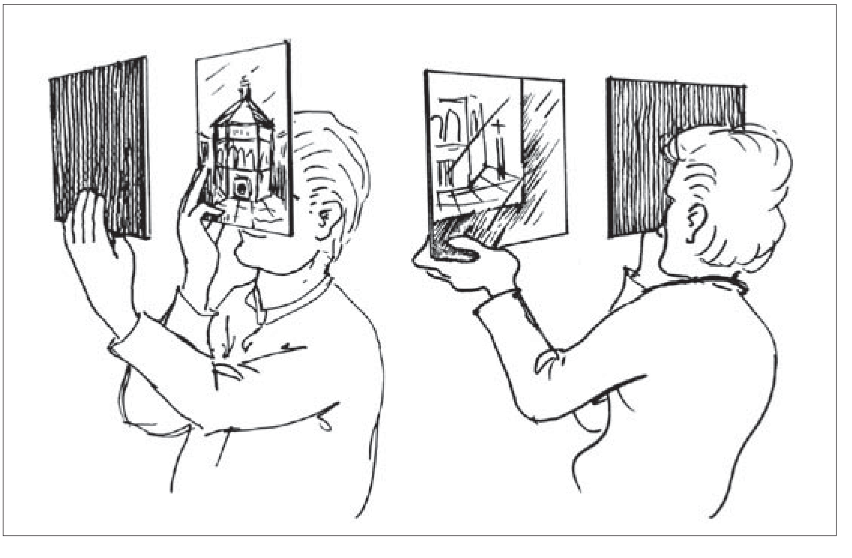
Figure 7

more (Lindberg, 1976). By the early fifteenth century, it had spread to most of the universities of Western Europe, and many preachers, especially Antonino, liked to make moral analogies based on *perspectiva* principles (Antonine, op. cit., v. 3, Titulus 9, Chaps. 1-3).

But let me stress that this ancient science, which today we call 'optics,' had as yet nothing to do with the "perspective of painting." It had strictly to do with explaining how light rays enter the eye, how light rays refract when entering a denser medium, and how mirrors reflect. Then, suddenly some time around 1425, the Florentine sculptor, engineer, architect, and all-around artisan-impresario, Filippo Brunelleschi, painted a small picture of the Florentine Baptistery to be viewed by looking at its mirror reflection through a small hole drilled in the back of the picture with the mirror held at arm's length in front (Figure 8) (Saalman, 1970, p. 10-1). A contemporary of Brunelleschi who must have seen the original picture claimed the artist actually discovered his new rules by applying the same optical geometry that the old science had long since divined as to how objects are reflected in mirrors (Spencer, 1965, v. 2, p. 178v-179r). Unfortunately, this remarkable artwork has been lost since the mid-fifteenth century. Scholars generally agree however that it was the first painting in all of world art history to have been constructed according to the geometric laws of what we now understand as artistic 'linear perspective,' or what at the time was called *perspectiva artificialis* to distinguish it from *perspectiva naturalis*, the original science of optics.

Mirrors in the late Middle Ages were not only objects of scientific optical study, but were believed to have some sort of divine significance. Pilgrims often carried them to sacred shrines in order

Figure 8



to capture the reflections of holy relics, the miraculous powers of which were believed to be retained in the mirror even when the reflections themselves had disappeared (Schwarz, 1959, p. 90-105). Moreover, earthly reality itself was thought to be only a weakened mirror reflection of the perfect reality of heaven. Antonino often sermonized about the mirror as allegory of human mortality, especially as implied in the famous words of St. Paul in his Epistle to the Corinthians (I, 13:12): *"videmus nunc per speculum in enigmata tunc autem facie ad faciem"* in the Vulgate Latin, which was translated into the austere King James English as "For now we see through a glass darkly but then face to face" but which should be more literally rendered as, "At present we see things indistinctly, as in a mirror, but then face to face."

Brunelleschi's demonstration indeed permitted viewers to believe that they had penetrated the very enigma of the mirror, to see both the virtual reflection and actual Baptistery 'face to face' behind the reflection, just as St. Paul had preached. His small hand-held panel of the Baptistery astonished fifteenth-century Florentines because it revealed not just a superior likeness in the modern secular 'photographic' sense, but rather because the artist's perspective image seemed to enhance as never before the sacredness of the Florentine Baptistery. Moreover, Brunelleschi's viewers were enticed to believe themselves envisioning the very process by which "the prophets see God or his divine mysteries behind the images and likenesses of sensible things," as Antonino preached. "Spiritual geometry works to measure temporal things … It measures dimensions not as quantities but as virtues within God…" (Antonine, op. cit.; see also Edgerton, 1977, v. I, p. 115-30).

Nevertheless, the first written connection between art and optical science was not recorded until 1435, when the humanist-scholar, Leon Battista Alberti (1406-72), stepped literally into the picture. In that and the next year, Alberti wrote a book on painting in two versions: *Della pittura* in Italian and *De pictura* in Latin, the first book to treat the visual arts as an appropriate humanist subject, as worthy of the same intellectual study as the great classics of antique Greek and Roman literature (Alberti, 1972). Alberti, who certainly accepted without question all the religious analogies between *perspectiva naturalis* and divine intention, nevertheless preferred to bring the matter more down to earth, as it were. For him the real advantage of Brunelleschi's method was that the very rigidity of its structure and strict adherence to such an absolute law of nature as Euclid's geometry must signify not just divine order but also human moral order. Alberti was so taken by the fecundity of the arts flourishing in Florence (he dedicated the Italian version of his book to Brunelleschi) that he now believed that painting in particular, if it followed the rules correctly, could provide ethical guidance to noble human behavior just as surely as the writings of Cicero.

Alberti's actual perspective method was no more than a codification of Brunelleschi's method already in practice by a number of artists in 1435, but he did present it in the form of simple sequential steps which, as his treatise increasingly circulated in Italy and across the Alps, helped to proliferate the new art-science throughout Europe (Figure 9). His most original contribution, however, was what has ever since become known as 'Alberti's window' (Figure 10), an open frame gridded by perpendicular threads through which the artist should view the scene to be painted, and then transfer the coordinate details in scale onto his similarly gridded picture. In essence, even if inadvertent, it shifted the purpose of perspective painting not as a depiction of divine mystery revealed by geometry, but as worldly perfection framed by geometry.

By the early sixteenth century, however, even as Alberti's perspective method was accepted almost everywhere in Western Europe as providing the ultimate illusion of visual reality in art, Italian painters, while not abjuring the optical truthfulness of Alberti's perspective, nonetheless began to tire of its geometric rigidity. Furthermore, they were finding new visual excitement in creating the illusion not so much of depth but of frontal projection. This new fascination was remarkably encouraged by recent archaeological discoveries of ancient Roman relief sculpture, where

Figure 9

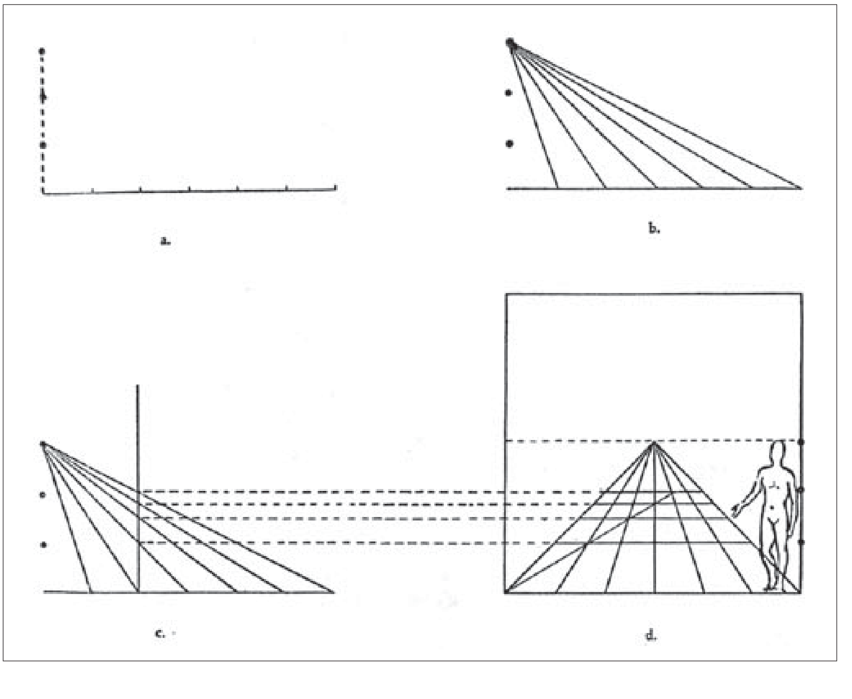


Figure 10

figures were carved protruding from the surface of stone or plaster, arranged as if in lateral procession with their forms made visible not by painted colors but by the contrast between their lighted and shaded sides, and the actual shadows they cast against the background plane. Instead of simulating a 'window' view of deep space beyond the pictorial surface, the ancient carvers created an equally 'lifelike' illusion of forward projection. This new archaeological fascination, especially after the 1520's, resulted in a widely popular 'relief-like' style of classical painting in central Italy (Hall, 1999). Artistic mastery of this novel mode nevertheless still depended on knowledge of basic Albertian perspective as applied to the related optical geometry of shadow casting, the laws of which had likewise been enumerated by Alberti in his 1435/6 Treatise on Painting.

Finally, fast-forwarding to seventeenth-century Florence, nearly two hundred years after Brunelleschi's mirror and Alberti's window had impressed their profound effects upon European art and thought, we encounter Galileo Galilei (1564-1642), the great astronomer and physicist. Not surprisingly, the birth of Galileo in nearby Tuscan Pisa on February 15, 1564, just three days before the death of the great Michelangelo Buonaroti in Tuscan Florence, has given rise ever since to speculation that there must have been some kind of occult connection between these two events (Bredekamp, 2000, p. 423-62). For indeed, Galileo, about to become as equally revered in science as Michelangelo in art, did seem mysteriously to have inherited a strain of that same artistic talent. Whether or not Galileo's remarkable ability owed to the above coincidence, or just to the fact that for the past three centuries such talent seemed almost genetic in the Tuscan population, his profound understanding of linear-perspective drawing, called *disegno* in Italian, nonetheless helped mightily to open his eyes to new revelations of nature that had escaped understanding everywhere in the world since the beginning of the human race.

Two years before Galileo's birth, Giorgio Vasari (1511-74), the 'first art historian,' had founded the *Accademia del Disegno* (Academy of Drawing) in Florence. This was intended to be an organization where painters, sculptors, and architects could meet together not as mere artisan guild-members but as intellectuals, conversing about current trends in philosophy, literature, and science. Vasari wanted to establish a center where artists could keep up to date on geometry and anatomy, the sciences he believed essential to the practice of the visual arts. Under geometry, he especially stressed the study of both linear perspective and *chiaroscuro*, literally 'light-dark,' the rendering of shades and shadows. The Academy should even provide for a professional geometer to teach these subjects to less-prepared artist-members. In 1588, the 24-year-old Galileo considered himself sufficiently trained in the art-science of *disegno* to apply for this position. While there is no record that he was offered the job, it was perhaps during this period that the aspiring young teacher began his lifelong friendship with the painter Lodovico Cardi, called Cigoli (1559-1613), five years older and already a member. Cigoli lauded Galileo's knowledge of geometry, even acknowledging that in perspective drawing, Galileo was his 'master' (ibid.). Galileo's increasing competence in this skill led finally, in 1613, to his own election to the prestigious *Accademia*.

In 1612, Cigoli found himself embroiled in one of those endless Renaissance debates over which was superior, painting or sculpture, and asked his friend for support. Galileo replied that painting is surely the superior art because it imitates what is visible but not immediately tangible:

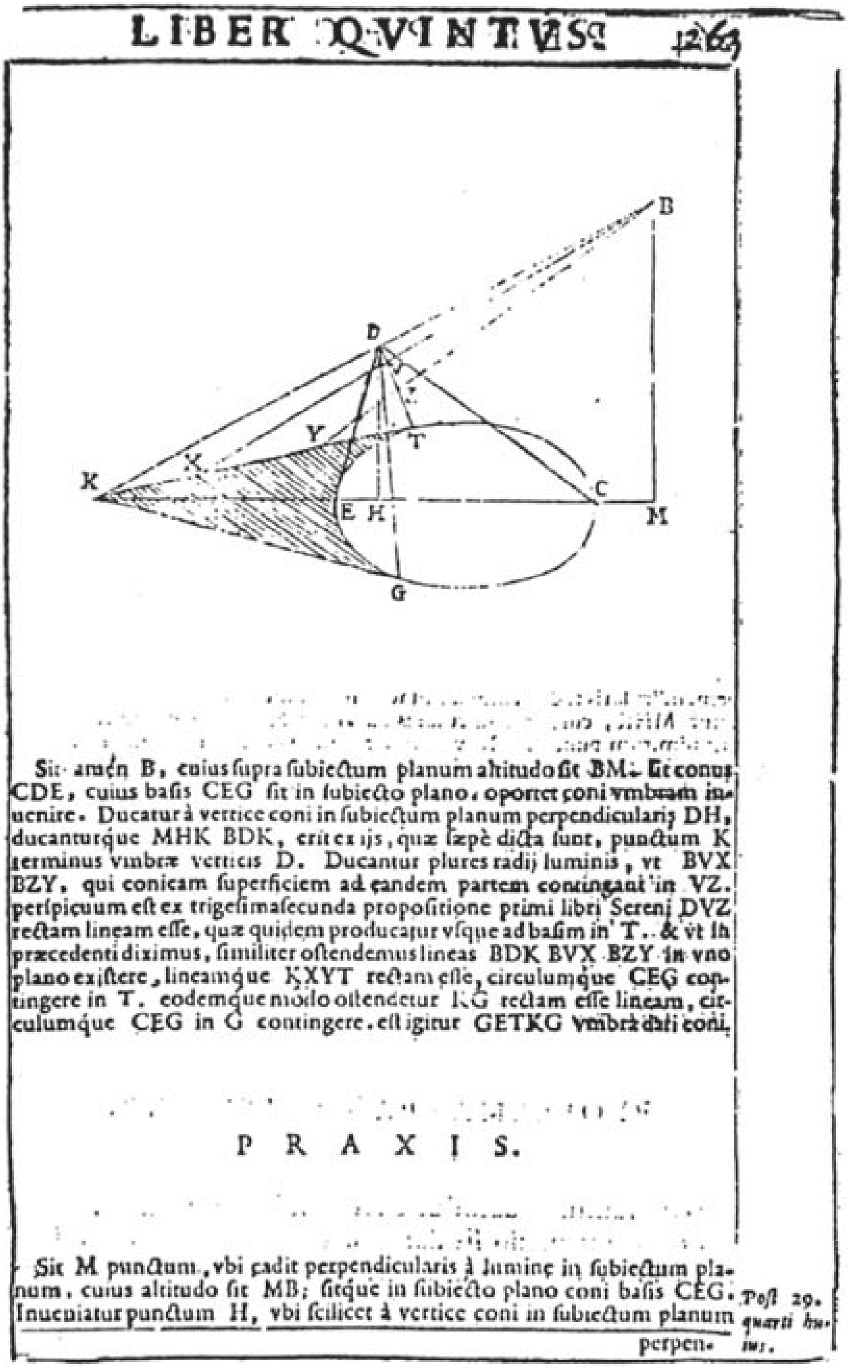
> The statue does not have its relief by virtue of being wide, long, and deep but by virtue of being light in some places and dark in

> others. And one should note as proof of this, that only two of its three dimensions are actually exposed to the eye: length and width (which is the *superficies* ... that is to say, periphery or circumference). For, of the objects appearing and seen we see nothing but their *superficies*; their depth can not be perceived by the eye because our vision does not penetrate opaque bodies. The eye then sees only length and width and never thickness. Thus, since thickness is never exposed to view, nothing but length and width can be perceived by us in a statue. We know of depth, not as a visual experience per se and absolutely but only by accident and in relation to light and darkness. And all this is present in painting no less than in sculpture ... But sculpture receives lightness and darkness from Nature herself whereas painting receives it from Art... (Panofsky, 1956, p. 32-7)

Galileo apparently cared little for the abstract vagaries of the Mannerist style as recently practiced by certain artists in his native city, preferring the classically based volumetric, more or less uncolored *chiaroscuro* painting advocated by the *Accademia del Disegno* – in fact, the favored style of Leon Battista Alberti. I must also add that, by the late sixteenth century, the study of linear perspective in general and *chiaroscuro* in particular appealed not only to artists but ever more to professional scholars especially in Italy and Germany who otherwise had no interest in the visual arts. Numbers of highly technical perspective books were printed with this audience in mind. In Italy, prestigious mathematicians like Federico Commandino and his student Guidobaldo del Monte both published on the subject. Commandino was the first professional geometer to discuss linear perspective and introduce its pictorial conventions to theoretical mathematics.

Guidobaldo del Monte was to become one of Galileo's strongest supporters, helping the young scientist to find his initial teaching job at the university of Pisa in 1589, and his second at the university of Padua in 1592. Guidobaldo's treatise, *Perspectivae libri sex*, published in Pesaro, 1600, contained a whole section on cast shadows and would surely have been studied by Galileo. Figure 11 shows one of Guidobaldo's woodcut illustrations of various solids under raking light, indicating how they cast their shadows on a plane. As a perspectivist, Galileo would likely have been familiar with Daniel Barbaro's *La pratica della perspettiva*, published in several editions in Venice during the late 1560s, and often consulted by members of the Florentine *Accademia*. Barbaro offered a number of difficult drawing exercises including how to draw spheres with raised protuberances, and how these would then receive light and cast shadows on a curving surface. If Galileo were not familiar with Barbaro, he most certainly studied another similar work also entitled *La pratica di prospettiva*, by Lorenzo Sirigatti in 1596. The

Figure 11



LIBER QVINTVS. 263

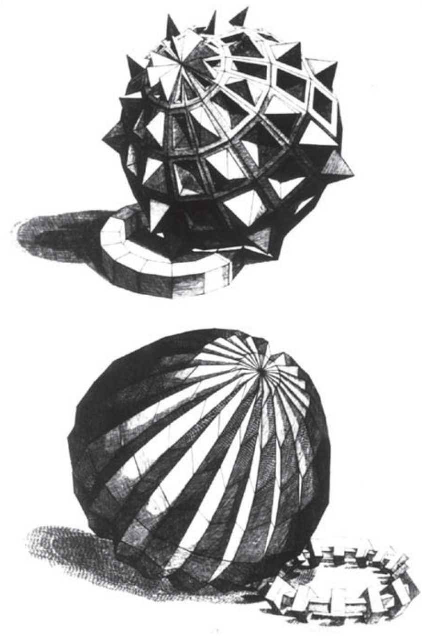
Sit tamen B, cuius supra subiectum planum altitudo sit BM. Et conus CDE, cuius basis CEG sit in subiecto plano. oportet coni vmbram inuenire. Ducatur à vertice coni in subiectum planum perpendicularis DH, ducanturque MHK BDK, erit ex ijs, quæ sæpè dicta sunt, punctum K terminus vmbræ verticis D. Ducantur plures radij luminis, vt BVX BZY, qui conicam superficiem ad eandem partem contingant in VZ. perspicuum est ex trigesimasecunda propositione primi libri Sereni DVZ rectam lineam esse, quæ quidem producatur vsque ad basim in T. & vt in præcedenti diximus, similiter ostendemus lineas BDK BVX BZY in vno plano existere, lineamque KXYT rectam esse, circulumque CEG contingere in T. eodemque modo ostendetur KG rectam esse lineam, circulumque CEG in G contingere. est igitur GETKG vmbra dati coni.

P R A X I S.

Sit M punctum, vbi cadit perpendicularis à lumine in subiectum planum, cuius altitudo sit MB; sitque in subiecto plano coni basis CEG. Inueniatur punctum H, vbi scilicet à vertice coni in subiectum planum perpen- Post 29. quarti huius.

latter was himself a charter member of the *Accademia* and *cavaliere* in the court of Grand Duke Ferdinand de Medici. This handsomely published treatise consisted of two sections, the first giving standard instruction in how to project multi-faceted solids and the second a series of twenty-four plates illustrating special problems of *chiaroscuro*, including several remarkable engravings of shaded spheres with both raised protuberances and recessed channels (Figure 12).

Figure 12

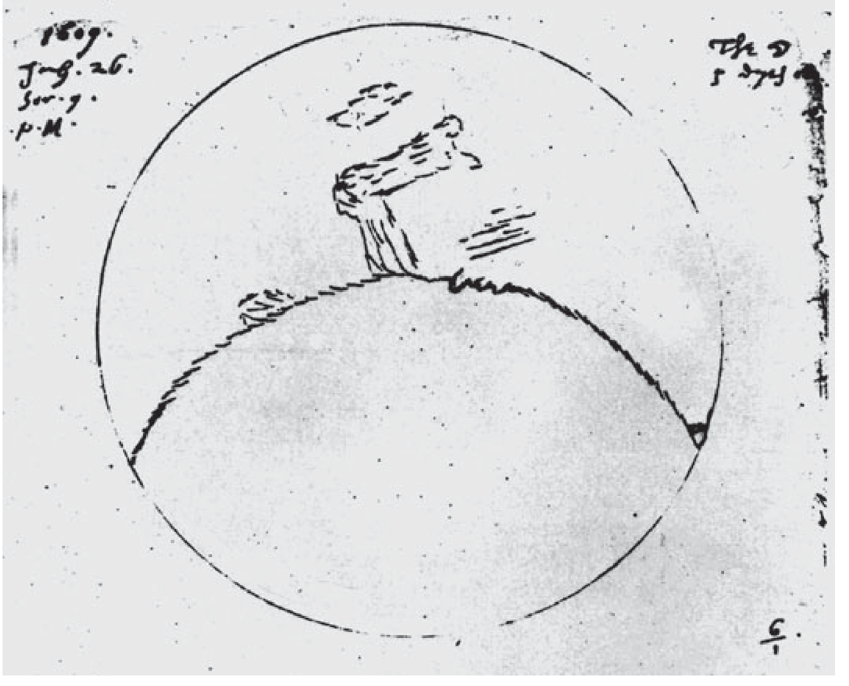


Let us for a moment take leave of Florence and look in on Jacobean London during the summer of 1609, where we encounter Galileo's scientific contemporary, Thomas Harriot (1560-1621), who has just procured a fascinating new instrument invented the year before in Holland, which he called a 'perspective tube,' and which, of course, we now call the telescope. The Dutch inventors had thought that the new device would be most useful to sailors for spotting distant ships at sea, or to military commanders for discerning far-off enemy installations, but Harriot did the novel thing of turning it on the moon. He even made an extant drawing of the moon as seen through his 'perspective tube' (Figure 13). Unfortunately, he added no explanation save the (Julian calendar) date and time of his observation: "1609, July 26, hor.9p.m.,...The [first quarter] 5 dayes old." In any case – and the reason why he is hardly remembered in the history of astronomy – Harriot's crude sketch reveals nothing new.

Europeans of his time still had no reason to doubt Aristotle's definition of the moon as a perfect sphere, the prototypical form of all planets and stars in the cosmos. Christian doctrine added to this euphoric image by having the moon symbolize the Virgin's Immaculate Conception. 'Pure as the moon' became a commonplace expression for Mary, implying that the universe, like her, was incorruptible, that God would not have created the moon or any heavenly body in another shape. Renaissance artists, especially those serving zealous Catholic patrons, frequently depicted the Virgin standing on such a moon, as did Bartolomé Estabán Murillo (1617-82) well into the seventeenth century, especially in Spain (Figure 14). We see her here in one of many paintings Murillo did of the subject, poised upon a ball marbled like translucent alabaster but with a highly polished, utterly smooth surface.

In Thomas Harriot's England, anti-Aristotelian Francis Bacon (1561-1626) had concluded that the lunar body was not solid at all, but rather composed of some unexplained 'vapour.' Harriot's

Figure 13



own opinion about the moon's composition remains unrecorded. Nonetheless, he drew the terminator, that is, the demarcation line between the illuminated and shaded portions of the moon, with short, ragged strokes as if it fell over a roughened surface. On the upper half of the sphere, Harriot indicated the configurations of what we now know as the great lunar 'seas,' the *Maria Tranquilitatis*, *Crisium*, and *Serenitatis*, which do seem to have appeared to him as surface markings rather than internal, vaporous discolorations. Nevertheless, he was unable to recognize the significance of these observations. His 'perspective tube' only confirmed more or less what the ancients had always said he would see. The "strange spottednesse of the moon," as Harriot called the phenomenon, remained as mysterious to him as ever.

Later in the same year, 1609, Galileo built himself a similar telescope, based only on news of its prior invention in the Netherlands, but with no knowledge of Thomas Harriot. Galileo's own home-made 'perspective tube' was in effect no more than 'Alberti's window' enhanced by magnifying lenses. He too aimed it at the moon, and as he evaluated what he observed, his own perspective drawing experience made it clear to him that Harriot's 'strange spottednesse' was really dark shadow cast by protruding mountains on the moon's irregular surface. To the startled public who read his book, *Sidereus nuncius* (*Starry Messenger*) in 1610, Galileo's 'perspective tube' quite shattered 'Brunelleschi's mirror.'

Figure 14

What Galileo's version of 'Alberti's window' revealed was that the earth was not necessarily a pale reflection of the immaculate heavens as 'Brunelleschi's mirror' proclaimed, but in the case of the moon just the other way around. Beyond any Jesuit doubt, that is, if one of them dared to look through his 'perspective tube,' Galileo proved that the first 'planet' in Dante's magnificent ascent to the heavenly Empyrion was hardly the 'eternal pearl' described by the poet, but rather a most imperfect sphere, marred and crinkled just like the lowly earth.

Why did Thomas Harriot miss what Galileo saw so precisely just a few months later? Was it only because his telescope was less powerful than Galileo's? To the latter question, I answer no, because the moon through any 'perspective tube' of the time could hardly have looked as sharp as it does in a modern Lick Observatory photograph familiar to every college astronomy student (Figure 15).

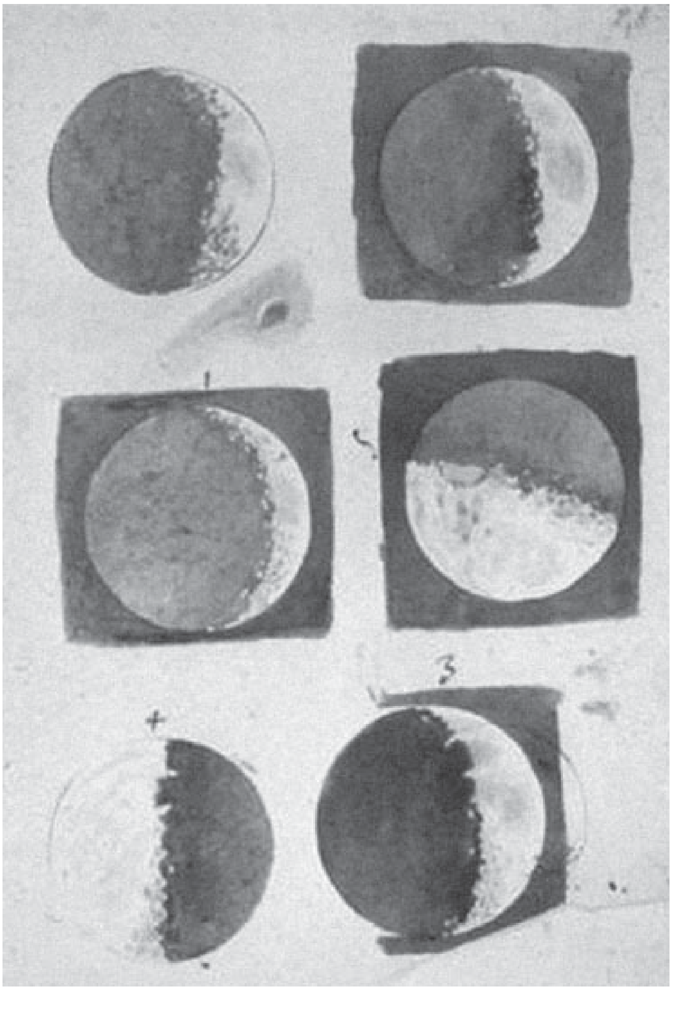
Both Galileo's and Harriot's instruments, mounted on rickety home-made stanchions, must have been difficult to focus to say the least. Moreover, such primitive devices had very narrow fields of view; only about a quarter of the moon could be observed at one time (van Helden, 1974, p. 44). In sum, neither the English nor the Tuscan scientist could have seen the moon so distinctly that its true surface topography would be instantly self-evident. Besides, quite a number of such 'tubes' were being produced in several centers of Europe by the end of 1609. Would not someone else also

Figure 15

have thought to aim the instrument toward the sky? If one knew nothing *a priori* about the moon's external topography, would its grayish blotches be seen immediately as shades and shadows of mountain ridges? Especially if the observer, like all people before 1610, was already certain such blotches had something to do with the moon's translucent internal composition?

Perhaps Galileo surely made some illustrations right there on the spot as he stared at the moon from atop the San Giorgio Maggiore campanile in Venice. While none of these have survived, we are in possession of seven finished sepia studies, which I believe were done later, based on his first *ad hoc* sketches. These small finished wash drawings, four of the waxing and three of the waning moon, are still preserved on two sides of a sheet of artist's water-color paper in the Biblioteca Nazionale in Florence (Figure 16). All were certainly done by someone well-practiced in the manipulation of

Figure 16

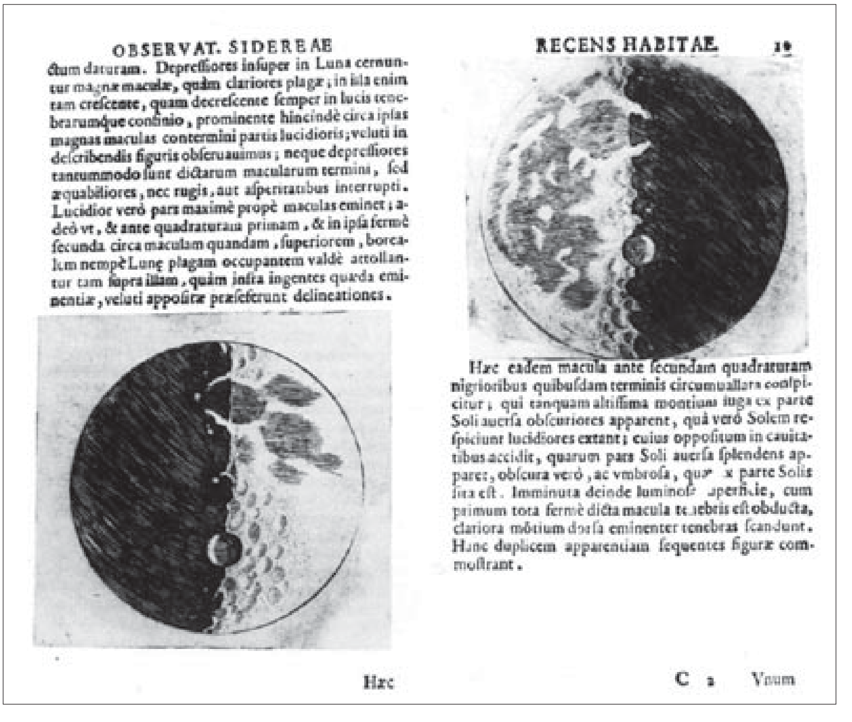


ink washes, especially the rendering of *chiaroscuro* effects. They are by an experienced artist, and we have no reason to believe by anyone other than Galileo himself.

Galileo no doubt prepared these washes as models for the engraver who would illustrate his book, *Sidereus nuncius*, which he rushed to publication barely five months after he began looking at the skies through his home-made telescope. Only five engravings of the moon's phases were printed in *Sidereus nuncius*, none exactly replicating the wash drawings.[4] Figure 17 indicates how two of these appeared in Galileo's book.

[4] There is no way Galileo could have made such careful pen-and-wash studies during his exciting first moments at the telescope, as anyone who has ever stood in the cold, windswept tower of San Giorgio Maggiore (Galileo's open 'observatory') should quickly understand. Like any seventeenth-century 'landscape painter,' Galileo returned to the studio to finish his pictures, based on remembered impressions, verbal notes, and hasty diagrams. *Plein air* painting, after all, was not invented until the nineteenth century.

Figure 17


OBSERVAT. SIDEREAE

ctum daturam. Depreſſiores inſuper in Luna cernuntur magnæ maculæ, quàm clariores plagæ; in illa enim tam creſcente, quam decreſcente ſemper in lucis tenebrarumque confinio, prominente hincindè circa ipſas magnas maculas contermini partis lucidioris; veluti in deſcribendis figuris obſeruauimus; neque depreſſiores tantummodo ſunt dictarum macularum termini, ſed æquabiliores, nec rugis, aut aſperitatibus interrupti. Lucidior verò pars maximè propè maculas eminet; adeò vt, & ante quadraturam primam, & in ipſa fermè ſecunda circa maculam quandam, ſuperiorem, borealem nempè Lunę plagam occupantem valdè attollantur tam ſupra illam, quàm infra ingentes quędam eminentiæ, veluti appoſitæ præſeferunt delineationes.

Hæc

RECENS HABITAE. 19

Hæc eadem macula ante ſecundam quadraturam nigrioribus quibuſdam terminis circumuallata conſpicitur; qui tanquam altiſſima montium iuga ex parte Soli auerſa obſcuriores apparent, quà verò Solem reſpiciunt lucidiores extant; cuius oppoſitum in cauitatibus accidit, quarum pars Soli auerſa ſplendens apparet, obſcura verò, ac vmbroſa, quæ ex parte Solis ſita eſt. Imminuta deinde luminoſa ſuperficie, cum primum tota fermè dicta macula tenebris eſt obducta, clariora môtium dorſa eminenter tenebras ſcandunt. Hanc duplicem apparentiam ſequentes figuræ commonſtrant.

C 2 Vnum

Figure 18 is another Lick Observatory photograph showing the same second-quarter waxing Moon as illustrated at left in *Sidereus nuncius*. Galileo's accompanying matter-of-fact textual description of these engravings belies both his own excitement and the stupendous impression they made upon an unsuspecting world:

> [I] have been led to the conclusion that … the surface of the Moon is not smooth, even, and perfectly spherical, as the great crowd of philosophers have believed about this and other heavenly bodies, but, on the contrary, to be uneven, rough, and crowded with depressions and bulges. And it is like the face of the Earth itself, which is marked here and there with chains of mountains and depths of valleys. (Galileo, 1989, p. 40)

Figure 18

As stated, the illustrations in *Sidereus nuncius* are not exact copies of any of the wash drawings. It would seem that Galileo furnished the latter only as guides to the engraver, who was apparently asked to emphasize the more spectacular features of the moon's surface. He even permitted the engraver a certain artistic license to exaggerate the size of that particularly dark, deep crater we see lying just below center along the terminator in Figure 17. This is Albategnius, and Galileo wished to compare its steep sides to the high mountains on Earth surrounding the region of Bohemia. Thus he bade his engraver to render it large, to dramatize that the moon is covered all over with such rugged depressions. We should also bear in mind that the engraver would probably not have looked through the telescope himself, but depended solely on the astronomer's drawings and, no doubt, Galileo's rather excited verbal descriptions.

Galileo's original wash drawings reveal a much more 'painterly' lunar surface than do the published engravings. Most modern historians have talked about only the latter, which by virtue of their metallic, linear technique, make Galileo's moon look like the arid and lifeless body our modern astronauts discovered it to be. His wash renderings, on the other hand, show that he still regarded the Moon somewhat in the old medieval 'watery' spirit. With the deft brushstrokes of a practiced water-colorist, he laid on a half-dozen different grades of washes, imparting to his images an attractive soft and luminescent quality. Remarkable indeed was Galileo's command of the Baroque painter's convention for contrasting lighted surfaces, and his ability to marshal darks and lights to increase their mutual intensities. In the upper left of the sheet of sepia drawings, in Figure 16, we see how he set down a little practice patch of dark and light washes surrounding a white area, probably to help his engraver realize the form of the lunar crater as it took shape in the waxing light. With artistic economy worthy of Tiepolo, Galileo indicated the concave hollow with a single stroke of dark, leaving a sliver of exposed white paper to represent the crater's glowing brim.

Is it preposterous to claim that these simple, yet highly professional paintings belong as much to the history of art as they do to the history of science? While no comparable art work exists also attributable to Galileo, we do have much contemporary verbal testimony concerning his considerable skill as a draftsman. In the true spirit of the Florentine *Accademia*, Galileo seems to have engaged in *disegno* not for the sake of self-expression but rather to discipline his eye and hand for science. And yet he has at the same time in these *chiaroscuro* washes anticipated the independent landscape in the history of art. His almost impressionistic technique for rendering fleeting light effects reminds us of Constable and Turner, and perhaps even Monet. One needs only to read on in *Sidereus nuncius* to appreciate his wonder, as well as his rational understanding as he gazed upon the transient moonscape, noticing it was covered with small spots having:

> their dark part on the side toward the Sun, while on the side opposite the sun they are crowned with brighter borders like shining ridges. And we have an almost entirely similar sight on Earth, around sunrise, when the valleys are not yet bathed in light but the surrounding mountains facing the Sun are already seen shining with light. And just as the shadows in the earthy valleys are diminished as the Sun climbs higher, so these lunar spots lose their darkness as the luminous part grows. Not only are the boundaries between light and dark on the Moon perceived to be uneven and sinuous, but what causes even greater wonder is that many bright points appear within the dark part of the Moon, entirely separated and removed from the illuminated region and located no small distance from it.

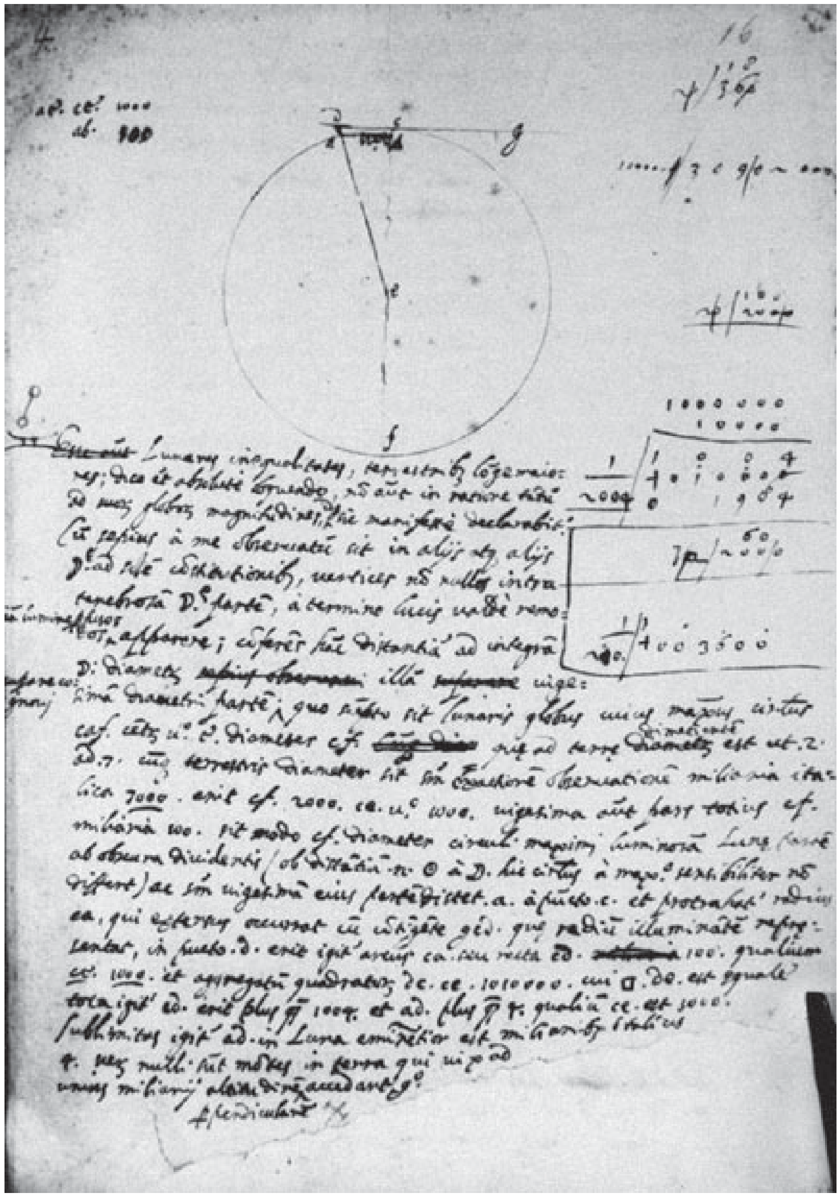
> Gradually after a small period of time, these are increased in size and brightness. Indeed, after 2 or 3 hours they are joined with the rest of the bright part, which has now become larger. In the meantime, more and more bright points light up, as if they are sprouting, in the dark part grow, and are connected at length with that bright surface as it extends farther in that direction … Now on Earth, before sunrise, aren't the peaks of the highest mountains illuminated by the Sun's rays while shadows still cover the plain? Doesn't light grow, after a little while, until the middle and larger parts of the same mountains are illuminated, and finally, when the Sun has risen, aren't the illuminations of plains and hills joined together? (Ibid., p. 41-3)

Did ever a Baroque painter express the new secular spirit of landscape art better than this? Was ever an artist's eye better prepared to recognize the universal geometrical principles of perspective optics and *chiaroscuro* even at work on the moon? Moreover, after thus having marveled at the picturesque lunar terrain, Galileo quickly reverted to his scientific self and made two other amazing perspective-related discoveries. The first was when he noticed that some of the lunar peaks were tipped with light within the shadow side even as the terminator boundary lay a long way off. At the same time, he was able to convert this phenomenon into a geometric diagram for solving a shadow-casting problem such as he may have recalled from Guidobaldo del Monte.

Figure 19 illustrates another manuscript page which Galileo prepared for *Sidereus nuncius.* On it he drew a circle representing the moon, divided by the terminator, which he marked *cef*. The Sun's shadow-casting light rays he indicated by the tangent line *dcg*. With particular ingenuity, considering that his primitive telescope had no cross-hair sighting device, he was able to estimate the real distance of the lighted lunar mountain peak to the terminator as being about one-twentieth (line *dc* here in the diagram) of the Moon's whole diameter. This distance, more or less comparable to line *DK* in Guidobaldo del Monte's cone/shadow diagram (Figure 11), then allowed him to triangulate the mountain's height. Since the moon's diameter was known to be two-sevenths of the Earth's own diameter, or about two thousand miles, Galileo's triangle *ced*, with *ce* equaling one thousand miles, and *cd* one hundred, revealed by Pythagorean calculation that *da*, the mountain's height on center from its base, reached more than four miles into the lunar sky! By applying a problem well known to students of Renaissance perspective, Galileo added yet another fact to his already wondrous revelations, that the mountains on the moon were more spectacular than the Alps here on Earth.

Galileo's telescopic observations of the moon, announced in *Sidereus nuncius*, opened the eyes of Renaissance Europeans to a

Figure 19

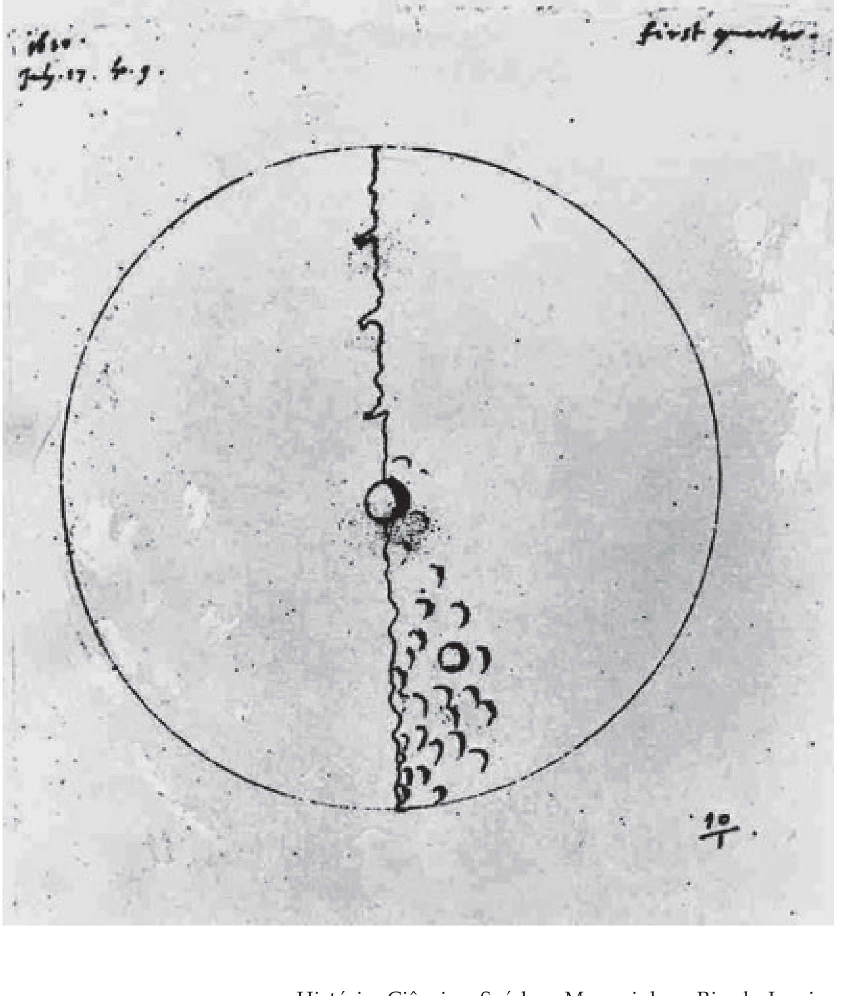


celestial reality they had never before imagined. If Thomas Harriot's Britain still lingered in the pre-perspective Middle Ages, Galileo offered that insulated land a crash course in Italian ways of seeing. Suddenly, everywhere in Britain, amateur as well as professional philosophers were able to conceive of the same "mountains and umbrageous dales" as Galileo had just described, whatever the quality of their own telescopes. The landscaped moon as well as the 'perspective glasse' became instant metaphors in the writings of Dryden, Donne, Butler, Milton, and many other British poets.[5] Even Harriot, once he had read *Sidereus nuncius*, finally 'saw' the shaded craters which had eluded him a year before. In July of 1610, four months after *Sidereus nuncius* was published, Harriot drew yet another lunar picture (Figure 20).

Again, there is no written comment, but the Englishman did sketch the moon's concavities in pen-stroke circles and half-circles, even exaggerating Albategnius in imitation of the *Sidereus nuncius* engraver's drawing. It is a curious fact, if only a coincidence, that in 1611, hardly a year after England received Galileo's stunning announcement, Inigo Jones, the first Englishman to have talent and training in the conventions of Italian perspective drawing, was appointed Surveyor General to the Prince of Wales, and Sebastiano Serlio's "Treatise on Architecture," the most widely read textbook on the neo-classical style – including a special section on linear perspective – was translated into English. Both events, following immediately upon the news of Galileo's telescopic

[5] Even in Protestant England, John Donne (1572-1631), when he heard of Galileo's discoveries, suspected (with tongue in cheek) that it was all a Jesuit plot anyway (as he wrote below in his fiercely satirical tract, 'Ignatius his Conclave' in 1611): "I will write the Bishop of Rome: he shall call Galileo the Florentine who by this time hath thoroughly instructed himself of all the hills, woods, and cities in the moon. And now being grown to more perfection in his art, he shall have made new glasses, and with these having received a hallowing from the pope, he may draw the moon, floating like a boat upon the water, as near the Earth as he will. And thither (because they ever claim that those employments of belong to them) shall the Jesuites be transferred, and easily unite and reconcile the Lunatique Church to the Roman Church. And without doubt, after the Jesuites have been there a little while, there will soon grow naturally a Hell in that world, over which you [?] Ignatius Loyola shall have dominion...".

Figure 20



discoveries, signaled the arrival finally of the full-blown Italian Renaissance to the British Isles.

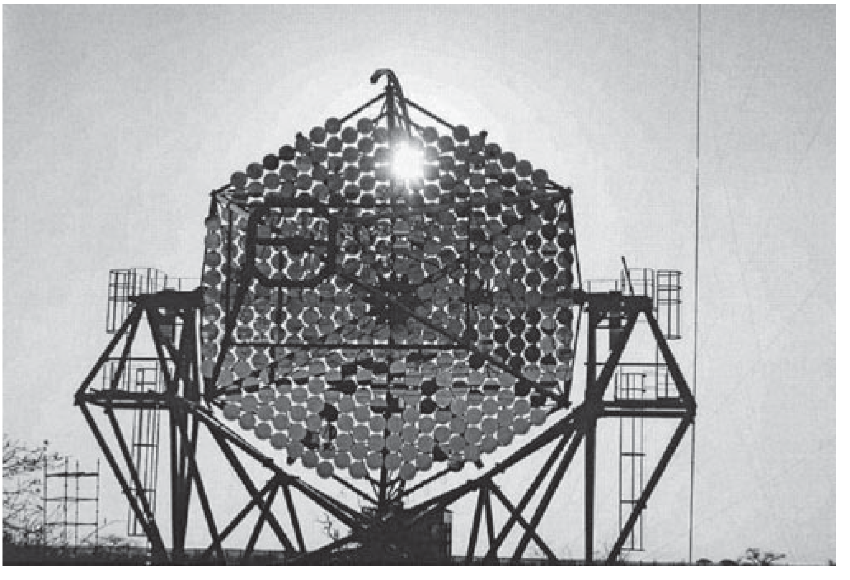
There still remained, of course, some recalcitrant souls who so firmly believed the moon was 'pure' that they could not be persuaded to look through Galileo's telescope. The Roman Catholic Church, however, was quick to co-opt the new discovery. In 1612, Galileo's friend Cigoli the painter was commissioned to fresco the domed ceiling of the Pauline Chapel in the Basilica of Santa Maria Maggiore in Rome. The artist was permitted to depict there the Virgin Mary standing on a crater-pocked Moon, no doubt inspired by one of Galileo's original drawings (Figure 21) (Ostrow, 1996, p. 218-35).

To this day Cigoli's painting is officially and prudently called the *Assumption* rather than the *Immaculate Conception*. By this admission in such a sacred place, the Church tacitly acknowledges that Galileo was not altogether wrong about at least some of the heavens looking just like Earth.

Figure 21

It is worth noting in conclusion, however, that as astronomers after Galileo demanded to see ever more distant planets and stars, the perspective tube had to be extended longer and longer with magnifying lenses larger and larger. Finally, no less than Sir Isaac Newton (born the same year Galileo died) realized that another optical component must be added to the instrument to increase its power. In order to reveal ever more of the great beyond still shrouded *in enigmata*, 'Alberti's window' *cum* telescope needed to be further enhanced by reinstalling 'Brunelleschi's mirror' (Figure 22).

Figure 22



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