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LEONARDO'S INVENTION OF THE VIOLA ORGANISTA
MELODIC, CHORDAL, AND OTHER DRUMS INVENTED BY LEONARDO DA VINCI

LEONARDO'S INVENTION OF KEY-MECHANISMS FOR WIND INSTRUMENTS

ESTRATTO DA "RACCOLTA VINCIANA,"
FASCICOLO XX

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LEONARDO'S INVENTION OF THE VIOLA ORGANISTA

It is odd that the many sketches for musical instruments and musical machines contained in the pages of Leonardo da Vinci's notebooks have never found a thorough and systematic interpretation. It is true that some look rather fantastic, at least to us today, and others are clearly only quick embodiments of passing ideas put down on paper by Leonardo to aid his own memory. However, nearly all the sketches reveal themselves as most interesting, and many as ingenious new inventions, if they are scrutinized and analyzed in the right context: that is, against the background of the instruments existing at Leonardo's time, and with a knowledge of clockworks and other mechanical devices used by Leonardo outside the field of musical instruments, and examined in the light of Leonardo's leading ideals for instruments which can be distilled from a comparison of all the drawings and his many remarks on music, musical aesthetics, and acoustics.

Among the many musical instruments and machines contrived by Leonardo — string instruments, drums and wind instruments — the viola organista is by far the most complicated. No less than six different pages in the notebooks show sketches for it: fol. 28 r, 28 v, 45 v, and 46 r in Codice H; fol. 50 v in Codice B; and folio 218 r-c in the Codice Atlantico. None of them are precise drawings for an instrument builder, and some are not even completely thought through since several details would probably have been found impracticable in actual construction. However, to anticipate the out-

I wish to express my gratitude to the Heineman Foundation which kindly sponsored my work on Leonardo in 1961, and to the American Council of Learned Societies which generously granted me a fellowship for continuing my research in Europe in 1962/63.
come of our analysis, they are all concerned with the idea of a stringed instrument with keyboard in which the strings are set into vibration by a mechanical device — a wheel, or bow with a back-and-forth motion, or a belt of hair moving across the strings as a sort of endless bow. Such an instrument would fill a big gap in the multitudinous array of instruments not only of Leonardo's time but also of ours today. It would combine the polyphonic possibilities of the keyboard with the tone color of strings and thus would be something like an organ with string timbre instead of wind timbre.

The mechanical obstacles confronting the builder of such an instrument are obvious. The bow in the hand of a fiddler selects the string wanted; it can easily turn from one string to another or even press against two strings simultaneously and, in the case of the early viol with a flat bridge and soft bow, against three strings at the same time. The bow can travel either quickly or slowly and exert heavy or light pressure upon the strings. But if a mechanical bow is to be used, the problem immediately arises as to how to select, in turn, the strings which are supposed to sound, and how to press them against the vibrating device, be it a friction wheel or a belt of hair or a shuttling bow.

Instruments with friction wheels existed before Leonardo's time and were still popular in his day although their mechanism and musical capacity were incomparably more simple than his elaborate contrivances, which amounted to nothing less than a one-man orchestra. In connection with these other instruments we must mention, above all, the hurdy-gurdy — known variously as the ghironda, vielle à roue, and Drehleier — a sort of mechanical fiddle of venerable history. This instrument was already popular in the Middle Ages and was spread at that time almost all over Europe, and it is still being played today as a folk instrument in certain regions of France (1).

(1) An account of the origin of this instrument, its function, evolution, and colorful changing history as a representation of religious and pastoral symbolism, can be found in my article "Bagpipes and Hurdy-gurdies in their Social Setting", Metropolitan Museum of Art Bulletin, Summer 1943, pp. 56-83.
The hurdy-gurdy can have different shapes: its soundbox may resemble a lute, guitar, or fiddle, but the strings stretched along it are neither plucked nor bowed, being set into vibration by a wooden wheel revolving in the middle of the soundbox and turned by a crank at its tail end (Ill. 1). The smooth edge of the wheel, which is coated with resin, serves as an endless bow. Like the pipes of the typical bagpipe, the strings differ in kind and function: there are stopped ones (the melody strings, or chanterelles) running along the middle of the soundbox and open ones (the drones, or bourdons) running on either side. The melody strings are stopped by a primitive key mechanism, a set of stopping rods — naturals and sharps — equipped with little projections that press inward against the strings when the rods are pushed in (Ill. 2). Thus, a full scale can be produced. When released, the rod falls back of its own weight. Consequently the hurdy-gurdy is held and played with the key-

Ill. 1 — French hurdy-gurdy in lute shape, 18th century.
New York, Metropolitan Museum of Art.
Ill. 2 – Wheel and stopping mechanism of a French, 18th century hurdy-gurdy in guitar shape. New York, Metropolitan Museum of Art.
board down. As the two melody strings are tuned in unison, each rod has two projections simultaneously stopping both strings. When there are two drones, they are tuned in octaves; when there are more, the octave is strengthened by an added fifth.

A construction of this kind gives the instrument three distinctive features. First, it is mechanized — that is, the strings are touched neither by plucking fingers nor by a bow, but by an intervening mechanical device, the friction wheel. Secondly, the hurdy-gurdy, through its wheel, makes possible something which neither the lute nor the violin nor the harpsichord can render — a continuous sound; the wheel overcomes the pauses between the single strokes of plucking or bowing. The third distinctive feature is the accompaniment of a melody by an invariable bass, the drone.

The early history of the hurdy-gurdy is beyond the scope of this article, since it has no bearing on Leonardo’s invention. Thus it should only briefly be mentioned that the hurdy-gurdy developed from the organistrum of the tenth, eleventh and twelfth centuries — a large box with a wheel and a crank turned by one player, while another manipulated a primitive stopping mechanism. Organistra are depicted in the sculptures of Romanesque churches such as the cathedrals of Moissac and Santiago de Compostela (Ill. 3). By the time of Giotto, the smaller and handier one-man instrument, the hurdy-gurdy, had replaced the organistrum. As has been pointed out, the mechanism of the organistrum and of its successor, the hurdy-gurdy, did not allow the selection of single strings to be sounded alone due to the action of the wheel rubbing simultaneously against all the strings. It was, in fact, just this limitation which gave this instrument its charm as a vehicle for that characteristic drone-music which is still familiar today, even to musical laymen, through the large family of bagpipes (2).

But while the drone principle is a very ancient one — for instance, in the music of Western Asia, and also of importance in the development of Occidental polyphony — it plays no role in the invention

(2) On the historical relation between hurdy-gurdies and bagpipes as equivalent providers of drone music, see also the article cited above in footnote 1.
of Leonardo which we are discussing here. On the contrary, Leonardo's invention aimed at a machine of maximum freedom and flexibility, offering to the player precisely that choice of tones or chords wanted at the moment. A drone, humming on continuously, would have been only an undesirable restriction of the harmonic possibilities of an instrument such as the «viola organista» (3).

Ilh. 3 – Organistrum played by two elders. From the Portico de la Gloria of the Cathedral of Santiago de Compostela. End of the XII century.

(3) It is worth mentioning, however, that the instrument used by Leonardo for his improvisations, the lira da braccio, was equipped with two open strings, apart from the five stopped strings, and the former could be used as temporary drones at the discretion of the player. (See my article, «Lira da Braccio», Die Musik in Geschichte und Gegenwart, Vol. 8, New York-Basel-London, Baerenreiter, 1960).
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Before turning to the analysis of the single drawings, it should be pointed out that their interpretations support each other, since several elements such as keys and push-buttons occur in several of the drawings. Lacking any external indications as to their chronology, I have arranged the order according to the inner logic of the development of one solution from the preceding, less satisfactory one.

* * *

Codice Atlantico, fol. 218 r-c (III. 4): This page is completely filled with several sketches concerned with different machines. For convenience I will call them A, B, C, D and E, from top to bottom.

A and B cover the upper third of the narrow page. There is one thing which immediately strikes the eye in B — a precise sketch for the typical bow for the viol or the lira da braccio of the time (4). The bow is placed over an oblong box, without any clear indication as to how it is attached. It is crossed by two sets of double lines; the upper set, marked «sopra 'l fondo», is drawn more heavily than the lower set, which is marked «sotto 'l fondo». These two double lines converge toward the right, the upper set being drawn strictly parallel to the side walls of the box, and the lower set at a marked angle. This latter fact alone, in view of the unerring sense of perspective habitual with Leonardo even in his smallest sketches, would seem to exclude the assumption that the lower double line indicates vibrating strings.

But the upper set evidently does represent a double string, for we can see these two lines fastened at the left end to two pins, evidently tuning pins which protrude from a cube. A clearer idea of this fastening method is gained from sketch A, which is apparently a detail for B. There we notice four sets of double strings

(4) See for instance: Giovanni Bellini's altarpiece in San Zaccaria, Venice, 1505, which includes an angel playing a lira da braccio; Bartolommeo Montagna's angel playing a lira da braccio in his altar picture in the Brera Gallery, Milan; and closer to Leonardo, the angel with the lira da braccio by Ambrogio de Predis, flanking Leonardo's Madonna of the Rocks, in the London National Gallery.
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with their tuning pins, which are inserted in four little individual doors or frame-shaped bridges. We may ask why the tuning pins are not fastened directly to a wrest plank, as it is done in harpsichords or spinetti. The answer, it seems to me, is connected with the problem of selecting the strings which should actually sound — that is, to bring the proper string into contact with the hair of the bow. A device was needed to grasp the proper string and lower or raise it against the bow, from its resting position, in order that the string might be set into vibration. If we look at the uppermost of the four little «doors» or frames, we note, protruding from it, three lines strongly suggesting a key. A glimpse at the corresponding area of sketch B confirms this assumption. There must, therefore, have been a keyboard acting through some intermediate levers or wire loops on the strings. But we consult the drawing in vain for such a device.

If we assume the existence of keys, as suggested, then we must also assume double strings, as mentioned above, and not single strings, because the supposed key in the drawings corresponds to one set of double strings. Double strings for the purpose of giving a louder tone were common in the hurdy-gurdy, as it has been described, with its two melody strings tuned in unison and its several bass drone-strings tuned in unison and sometimes at the octave and the fifth, in addition. Which leads to the question of how many strings Leonardo's machine was meant to have. We believe that the four double strings in A give only an idea of the arrangement but do not exclude the possibility that there were more than four pairs. To construct such a complex machine for only four double strings, each sounding only one tone, would hardly have been worth the trouble unless there were also a stopping device, perhaps similar to the tangents of a fretted clavichord or the teeth on the stopping rods of the hurdy-gurdy which made it possible to produce more than one tone from each string. But while these devices in the clavichord and hurdy-gurdy are simple and easy to construct, in our machine where the keys would be busy in pressing the strings against the bow, any stopping mechanism subdividing each string for the proper pitch would have been a cumbersome affair and would require more fingers than God has given to one man.
There remains, finally, another question that is likewise, alas, not sufficiently answered by the drawing — the method of moving the bow. As we stated before, no device is visible for fastening the bow to the box. In principle, two ways would be feasible, either to move the bow against the strings or to move the strings against the hair of a stationary bow. The only clue is the device drawn in the middle of the long side of the oblong box in B (Ill. 5). But here the drawing is too muddled to be reliably interpreted. It may perhaps indicate a sled, gliding on top of the narrow box or log to the left of the big box. But whether this was to move the bow or the set of strings cannot be decided. One can only say that moving the strings sideways under the bow would have been practical with only a few strings; with a considerable number, let us say as in a small spinetta, it would have been difficult even if we do not take
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into account the problem of having to move the keyboard along with the strings and, at the same time, manipulate its keys. Thus, the method of moving the bow back and forth seems more probable. But then again, this method would be very close to what a fiddler does, without any complicated mechanism. In many pages of his notebooks, Leonardo was thinking aloud (so to speak) with pencil in hand, amending and replacing again and again his verbal statements and explanations, and often abandoning them in favor of a different formulation. Why should he have done otherwise in his sketches of novel mechanical conceptions? It may have been precisely the difficulties described which prompted him to abandon the idea of an actual bow and turn to a more practical device — the friction wheel.

Drawing C (Ill. 6) in the middle of the page shows an elaborate mechanism with a large spoked wheel. The idea of the bow in B
has apparently been abandoned as impractical, and the vibrating element here is a wheel. Leonardo was, of course, familiar with the popular ghironda of his time which was then, in its simplest form, a peasant instrument and yet noble enough in more elaborate forms to be played by angels (5). A beautiful ghironda is played by an angel in the Sforza Book of Hours (Plate XXIX), written precisely at the time when Leonardo was in Milan (III. 7); and an even more beautiful one is played by one of the numerous angels in Gaudenzio Ferrari’s fresco in the cupola of the church of Santa Maria Novella in Saronno, north of Milan (III. 8).

In the present drawing, the wheel is set into the front part of a large soundbox which carries the strings. The curved bridge (« ponti ») and several hitch pins (« bischeri »), to its right, are clearly drawn. The large wheel has spokes and a central disc with pins which tally with the sticks of a revolving vertical drum. The wheel is evidently kept in motion by a horizontal cylinder partly seen at its right, whose axis terminates in a little wheel which, in its turn, is moved by ropes extending down into a little box where we may assume there is a spring as « prime mover ». Such springs were used by Leonardo in similar devices such as, for instance, in his flying machine (cf. Ms. B, fol. 74 r). Instead of springs, the force could of course be supplied by a foot pedal or a weight.

There are two mechanical problems which would have to be solved in a mechanism such as this. The first concerns the contact between the strings and the edge of the wheel, and the shape of the sounding board thereby required. Our drawing gives only an ambiguous answer. If the wheel is really a friction wheel, the strings rubbed by its edge have to be placed on a plane curved correspondingly, that is, on a concave soundboard. Would the whole soundbox then have to be curved? The seven or eight little curves visible over the words « vocato armonico » would seem to indicate a rounded bottom of the soundbox. But how about the shape of the soundboard itself? The curved double line indicating the bridge, and marked « ponti », does not answer our question since the bridge, as every harpsichord builder knows, may be curved in the hori-

(5) Emanuel Winternitz, « Bagpipes and Hurdy-gurdies... », pp. 66 ff.
Ill. 8 – Angel playing hurdy-gurdy. From the cupola fresco in the Santuario at Saronno, by Gaudenzio Ferrari.
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horizontal plane, corresponding to the different lengths of strings from treble to bass. Also, a large soundboard of concave shape would not be easy to build although Hans Haiden's Geigenklavizimbel, built about 1600 in Nuremberg and illustrated in Praetorius's *Syntagma Musicum*, II, «De Organographia» (1618), had a soundboard of five concave sections corresponding to its five friction wheels (III. 9). It may be even more instructive to compare Leonardo's sketch and the illustration of Haiden's instrument with pictures of the only surviving old Geigenwerk built in 1625 by Fray Raymundo Truchado, and preserved in the Mahillon Collection of the Conservatoire in Brussels. Illustration 10 shows the whole instrument, with the keyboard deeply set in at the front, the crank protruding at the rear, and the strings running over wheels set into the soundboard. Illustration 11 shows a top view of the soundboard (6). Illustration 12 gives an oblique view of the arrangement of the wheels, bridges and the hooks that force the strings against the edge of the wheels (7).

The other mechanical problem concerns again, as we saw in the first drawing, the way in which the player selects the strings (8). In the hurdy-gurdy this was no problem — the wheel rubbed all of them at the same time. But Leonardo's elaborate machine was evidently meant to produce more complex music than the pastoral music of the hurdy-gurdy, with its never-silent melody in the treble and incessant drone in the bass. Richer polyphony was to be expected at the time of Isaac, Agricola, and other famous visitors to the court of Milan and therefore a selecting device for each string was needed. As an indication of this device, we must consider the keyboard at the left, for thus one should be inclined to interpret

(*) I am grateful to the late conservateur, M. René Lyre, for providing me with these two photographs.

(?) I took this photograph years ago in bad light and with a small camera. It is slightly blurred, yet shows clearly enough the salient features of the wheel mechanism.

(*) Even if the wheel mechanism was meant to be an automat, a selective device would have been necessary. The musical automat known from later times, as illustrated in ATHANASIUS KIRCHER'S *Musurgia Universalis* (Rome, 1650), all used the pin barrel as the central device to pluck the strings.
Ill. 9 – Geigenklavizimbel, woodcut from Michael Praetorius’ Syntagma Musicum II, “De Organographia”, Nuremberg, 1618.
the set of parallel lines in front of the architectural structure that carries the wheel and which is, by the way, shaped after the form of an organetto of the time. But how these keys select the strings is not revealed in the drawing.

Ill. 11 – Top view of the instrument shown in illustration 10.

However, the last two drawings on our page, sketchy as they are, evidently are concerned with this problem of selection (Ill. 13). In D, which is crossed out and labeled «falso» (9), we see a concave soundboard with a number of strings running from left to right,

(9) Evidently Leonardo, when abandoning sketch D by marking it «falso», added «buono» to sketch C.
Ill. 12 – Wheel mechanism of instrument in illustration 10.
and a wheel equipped with strings set into the curve of the soundboard in about the same place as in C. There is no hint of a keyboard as in C, but four sets of diagonal lines cross the strings and terminate in short, upright marks just where the further ends of the lines meet the strings. Of these four sets of lines, the first which is nearest the wheel and reaches the first string has eight such marks.

The second set, touching the second string, has nine marks; the third, reaching the third string, likewise has nine marks; and the last, touching the forth string, shows five marks although this number may be less than the others merely because the margin of the paper had been reached. In viewing this drawing, the only association I can make is with the keys and tangents of a fretted clavichord, in which the keys, which are equipped at their rear ends with little upright metal blades which strike the string, not
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only make it vibrate, but also divide it at the proper point in order to obtain the desired tone.

Leonardo was familiar with the clavichord, called at his time "monocordo" and also "manicordo" (one of the playful, popular etymologies of the Renaissance). The monocordo of the Renaissance, despite its name, had many strings (10) — the beautiful large clavicord or monocordo represented in the intarsias of Federico Montefeltro in his palace at Urbino (Ill. 14), long before Leonardo's time,

(10) In the Windsor Ms. 12350, Leonardo refers to the light reflected on the strings ("chorde") of the monochord.
had no less than twenty-two strings and forty-seven keys (11). Now if the schematic lines in our drawing suggest the clavichord action at all, then the first string nearest us could render eight tones, the second — nine, the third — nine, and the last at least five: in sum, thirty tones — two octaves and a fourth on a chromatic keyboard.

A different method is followed in drawing E, which shows a scheme for a soundboard in more of a central top view than in the other sketches, with a wheel (or possibly a bow) on the left. Here the arrangement of fifteen strings each crossed by a «tangent», and thus amounting to an equal number of strings and tangents, would correspond to the action of the unfretted clavichord in which each string sounds its whole length — one tone — rather than being subdivided into many tones by the action of several tangents on one string, as in the fretted clavichord described above. If Leonardo really thought of something like a clavichord action, then the keys reaching across the strings, with the wheel at the left side of the player, would by means of the tangents press the strings against the wheel or bow. And the keyboard in front of the wheel, such as in C, would have been unnecessary. For this reason I do not think that D and E are merely supplementary sketches to C.

In looking back at all the drawings on page 218 r-c, we find that even if we were to discard everything which is only guesswork and unexplainable detail, the following facts remain: Leonardo begins with the idea of a mechanical bow moving back and forth, similar to the actual hand-moved bow of a fiddle; then he discards this idea and turns to the more reliable device of the friction wheel, adds keys, and evidently begins to grope for a method of how to stop the strings and how to make them touch the wheel. We can now justify why we began our interpretation of Leonardo’s musical machines with 218 r-c: it includes the most primitive device — the fiddle bow — and one other traditional device known from the ghironda — the wheel. But no satisfactory method seems to have been found. The wheel mechanism comes nearest to a practical

solution and in fact, long after Leonardo and certainly without his influence, was incorporated into Haiden's Geigenwerk which we described earlier. However, we will see in the other drawings discussed here that the wheel idea is likewise abandoned.

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Ms. H, fol. 28 v (Ill. 15) contains three drawings, but before trying to interpret them one must pose the question as to which is the top and which is the bottom of the page. The natural position for the big musical machine would seem to be with the flat side down, as if it were to be placed on a table. But in that case, the few words written on the page, "tessta della viola" and "tasti della viola", would be upside-down. In the facsimile edition of Ms. H (Revaissone-Mollien, 1891), the page is reproduced with the writing upside-down. It may be, of course, that Leonardo drew the machine that way and made notes later without regard to the position of the drawings. On the other hand, the explanations are done with unusual neatness, aligned with the drawings. Thus, the following analysis refers to the drawing with the writing in upright position.

The large instrument on the left is a polyeder with a broad flat base and five sides, of which at least two are employed as soundboards. The most striking detail is the friction device — this time a double belt, probably of hair or silk thread, passing over three small spindles at the upper end of the soundbox. The spindles are evidently activated by the double wheel shown at the lower end of the soundbox, whose source of motion is indicated. Two of the sides of the soundbox middle and left, carry strings; the left also clearly shows a bridge for the hitch pins. The little circles arranged on the upper end of the soundbox may indicate keys or pushbuttons. If this is so, the line leading down from one of the middle keys to one of the strings may indicate a lever by which the key brings the string in contact with the double belt, or endless bow. And further expanding our assumption that these little objects are keys, their number and arrangement would make one expect that strings would cover all sides of the soundbox and not just the two which I have
pointed out. But in that case, how would the box be held or placed? This is not clear in the drawing.

Although many details are drawn in only a suggestive manner, Leonardo did take great care to make clear that the bow passes
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over rather than beneath the strings. Attention should also be
drawn to the fact that in this drawing we meet for the first time
the name given by Leonardo to this type of machine — «viola».

The double wheel device on the lower end of the soundboard
can be identified with the help of Mss. H 28 r, H 46 r and H 45 v,
as part of the motor that furnishes the drive for the endless bow
or arcetto. However, the way by which it is connected with the
arcetto is not indicated in the present drawing. The smaller poly-
gonal soundbox on the same page is perhaps a passing idea or a
variant of the larger instrument.

The drawing of the «tasti» consists of a double row of push
buttons in the same cubic shape which we will encounter again in
Ms. H, fol. 45 v. They have no visible relation to the instruments
on this page. The possibility that the double row may imply a
chromatic arrangement must remain an open question.

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The opposite side of the same leaf, Ms. H 28 r (III. 16), gives
more detailed although different versions of the wheel mechanism
that drives the endless bow indicated in Ms. H 28 v. On the left
a large wheel is shown, and beneath it a rod cylinder or pinion cage,
whose vertical rods engage horizontal pins of a contrivance which
is only sketchily drawn but whose shape reminds one of that part
in clock-works which serves to retard and regulate the motion of
the wheels. On the right of the horizontal wheel there is an indic-
ation of the threads or hairs of the arcetto (see Ms. H 28 v).

The wheel machinery in mid-page is somewhat different although
probably only in the shape and dimensions of the structural parts,
not in their function. The pinion cage is much larger and more
distant from the upper wheel. The drawing of its vertical rods is
somewhat obscured by a cluster of horizontal lines which may
again suggest an anchor device. Of greatest interest, however, is
the indication of the endless bow, running from the right of the
pinion cage towards the spindle (or, possibly, capsule) which con-
tains the spring. The explanation written there says: «a molla
ceritor ni indi rieto perse il moto dell’arcetto» (a molla ci ritorni
indietro per se il moto dell’arcetto); we may translate this, «towards the spring, returns by itself (automatically) the motion of the bow device». This explanation is important, for it permits some conclusions as to the type of motion of the arcetto, whose
name, by the way, we find only on this page and in Ms. B, fol. 50 v.

If the thread moving the arcetto returns to the spring, it is evidently wound up there on a spindle, and was wound up before at its other end, around the pinion cage. This implies a continuous motion in one direction without pauses, rather than the movement back and forth which the fiddle bow performs. (We will come back to this problem in the interpretation of Ms. B, fol. 50 v). When the spring was coiled, the thread of the arcetto must have been wound around the pinion cage; and when the spring was released, the thread was drawn towards it in a smooth motion, due to the retarding motion of the anchor, until it was wound up on the spring.

There remains another question: the meaning of the three long rods extending below the wheel machinery, ending in what appears to be something like curved, half-moon shaped stands. But they are certainly not stands carrying the wheel machinery and they appear «below» only if we look at the page according to Leonardo’s writing. The whole issue becomes clear if we turn the page so that the half-moons appear on the left and then compare them with the similar «stand» in Ms. H 46 r, and with Ms. H 45 v where we find the wheel device together with the long rod and half-moon connected with the whole instrument. It seems highly probable then that the half-moons are two-pronged handles for winding, with the help of the long rod, the spring enclosed in the wheel machinery. If my interpretation is at all correct, the wheel capsule would he best visible beneath the wheel in Ms. H 46 r.

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Ms. H, fol. 46 r (Ill. 17), shows on the left a wheel device for propelling the arcetto, similar to the ones in Ms. H 28 r. The upper drawing shows a birds-eye view of a mechanism with at least twenty-six strings and a keyboard of sixteen keys. I am not able to explain the two vertical double lines extending from its upper end. The drawing is not precise, for the long oblique bridge which follows the gradation of strings from bass to treble does not cross all the strings. The whole drawing is connected with the viola orga-
nista only if one interprets the double line, which crosses the strings at their upper end, as the arcetto. But this is just as doubtful an interpretation as saying that at the left and right ends of the double-line are revolving cylinders or spindles over which the arcetto would
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pass. Both of these interpretations are possible but unfortunately the sketch is too unclear to draw such conclusions with any degree of certainty.

The sketch on the right has no connection with musical instruments. It is evidently a map of a section of a river, perhaps for a project of canalization. The inscription says, «Altagiara».

* * *

Ms. H, fol. 45 v (Ill. 18), as we will see, is the result of the struggles and attempts embodied in the preceding pages. The upper sketch, although very small, shows a perfectly consistent, workable keyboard instrument with an endless bow. The soundboard of the
oblong box carries eight strings, corresponding to the eight push-buttons or keys (similar in shape to those drawn in Ms. H 28 v) projecting from the front board of the sound box. It goes without saying that there could have been more strings and keys, and the drawing only suggests the construction of the machinery. The double line which marks the arcetto, crossing the strings between the two corner spindles, is clearly visible. The arcetto is moved by the wheel contrivance developed in Ms. H 28 r and H 45 r, and is most similar to the latter.

But there is one more important detail about which the preceding pages have given no information: the action of keys on the strings to enable them to make contact with the arcetto. The reader would do well to look first at the lowest sketch which shows a schematic side view of this device — the levers connecting a single key with a single string; and a longitudinal view of one string running, parallel to the soundboard, toward the rear bridge and from there, with a slight change of direction, toward the hitch pin. If the player pushes the projecting end of the key into its hole in the frontboard, a set of two, right-angular levers similar to the tracker mechanism used in organs, with their pivots clearly marked, turns a little capsule or cylindrical casing that moves around the horizontal axis. Firmly attached to this casing is another right-angular lever terminating in a little circular loop that grasps the string some little distance to the right of the point where the arcetto passes over the strings. Upon receiving the impetus from the key, this loop-lever then draws the string against the moving arcetto, thus creating the required friction. If the reader turns to the whole instrument with this schematic longitudinal sketch in mind, he will recognize the complete contrivance there built in.

The two little sketches at the right are slight variations in the shape of what I have called the contact lever; in the upper sketch the lever is built with a sharp bend, and in the lower sketch, showing three levers side by side, it is shown with a slight curve.

With a mechanism such as this, the player would be able to graduate the intensity of friction and thus the volume of tone, by varying the pressure of his fingers against the keys. This feature of Leonardo's instrument is of inestimable importance; the harp-
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sichord, the keyboard instrument closest to the present sketch in general shape and construction, with strings running back from the player and each sounding their full length or one tone, was incapable of providing the increase or decrease of tone-volume through the varying of finger pressure. In the harpsichord these dynamic variations could only be achieved by «pulling a stop» and thus bringing into play one or more additional sets of strings. The clavichord, the only other contemporary instrument with a keyboard, permitted some dynamic shading through its tangent action on the strings, but it had an incomparably smaller tone than that of the harpsichord of Leonardo’s time. The modern pianoforte which, as its name reveals, permits dynamic shading (through hammer action on the strings by means of finger pressure on the keys), was invented only in the early years of the eighteenth century.

* * *

The last of the drawings for the viola organista, Ms. B, fol. 50 v (III. 19), does not concern itself with the actual instrument but only with an auxiliary mechanism (19), a device for producing an even motion of the arcetto which is quite different and supposedly superior to the wheel motors drawn in Mss. H 28 v, H 28 r, and H 45 r. Those three pages showed contrivances to move the arcetto belt by means of, in all probability, a coiled spring acting as generator. The details of the connection between the spring and the wheel controlling the arcetto were not revealed, but one thing is quite clear: the motion so produced could not have been very smooth and reliable. Metal springs have their caprices — they act strongly at first and then gradually lose power until the exhaustion point. To counteract this disadvantage and to achieve a smooth and even motion of the arcetto, Leonardo evidently searched for a more re-

(19) I am fully aware of the fact that by general consent Ms. B dates a few years earlier than Ms. H. Nevertheless I preferred discussing this page from Ms. B here at the end of this article since it concerns an auxiliary mechanism which can be better understood after discussion of the instruments designed in Ms. H.
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liable device. His solution is shown in the left upper corner of Ms. B, 50 v.

Before studying the entire machine, we should turn to the text — the most elaborate and revealing among all the pages dealing with the viola organista: «Questo e il modo del moto dello archetto della viola organista e se farai le crene della rota de 2 tempi che siano minori l'una quantita de denti che l'altra e che non si schon-trino insieme chome apare in a. b. sara all'archetto uno (cho) equale movimento se non e andra a schosse esse farai a mio modo la ro-chetta f. senpre anderan eqnale ». In free translation: « This is the way the motion works of the viola organista. If one makes the notches to respond not to the same time but to two different times, so that one set of teeth is smaller in number than the other (on the opposite side of the wheel), and the teeth (on the left) do not correspond (the teeth on one side of the wheel not projecting on the same level as those on the opposite side) as it appears in a. b., the archetto will have an even motion while otherwise it would run in jerks. But if you make it in my way the spindle f. will turn evenly ».

This text contains some unclear or at least ambiguous passages which I believe become clearer through the study of the drawing, which itself is only a rapid embodiment of the basic idea, leaving some important detail, open. Thus we must make the best of the situation and try to understand the drawing and its verbal ex-planation, each in the light of the other.

The « archetto della viola organista », that is, the unending bow, is seen at the top of the drawing. It runs over two rolls of which the right-hand one is set into a little cylinder marked « f » in the drawing, and is called « rochetta » (roll, or spindle) in the text. The source of motive power is indicated in the lower left corner of the drawing — a round box from which a cord comes and is wound over a horizontal cone. This cone is known as a fusée (19)

(19) I do not know of any earlier representations or descriptions than this. A. Lloyd, in *Chats on Old Clocks* (New York, 1952, p. 40) considers it possible that the fusee, employed in 1525 in an extant metal clock made by Jacob Zech in Prague was inspired by Leonardo. However this may be, the fusee appears not only in Ms. B 50 v, but also in several other drawings of Leonardo.
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(from the medieval *fusus*, *fusella*, or *fusata*); it is a form of spindle used in machines driven by spiral springs. When the spring uncoils, its pull gradually decreases; the cord pulled by the spring is wound around the fusée pulling first its thin end with small leverage effect, and proceeding gradually to the wide end, thus counteracting the decrease of the force and producing an even drive. The use of the fusée in our drawing indicates that the cylindrical box or barrel in the drawing does not represent a weight, that time-honored source of motion for clocks and other mechanisms, but is rather an encased spring. This assumption is also supported by the four similar barrels in the lower drawing on the same page. They are all connected with fusées, and there the text expressly mentions «4 molli per l’oriolo» (four springs for the clock). They are staggered in an ingenious way so that the first of the springs, after uncoiling and crasing its pull, sets into motion the next one, and so forth until the last one has unwound itself. While the text (14) does not mention any application of this combined spring device to musical machines, it would of course be possible and would give the player a much longer time before he had to rewind the spring.

The arbor (axle) of the fusée carries also a large spoked wheel which again drives another spoked wheel, probably by means of a toothed drum attached to the upper wheel. This device would impart to the upper wheel a much greater speed of revolution than that of the first wheel. The second wheel shares its arbor with the indented wheel, which shows only its broad rim in the drawing. It is the indented wheel whose teeth («crene» and «denti») are mentioned in the text. These tooth-like projections on either side of the broad rim are not placed symmetrically but on different levels. The letters «a» and «b» in the drawing make it clear that a tooth on one side corresponds to a recess or indentation on the other.

(14) Text for the drawing of the four cones or fusées in Ms. B 50 v: «4 molli per l’oriolo, che egualmente, quando l’una a finito suo corso, l’altra comincia. E nel voltare che fa la prima, la seconda sta ferma, e la prima si fissa a vite su la seconda e egualmente, e tutta ficta, la seconda molla piglia il medesimo moto; e così fanno tutte».
To understand this asymmetry, we must undertake a little digression into the escape mechanism of clocks, particularly what is called the crown wheel (15) or escape wheel, and the verge (also called «balance staff», or simply «rod») (Ill. 20). The pull of the weight or of the coiled spring in the clock mechanism would create a rapid motion of the wheels unless it was retarded. This can be achieved by attaching, to the arbor of one of the vertical wheels of the clock, another wheel with ratchetshaped teeth. Near this «crown-wheel» a vertical rod is held so that it can turn back and forth. For this purpose it is equipped with two projecting plates, the pallets, one on top and one down below usually at an angle of about one-hundred degrees to the top one. These pallets engage

(15) The picturesque Italian term for a wheel with such projections is «ruota Caterina». 
alternately with the teeth of the crown wheel — the upper pallet receives a thrust from one of the teeth and turns the verge in one direction, whereupon the lower pallet receives a thrust in the opposite direction and turns the verge back. The result is a continuous swinging back and forth of the verge, permitting the teeth of the crown wheel to slip by one by one and thus to provide a slow and regular motion of the crown wheel. The verge carries a cross bar with a weight on either end, thus increasing the inertia of the verge. The weights can be shifted towards the verge or away from it, to regulate the speed of its oscillation and therefore of the whole clock.

Clocks with this verge escapement existed before Leonardo, and he must have been familiar with this device. In the beautiful intarsias made by the school of Fra Giovanni da Verona about 1500 for the choir stalls of Monte Oliveto, south of Siena, which I visited some years ago in order to photograph the numerous musical instruments represented there, I found a depiction of a large clock with crown wheel and verge clearly delineated (Ill. 21).

The verge escapement in its traditional form, however, would not have been serviceable for Leonardo’s idea of an unending bow. As we have seen, the verge moves back and forth in little jerks; and the crown wheel, although it revolves in one direction, does so in little leaps whenever one of its teeth is released by one of the pallets of the verge. Both of these types of motion do not provide the constant pull needed for uninterrupted bowing of the strings of a musical instrument. And here is where Leonardo’s mechanical inventiveness provided an answer.

He retained the verge mechanism to retard the wheels, but at the same time he transformed it by thickening the crown wheel and equipping it with teeth on either side which project asymmetrically, as he explained in his text. Instead of one verge, Leonardo uses two, furnishing each with one pallet only. In the drawing, the verge on the right side has its pallet on the bottom, and the other on the top. A single verge, with one pallet only, would of course have no retarding effect because it would spin in one direction with rapidly increasing speed. Not so with two verges, as drawn in Leonardo’s sketch. They cooperate to provide retardation: since one verge has its pallet high and the other is low, both revolve in
Ill. 21 – Clockwork with escape mechanism. From the intarsias in the choirstalls of Monte Oliveto, by Fra Giovanni da Verona.
the same direction and turn the two horizontal wheels, left and right of the spindle «f», of which they are the arbors. These wheels then, by means of engaging teeth (not drawn in the sketch), impart to «f» that constant motion used for the unending bow, which is drawn on top with its right roll directly connected to «f».

* * *

As we pointed out at the beginning of this little study, an instrument controlling a multitude of bowed strings by only the ten fingers of one player must have been a dream of imaginative instrument builders for centuries. Such an instrument would not have been merely a counterpart of the organ, where ten fingers control numerous pipes, but would have surpassed the organ in one important aspect—that is, in the flexible dynamics permitting the fine gradation of volume. (The «swell» was invented for harpsichords only in 1769, and then, later, adapted for organs). In Leonardo’s viola organista, the finger pressure on the keys would have also modified the loudness of the tones produced by single strings so that, for instance, one middle voice could have been dynamically emphasized such as we are able to do today on the pianoforte. But again, even the pianoforte would have been inferior to the viola organista in one regard — for the striking of the hammers produces a tone that immediately begins to fade away or, as Leonardo says in the «Paragone», «... muoie durante la nascita», whereas the bowed strings of the viola organista would produce tones that crescendo and decrescendo but do not die away.

How vivid the dream must have been appears from the fact that from the sixteenth century on until the time of the French Encyclopedie, keyboard instruments were constructed, or rather, invented and re-invented. In 1581 Vincenzo Galilei, in his Dialogo... della musica antica, et della moderna, published in Florence, mentions a keyboard instrument with bowed strings in fact, as he says, like an «ensemble of viols» (16). In 1618 Michael Praetorius devoted a whole chapter in his Syntagma Musicum, II, «De Organographia»,

(16) See Appendix A.
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and a beautiful woodcut (Ill. 9), to the "Geigenwerck-Geigen Instrument, oder Geigen Clavicymbel" (17). In 1625 Fray Raymundo Truchado built his instrument with four friction wheels. In Italy also the dream must have lingered on. An official inventory of the Medici Collection (23 September, 1716) of musical instruments included an instrument with five wheels which, according to the short description given there, must have been a Geigenwerk (18). Oddly enough this fact has never been noted in the organological literature (19) and this is particularly strange since it was this inventory which was signed by Bartolommeo Cristofori, the inventor of the pianoforte, when he was appointed keeper of the Medici Collection. There are certainly good reasons for assuming that this instrument, which must have permitted crescendos and diminuendos by finger pressure, played a role in Cristofori’s invention of the pianoforte, whose hammer action made possible the gradation of tone volume by finger pressure.

But it has never been discerned that Leonardo was the first to realize this dream and arrive, after wrestling with various tentative constructive schemes, at a practical solution or, at least, a skeleton for a workable instrument. One is tempted to imagine the Magns putting together a real instrument in Milan or perhaps later in the laboratory given to him by Pope Leo X, in the Belvedere behind St. Peter’s. That no real instrument has survived to our day does not mean that he did not build one. Musical instruments are fragile — their soundboards, of necessity, are made of soft wood and easily warp, bend or crack under the tension of the strings and changes in humidity and temperature. And if they are not played and cared for continuously, they soon fall prey, as Leonardo

(17) See Appendix B.

(18) The description of the instrument: "Un Cimbalo con’ tastatura d’avorio, con’ invenzione di cinque Ruote per toccar le corde di budella ad’uso d’una ghironda, tinta di rosso, e filettato d’oro, con’ riquadrati copti di dom-masco rosso, con’ suo piede intagliato, tinto color’ sim., e dorato, con’ sua sopracopta di corame fod.a di tela, seg. N. 29 ».

(19) CURT SACHS, in his Real-Lexikon der Musikinstrumente (Berlin, 1913), gives the most complete listing of wheel instruments of this sort after Truchado (under the heading "Streichklavier", p. 360 b).
said, to that great consumer — Time. As any connoisseur of the history of instruments knows, many instruments and even whole collections have disappeared without a trace, and old treatises and illustrations, even as late as the Baroque, tell us of instruments of which not a single specimen has survived.

Emanuel Winternitz

APPENDIX A


«Strumento di tasti molto artificioso e bello. Un’altro esempio d’uno Strumento di tasti, che già l’Elettore Augusto Duca di Sassonia, donò alla felice memoria del Grande Alberto di Baviera, mi sovviene in questo proposito, più di ciascuno altro efficace, il quale Strumento ha le corde secondo l’uso di quelle del Liuto, e vengano secate à guisa di quelle della Viola da un’accomodata matassa artifitiosamente fatta delle medesime setole di che si fanno le corde à gli archi delle Viole; la qual-matassa con assai facilità, viene menata in giro con un piede da quello istesso che lo suona, e ne seca continuamente col mezzo d’una ruota sopra la quale passa, quella quantita che vogliano le dita di lui, il quale Strumento, due anni sono che io fui à quella corte, temperai secondo l’uso del Liuto, e faceva dipoi ben sonato, non altramente che un corpo di Viole, dolcissimo udire ».

(*A Very ingenious and beautiful keyboard instrument. Another example of a keyboard instrument which the Elector Augustus, duke of Saxony presented to the late great Albert of Bavaria, occurs to me in this regard, better than any other. This instrument has strings similar to those of the lute and they are bowed like those of a viola by a strand made ingeniously of the same hairs of which are made the hair of viola bows. This strand can very easily be made to revolve by the foot of the player and strikes (bows), by means of a wheel over which it passes, the number of strings wanted by the fingers of the player. When I visited that court two years ago, I tuned this instrument in lute-like fashion and when well played it produced the sweetest sound, not different from an ensemble of Viols *).
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The most telling word in this description is «matassa», which means also the skein of yarn held by one person as it is being wound, and it therefore describes accurately the position of the belt or unending bow of Leonardo's instrument, particularly as it is shown in Ms. B 50 v (Ill. 19).

APPENDIX B

DAS XLIV CAPITEL

Geigenwerk, Geigen-Instrument oder Geigen-Clavicymbel.
(in Scigraph. col. III).

Dieses Geigenwerk (welches an Gestalt und Proportion von aussen einem andern gemeinen gespitzten Clavicymbel ganz gleich, aus derselben Grösse, also dass mans auf ein Tisch hin und her setzen auch von einem Ort zum andern gar leicht tragen, und einer alleine, darauf dasjenige zuwege bringen kann, darzu sonst fünf oder sechs Geigen gehören, ist von einem Bürger in Nürnberg, HANS HAYDEN genant, erstlich erdacht und verfertigt, und die Invention vielleicht aus der Art der gemeinen Lyren (do mit einem Rade die Saiten angerühret werden, und ihre Resonanz von sich geben) anfangs hergenommen, und den Sachen weiter nachgedacht worden. Wiewol etliche, als der Galilaeus und andere wollen, dass vor unser Zeit alldereit solche Art Geigenwerk inveniret und ausspeculiret worden sei. Deme sei nun wie ihm wolle, so ist meines Erachtens gleich hiebevor solche Invention nicht vollkommen zu Werk gerichtet, noch ganz verfertigt worden; als dass gedachter HANS HAYDE solches vor die Hand genommen und zum rechten Stande bracht, wie nunmehr augenscheinlich und wirklich in der That zu finden. [68]

Es hat aber solch Geigenwerk anstatt der Tangenten fünf oder sechs stählene Räder, mit Pergament gar glatt überzogen und oben mit Colophonio, oder oleo Spicae vellavendulae (gleich den Geigenstreichern, oder wie es sonst ins gemein genennet wird, den Fidelbogen) bestreichen; solche Räder aber werden durch ein ander großes Rad und unterschiedene Rollen, unter dem Sangboden liegend, mit beiden Füssen von dem Organisten selbst, unten an der Erden geregieret und getreten, oder auch wol mit den Händen von dem Calcanten, oben an der Saite gezogen, also, dass die Räder allezeit im vollen Schwunge gehen und verbleiden müssen.
Wann nun ein Clavis vornen niedergedrückt wird, so rühret dieselbige Saite an der umlaufenden Räder eins, und gibt den Resonanz von sich, gleich als wenn mit ein Bogen drüber gezogen und gestrichen würde.

Die groben Saiten seind von dicken Messing und stählernen Saiten, mit reinem Pergament umwunden, also dass die untersten fast so dicke sein, als die groben Saiten auf den Bassgeigen, sinntemal etliche in der Tiefen bis ins FF und DD kommen; hernacher verlieren die sich an der Grösse allmählich, dass oben zum Discant nur allein blosse starke stähleene Saiten, ohne Pergament, aufgezogen gefunden werden.

Damit aber diejenigen, welche ein solch Instrumentum und Geigenwerk noch nicht gesehen, wissen mögen, was es vor ein sonderbaren Nutz und Gebrauch der Moderation und Veränderung halben vor andern dergleichen Instrumenten habe, so wil ich desselben vornehmen Instrumentmachers und Erfinders eigene Wort und Gedanken, welche er in einem kleinen Tractätlein, Anno 1610 in Druck herfürgeben, anher setzen, und ein jeden davon zu judiciren anheim stellen.

Es haben die Componisten sonderlich ein zeithero mit allem Fleiss dahin getrachtet, wie sie die Musicam im Gesang aufs höchst bringen möchten, also, dass sie nunmehr nicht wol höher zu steigen hat. Die Musicalische Instrumenta aber betreffend, obwol an etlichen grosse Mängel gefunden, als dass sie der schönsten Zier, nämlich der Moderation der Stimmen mangeln, so hat sich doch bei so viel kunstreichen Instrumentisten, so jederzeit gewesen, keiner unterstanden, demselben Gebrechen abzuhelfen und die Moderation der Stimmen auch ins Clavir zu bringen.

Wieviel aber daran gelegen, die Stimme zu formiren, das wissen diejenigen, so in den Capellen, die jungen Knaben und Cantores abzurichten pflegen. Es verstehts auch sonsten fast ein jeder, was es für ein Uebelstand nur an einem gemeinen Oratore ist, wann derselbe im aussprechen mit Erhebung und Niederlassung der Stimme, wie es der Text und affectus erfordern, keinen docorum halt, sondern immer im gleichen Ton an einander unabgesetzt fortredet. So nun dasselbige im Reden, vielmehr ist es im Singen verdriesslich zu hören.

Es ist aber ein jedes Clavirtes Instrument, sowol die Orgeln, welche doch sonsten, was die gravitatem belangt, den Vorzug vor allen andern Instrumenten haben, als auch alle andere Pfeiffwerk mit diesem Mangel behaft, dass sie nicht moderirt, noch die Stimmen zum lauten oder stillen Klang und Sono gezwungen werden können, sondern es gibt
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und behält die Pfeiffe ihren Laut in gleichem Ton, wie auch der Instrumentist den Clavem angreift, und ist unmöglich die Stimme zu stärken oder zu lindern; welches aber einer mit dem Bogen auf der Geigen, nach dem er stark oder leise drauf streicht und aufdrückt, thun kann. Und ist also der Instrumentist auf dem Clavem gefangen, dass er seine affecten nicht, wie sonst auf der Geigen (ob er schon den Text darauf auch nicht aussprechen kann) dennoch kann zu merken geben, ob traurige, fröhliche, ernstliche oder schimpfliche Gedanken in ihme sein: Welches aber allein durch die moderation der Stimme geschehen muss. Und ob man wol in den Orgeln mit Ab- und Zuziehung der Register, jetzt ein stilles, sanftes, liebliches, bald wiederumb ein lautes Getön und Geschrei machen kann, so heisst doch dasselbige, weil es in gleichem Ton still oder laut bleibt, keine Moderation, sondern es ist ein ungeformirte, ungebrochene Stimm, wie hier vorn von einer unabgesetzten Rede gesagt worden ».

» Also kann man auch die Stimmen auf den Instrumenten von Saiten, weder stiller noch stärker, als wie es der Clavis an sich selbst gibt, machen oder zuwege bringen: Und lässt sich der Sonus nicht erhalten, sondern so bald die Saite getroffen wird und sich hören lässt, verschwindet der Laut wiederumb, also, dass kein ganze tempus gleich vollkommen kann continuirt werden ».

» Welches Abnehmen und Verschwinden der Stimme der rechten Moderation zuwider ist: Dann dieselbige sich von der Stillen in die Stärke schwingen soll ».

» So ist auch von Nöthen, da man anderst daselbst einen ganzen Schlag vollkommen erhalten will, dass er in mehrtheil diminuir und zwier angeschlagen werde; welches aber wider die Natur eines herrlichen gravitatischen Gesangs in Muteten und Concerten ist, ob es wol in Passametzen, Galliarden und Tänzen passiren kann ». 

» Auf diesem Geigenwerk aber kann man beides haben, als nämlich die Stimme, so lang man will continuiren und moderiren, und nicht allein ein breuem, sondern auch gar ein longam und maximam unabgesetzt an einander continuiren, welches auf der Geigen (wegen des kurzen Geigen Bogens) auch nicht sein kann ».

» Und obwol der Text mit Worten sich nicht aussprechen lässt, so kann doch der Instrumentist seinen sensum zu erkennen geben, ob traurige oder fröhliche Gedanken in ihme sind, nachdem er das Clavier frech oder lind angreift. Für eins.

2. Zum andern kann der Instrumentist nach seinem selbst gefallen mit der Mensur abwechseln, die jetzt langsam, dann bald wiederumb
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geschwinder führen: Welches auch die *affectus* zu *movirn*, nicht undienlich: Und in andern *Instrumenten* gleicher gestalt kann in acht genom-
men werden.

3. Zum dritten kann auch der Gesang unversehens, wann es der Text also erfordert, bald laut *resonirend*, bald still, bald wiederumb
lautklingend gemacht werden.

4. Zum vierten ist es ganz lustig und verwunderlich zu hören, ob es wol nur ein *Clavier* und ein einzig Stimmswerk von Saiten hat, dass
doch einer allein dasselbige also verstellen kann, dass man nicht anders
meinet, denn es sein zween unterschiedliche *Chor* gegen einander, auch
dween unterschiedliche *Instrumentisten*, die mit einander *certirn*, und
einer dem andern *respondire*.

5. Zum fünften kann man auch einen natürlichen *Echo* darauf
hören lassen, gleich als wenn es einen Nachklang oder Wiederschall
aus dem Wald, oder zwischen den Bergen herfür gebe.

6. Zum sechsten kann mans auch auf die Manier und Art anderer
Instrumente, sonderlich aber gleich wie eine Laute machen und herfür
geben.

7. Zum siebenten, Wann einer begeht in einer Stimme den *Choral*
zuführen, und dass man denselben vor den andern Stimmen heraus
strärker, vernehmlich hören soll, es sei nun im Bass, Tenor oder Discant,
so kann es also auch gar sehr wol geschehen.

8. Zum achten, wie man sonst in die Pfeiffwerk mit einem sonder-
lchen Register *Tremulanten* macht, so kann dasselbig auf diesem *Clavier*
ohm einig Register, allein durch eine freie Hand, langsam or geschwind,
tremulirend und zitternd gemacht werden.

9. Zum neunten, lässt es sich auch auf gut Leyerisch: Und
zum zehnten wie Sackpfeiffen und Schalmeyen machen und hören: 
damit man die Weber und Kinder, so sich sonst der *Musica* nicht viel
achten, auch wol grosse Leute, wenn sie in etwas mit ein guten. Trunk
beladen, erfreuen kann.

11. Zum elften gibt es auch ein Cithern-Art, wie die jungen Gesellen
pflegen *gassatum* zu gehen.

12. Zum zwölften ist auch die Geigen-Bastarda genannt, darauf gut
zu *contrafacten*.

13. Zum dreizehnten kann man auch ein Fürstliche Hof- und Feld-
-Musica* darauf hören lassen, nicht anderst, als wann ihrer zwölf mit
Trommeten und *Clareten* gegen einander natürlich bliesen: darzu dann
die Heerpaucken, welche in etlichen dieser Geigenwerken mit ein-
bracht,
und durch ein Register gezogen werden, nicht so gar übel mit einstimmen,
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14. Zum vierzehnten, ob wol dies Instrument nur eine einfache Saiten bei jedem Clave hat, und wann es zugedeckt ist, ein gar stillen sanften Resonanz gibt wie Geigen, also, dass es in einem engen Gemach lieblich zu hören ist, so kann mans doch auch, wenn man will, und es offen gebraucht wird, so stark machen, dass es sich unter einem ganzen Chor von Singern und Instrumenten herauß gar laut und vernehmlich hören läßt.

Dies alles, und sonst noch mehr, kann ein Organist zuwege bringen, dieweil es anders nicht, dann ein gemein Clavier und keines sondern Griffs oder application bedarf, allein dass man mit einer leichten Hand und nicht mit voller Gewalt ins Clavier hinein falle.

Denn es will hierbei eine sehr fleissige Uebung hoch von nöthen sein, dass der Organist. 1. sich exercise und gewöhne mit den Füssen die beiden hölzernen Bretterlein unten an der Erde, welche die Rader oben regieren und umbführen, nach dem Tact, den er oder die Musici halten, stetig und unablüssig zu treten; so kann er alsdann im Tact desto besser fortkommen, und umb so viel weniger irr gemacht werden. 2. Dass er gar eigentliche und gute auf acht habe, die Claves mit den Fingern nicht zu hart oder gar zu gelinde angreifen, damit etliche Saiten nicht zu laut scharren, die andern aber zu wenig, oder gar nicht respon-diren: welches dann von ein jeden ohne sonderbare fleissige stete Uebung sich anfangs nicht thun lassen will.

Welcher aber nun dessen ein wenig gewohnt ist, und versteht die Lieblichkeit und moderation, so er auf diesem Instrument haben kann, der begehrt sich keines andern zu gebrauchen. Es ist auch umb so viel desto annemlicher, weil es nit so viel stimmens, als die Lauten und Geigen, oder auch andere besaitete Instrumenta bedarf, von wegen dass die Saiten nicht schaffen (*), sondern alle von Messing und Stahl sind, welche durch langen Gebrauch je lenger je besser werden, und sich nicht bald verstimen.

Und weil vielleicht dieses Werk und Instrument von etlichen (die solches noch nit in der Uebung und Gebrauch haben, und auch ent-weder zu practiciren und sich zu exerciren verdrossen sind, oder aber ganz nit darauf fortkommen können) verrichtet, und vor ein Bauren-Leierwerk geachtet werden möchte, so bitte ich, sie wollens nicht als- [72] bald schänden oder verachten, sondern sich so lang gedulden, bis sie dessen gewöhnen und ihne seine Art recht zu geben wissen: Als dann zweifle ich nicht, sie werden sich dessen mit Lust und Verwunderung gebrauchen und mir hierfür, dass sie nun die moderation im Clavier

(*) Saiten nicht von Schafen.
auch haben können, fleissig danken. Und dass sich solches also verhalte habe ich selbst an etlichen in der That befunden, die anfanglich daher davon gar nichts gehalten, weil es ihnen nicht allein zu schwer worden, sondern auch aus Faulheit und Nachlässigkeit sich darumb nicht bemühnen wollen. Als sie es aber vorgenommen, und sich darauf mit Fleiss etwas exercirt und geübt haben, ist ihnen dasselbe so lieb und angenehm worden, dass sie dessen nicht sattsam und überdrüssig gebrauchen können, ja auch viel lieber uff einem solchen Instrument, als einen guten Clavichordia oder Clavicymbel practiciret und gesehen haben."
MELODIC, CHORDAL, AND OTHER DRUMS
INVENTED BY LEONARDO DA VINCI

Leonardo was greatly interested in the construction of drums. Not only did he try to improve their playing technique, but he expanded their musical possibilities, such as the range of tones, far beyond the limitations of the conventional instruments of his time. He also gave some thought to the mechanization of military drums, which is not strange if one recalls his interest in devising tools of war from small daggers to gigantic war machines and battlements.

The following pages in his notebooks contain sketches of drums:

Cod. Atl. 355 r-c; 319 r-b; 306 v-a;
Cod. Arundel 263 fol. 137 v; fol. 175 r.

Cod. Atl. 355 r-c: This large page (Ill. 1) shows three instruments. The ones at the left and at the bottom are only faintly visible: at the left we see a string instrument with seven strings, by its shape vaguely related to the hurdy-gurdy (ghironda). Keyboards are placed not only at the side of the neck, but also appear strangely at the sides of the body. The function of such keys, if they are keys at all, remains mysterious since such a large number of keys does not seem to correspond to the much smaller number of strings.

The faint sketch at bottom of the page represents a set of twelve small kettle drums graduated in size. Simple as this sketch is, it clearly indicates Leonardo’s idea of utilizing the drum as a melody instrument, that is employing drums for producing all the tones of the scale and thus radically exceeding the role of the drum as primarily a reinforcement of rhythm.

The large drawing on our page represents, in accurate detail, a large kettle drum with the usual screws placed near the rim of the
Ill. 1 - Codex Atlanticus, fol. 355 r-c.
Ill. 2 – Codex Atlanticus, fol. 319 r-b.
skin, to tighten the latter for tuning. The three beaters are operated by a cogwheel, turned by a crank.

Cod. Atl. 319 r-b: The page shows (Ill. 2) beside a number of drawings not related to drums, eight sketches of drums. All of these concern drums which are driven automatically by the wheels of their carriages. There are five side views of mechanical drums, one schematic sketch in front view (bottom of the page), and two diagrams showing the wheels and axle of the carriage. The five side views represent slightly different versions of the same principle: the axe of the carriage wheel drives a central cog wheel, or pinion wheel, and this in turn, through other cog wheels or pinion cages, activates the beaters. In detail, the left upper sketch shows a side drum with four beaters which are moved in turn by the pins of a horizontal wheel. The sketch to right of it is a cylindrical drum in vertical position, with its skin on top, and the beaters work by a large vertical pin wheel. The sketch immediately beneath it wavers between two ideas: the cylindrical drum in side or vertical position.

The drawing beneath the center of the page is more detailed: here the cog wheel between the two carriage wheels engages two horizontal cog wheels evidently to beat the side drum both sides.

The last detailed drawing (middle-bottom) seems to employ pinion cages in place of cog wheels. The use of beaters on both sides is also clearly indicated in the frontal sketch in the right lower corner of the page.

Cod. Atl. 306 v-a: This sketch (Ill. 3) is clearly a detailed and slightly modified version of the sketch in Cod. Atl. 319 r-b beneath center. Here, the drum has a snare and five beaters. The teeth of the central vertical wheel engage with vertical rods of two side cylinders whose upper surface carry several oblique rows of pins which, in rapid succession, lift the levers that move the beaters. A crank protruding from one of the carriage wheels indicates that the whole machinery could be operated by hand if the carriage was not in motion.

Before turning to an analysis of Leonardo’s new ideas for the construction of melodic and chordic drums (Cod. Arundel 263, fol. 137 v and 175 r; Cod. Atl. fol. 355 r-c), it will be necessary to
inquire into the general state of drum construction at Leonardo’s time, especially the form and function of kettle drums which were the most noble and elaborate members of the drum family. Only against this background will it be possible to judge the novelty of Leonardo’s inventions and, in some cases, even to arrive at a reasonable interpretation of his sketches.

Small kettle drums, always used in pairs, entered the Occident from the Islamic near East at the time of the Crusades, and gradually became indispensable in martial music together with their inseparable companions, the trumpet. Large kettle drums came to central Europe and Italy during the 15th century from the Turkish empire. They could be tuned by turning one after another the screws which thus increased the tension of the skin (Ill. 7).

The most simple and obvious device to employ drums for playing a scale or a chord is to use a whole set of gradated drums. One of Leonardo’s sketches of this invention we have already mentioned discussing Cod. Atl. 355 r-c, a set of gradated small kettle drums.
Another similar sketch is found in a corner of Cod. Arundel 263, fol. 137 v, which is chiefly devoted to a wheel of pipes for producing musical canons (Ill. 4). There, in the left upper corner, a little diagram shows five bowlshaped drums of increasing size; they are attached by stems to a common base. Two beaters are indicated, one at left and one at right. The text explains: «tanpa nj sona ti co me ilmo na cordo ovei dolce mele» (timpani sonati come il monacordo ove il dolcemele): «kettle drums played like a clavichord or dolcimele».

My translation of «monacordo» by «clavichord» requires a justification. In the 15th and 16th centuries, the word monacordo also written monacordo or manicordo were used for two different instruments: a) the monochord, that venerable sound box with one or more strings, used for studying the numerical ratios of stopped strings (Ill. 5); b) the clavichord, which had a larger number of strings stretched over an oblong sound box, and a set of keys that had little flat upright metal plates («tangents») inserted at their rear ends to strike at the same time to stop the strings. The clavichord was fashionable already before Leonardo’s time. The beautiful intarsias in the Studiolo of Federigo da Montefeltre’s palace at Urbino include a large clavichord of no less 47 keys and
22 strings. The clavichord was also sometimes called manicordio, the word based in free association on monocordo but alluding to mano (hand).

The «dulce melos» was another contemporary keyboard instrument, of square shape with jacks standing freely on the rear end of the keys. These jacks had brass hooks that struck the strings when the keys were pressed (1). At any rate, Leonardo meant to compare his set of drums with a keyboard instrument, since the latter could produce melodies and chords.

Cod. Arundel, folio 175 r: This page (III. 6) contains three groups of sketches and observations. One concerning theoretical mechanics, specifically with gravitation and the behavior of weights (2) fill the top and the upper right of the page. The lower part of the page shows eight sketches for the construction of keyboards for wind instruments (3). The rest of the page, that is the left upper half and center, deals with drums, and to this section belongs also the large chordal drum with beater in the right lower section.

The eleven drum sketches represent an astonishing variety in aim and construction. We should like to point out here, before detailed interpretation, that the sequence from top to bottom is not haphazard; the drawings are not isolated apercus but rather seem to follow a methodical order progressing from group to group, each group dealing with a different problem. Thus we will take them up in our analysis from top to bottom and reflect on the method of the grouping at the end of our analysis.

A: The body of the drum is clearly a cylindrical snare drum. The problem begins with the indented line vertically crossing the skin, and the concentric cluster of black lines on the left from which

(1) The first description of the dulce melos is found in a 15th century Latin manuscript in the Bibl. Nat. in Paris. BOTTE DE TOULMON first brought attention to it in his Dissertation sur les instruments de musique au moyen-age, Paris 1844, comparing it to a pianoforte. CURT SACHS gave a more convincing description of it in his History of Musical Instruments, New York, 1940, p. 343.

(2) See the transcription of these passages in ARTURO UCCELLI, Leonardo da Vinci: I Libri di Meccanica, Hoepli, Milano 1940, p. 20.

(3) I have analyzed them in the following article in this issue of the Raccolta Vinciana.
evidently protrudes a crank. Leonardo’s explanation says: «tamburo di tacche fregate da rote di molle»; at least, this is the diplomatic translation in the facsimile edition of 1923, edited by Danesi. In English this would be: «A drum with (a device of) notches scraped by a wheel of springs». With the word «tacche», Leonardo probably indicates a small board with many little saw-like indentations. The «rote di molle» is probably not a wheel in the strict sense of this word, but a number of flexible metal sticks arranged like the spokes of a wheel. It is possible, however, to read roti instead of rote and to translate it «fragments» (or little pieces) of springs. The protruding crank is unmistakable; but the way in which the cluster of springs is attached to the drum is not clear from the drawing.

What, then, is the meaning of the whole? Leonardo’s explanation gives the technical ingredients of the mechanism, not its purpose. We probably have here a combination of a scraper action—that is, the springs beating against the indentations of the saw—with a cylindrical drum functioning mainly as a resonator or sound-reinforcement. The whole achievement then would be rather moderate: a different timbre and a sort of mechanization through crank-action, but no revolutionary invention as we will find in the following sketches.

B: This sketch is of incomparably greater importance and novelty than A. Leonardo says: «tamburo quadro del quale si tira e allenta la sua carta colla lieva a b» (square drum whose skin is tightened and slackened by means of the lever a b).

The drum, that is its body, — contrary to Leonardo’s words —, is
not square, but its head is. The function of the tightening mechanism becomes clear if the reader's eye separates, as it were, the outer shape of the drum from the levers which look so:

If the player pushes asunder the ends at the right, perhaps wedging his fist in between, the other ends open, scissor-like, thus tightening the skin, while the other hand is beating it. The result is that of a drum with pitch changeable during performance, something which the Occident did not know until the invention of the pedal machine drum, towards the end of the 19th century (4). This latter invention enabled the player to change the tuning so fast during performance that even a melody of moderate tempo can be played.

C: Here the shape of the drum is that of a kettle drum. This kind of drum was well-known to Leonardo. Small kettle drums, always used in pairs (naqqârâ, nacchere, nacaires, nakers) entered the Occident from the middle east during the Crusades if not earlier. Large kettle drums (tympana) were known in eastern Europe, especially Hungary and Poland, as early as the 15th century. In 1511 Sebastian Virdung, a priest in Basle, complains in his Musica getutscht of the "horrible noise of these drums, which disturb the pious old people, the sick and the devout in the cloisters, who try to read, to study and to pray", and considers them "an invention of the devil, and the suppression of all sweet melodies" (5).

(4) German patent April 2, 1881; see Zeitschrift für Instrumentenbau, 1903, XXIII, p. 636. West Africa and the Far East know the "hourglass drum" whose two skins are connected by external ropes which can be pressed by the player's arm or elbow to increase or decrease the tension of the skins and thereby change the pitch during performance. It is, however, improbable that Leonardo know this type of drum.

(5) Sebastian Virdung, Musica getutscht und ausgezogen, Basel, 1511, p. 25.
Virdung's illustration of the kettle drums (Ill. 7) shows a device which, according to all historic evidence, must have been quite novel at his time: there are ten screws visible which can lower or raise the iron frame by which the skin is stretched, and thereby tighten or slacken the skin. None of Leonardo's drums has this device. The present drum, like the ones in F ad G, show an earlier tightening device, namely laces. Cords like these may either connect the two skins on opposite sides of a cylindrical drum, as for instance in G, or in kettle or pot-shaped drums like C are slung from the rim of the skin around the body. For tuning purposes this net of cords can be tightened but this of course takes some time, and a quick change of skin tension during performance is out of the question.

Leonardo's sketch shows an extraordinary feature: the cords running from the circular frame of the drum are not fastened to its round bottom, but clearly go beyond it toward a sort of disc or ring to which we must suppose they are attached. From this contraption protrudes — drawn in Leonardo's inimitable "short-hand" technique — a screw and a crank. The only interpretation that explains all these unusual features is to consider them as a device that can, by turning the crank, change the tension of all the cords simultaneously and thereby change the pitch in a minimum of time. On such a drum, any melody could be played by
appropriate manipulation of the crank. This invention, whether Leonardo knew the hoop-tightening screws depicted in Virdung or not, goes far beyond Virdung’s device, and in fact anticipates the latest development of the modern pedal-tuned timpani or “machine drum” of the modern orchestra, which dates back no earlier than the middle of the 19th century. The screws on the Virdung instrument could be turned only one at a time and therefore would permit only slow tuning. As pointed out above, not until the pedal machine drum of the 19th century was a quick simultaneous tightening of all the screws on the hoop made possible.

In sketch C which we are here discussing, the drum apparently rests on a stand; the player could not hold the drum as both of his hands were engaged, one in turning the crank and the other in beating the drum. Thus, the presence of a stand would support the assumption that the crank serves to tighten the laces rather than activating a beating mechanism.

It seems appropriate here to at least mention a different interpretation. One may perhaps consider the crank as a device for beating the skin in some way from the inside of the body, and there are three sketches where cranks (*) are used to set the beaters or beating springs into motion: A, E and H. But in all these sketches the connection with the beaters is obvious and the beaters are clearly drawn. Moreover, in sketch C the crank is attached to a screw which would allow only slow turning as required for tightening, and not for rapid beating. Finally, sketch C appears as one in a row of five drums (B, C, D, E and F) which all aim at a workable solution of changing pitch during performance.

Sketch D is one of the most original solutions of the problem of obtaining a series of different tones from a drum while beating it. Here a snare drum with a long, nearly cylindrical body on a stand has several side holes in flute fashion. Before finally convincing myself that the little circles indicate holes, I decided to experiment,

(*) The study of the cranks in Leonardo’s machines is rewarding beyond their use in musical instruments, for they function only if turned counterclockwise, that is, as a left-handed person would turn them. This fact alone would have been a decisive argument in the controversy raging for generations about the reasons why Leonardo used mirror-writing.
and had built a little wooden tube with a skin on one opening and several sideholes. The closing of the various holes while beating the skin results in clear pitch differences, and one wonders why in primitive music or for children's toys such a «flute drum» was never utilized.

Sketch E shows a square box with a ratchet wheel worked by a crank. The several slightly curved lines on top of the upper side of the box seem to indicate springy tongues attached at one end to the surface of the box while the free end is lifted in quick succession by the spokes of the wheel, to snap back against the surface. The way in which the wheel is attached to the box is not shown unless one of the lines just mentioned indicates such a connection.

The unusual feature of this instrument is the flat oblong board on its right side, which is softly shaded while the square above it is strongly shaded. The board is, in my belief, a slide and the square above it a hole which can be opened or closed by moving the slide. The purpose would again be to obtain a change of pitch during playing. To verify my interpretation, I again built a model whose performance fully corroborated my assumption. Notice also the little projections on the bottom end of the slider, which can hardly be anything else than loops or handles for moving the slide.

There is still the question whether this instrument is a «drum» in the strict sense of this term, that is, an instrument with a membrane. We must rather assume that its upper surface is of wood,
since only this would provide the right basis for the springy tongue of the ratchet mechanism.

The drum in sketch $F$ is evidently based on the same principle as $E$ — the slide action. Here the body is that of a conventional cylindrical drum with laces. The side hole and slide are on top, and the right end of the slide again has some sort of handle for pulling. This drum has no mechanical beating machinery, but an ordinary beater.

The next sketch introduces a group of three drums ($G, H,$ and $I$) that are based on another method of expanding the function of drums: the production of simultaneous tones or chords, by combining several drums into one compound instrument. Sketch $G$ shows an instrument which is a combination of a side drum with snare, and several cones inserted into its base. Three cones are visible, but it is possible that there may be more, hidden behind. However, there are marks added at the right of the cones which may be the symbols for tones according to the Guidonian system of solmisation which designated the tones of the scale by syllables such as ut re mi fa sol la. This seems probable also from Leonardo’s caption, «tanburo a consonanza», though one cannot help wondering why the cones meant to produce different tones are of approximately the same size. Different tones, to be sure, f.i. the tones forming a triad, could be produced by different tightening of the membranes, assuming they had some.
At any rate, there cannot be any doubt that we have here a drum intended to produce a chord. It is a pity, however, that the drawing does not give the faintest idea about the connection between the body of the drum and the cones, or whether the cones are open or closed at their wide end or perhaps at their small end, or how deep they reach into the drum itself. There are several possibilities: 1) They may be open at both ends. This possibility can be discarded; a model that I built does not succeed in producing different tones. 2) They may be equipped with membranes at either or at both ends, and therefore, in fact, be drums themselves.

Sketch $H$ is another «consonance» instrument. The text says: «Una tabella a consonanza cioè 3 tabelle insieme». The body consists of three shallow boxes. To the left upper edge a ratchet mechanism is attached. A spindle turned by a crank is furnished with three sets of spokes that simultaneously operate springy tongues beating on the top of the three boxes. Thus this instrument was intended to produce a chord of three tones.

We do not see from the drawing whether this instrument has membranes. If not, it would, like that in sketch $E$, not be a drum in the technical sense of the word but an idiophone.

Still simpler in construction is the drum sketched at the lower right side of the page (Ill. 6). At first glance there may seem to be six «compartments» on the right side as opposed to five on the left. Actually, there are five skins at the left which bend around the edge of the whole box and are tied with cords around it. The text says: «Si come un medesimo tanburo fa voce gravi e acute secondo le carte più men tirate, così queste carte variamente tirate sopra un medesimo corpo di tanburo faran varie voce» («Since one and the same drum produces high or low tones according to the tighter
or looser stretching of the skin, so the present skins stretched at various degrees over the same body of a drum, produce different tones). The instrument clearly permits playing a scale.

The last two drawings of drums, sketches J ad K, present greater difficulties to interpretation than all the others. Both are evidently pot drums with detachable drumheads and a mechanism inside to make them sound. No separate beater is visible.

In the upper drum J, what appears to be a lid or cover at the left (or upper end of the pot) is detached. Whether this left end of the pot is simply open, or covered by skin, cannot easily be decided. Since Leonardo uses shading for open holes such as in sketches E ad F, we are inclined to interpret the round shape at this end as a head affixed to the drum, in addition to the one which is removed. In the lower drum, the corresponding section is dark and thus, probably, an open hole.

Also difficult to explain are the curved lines at the right of the upper drum. They are likely to indicate a base or handle for holding the pot, or perhaps a device for activating the inner machinery. Since no outside beater or drum stick is illustrated we must assume that it is the inner mechanism that beats the drum from inside.

The lower drum K, of a different and longer shape, also has a detachable cover and an inner mechanism. The latter, in this case, is activated by a spoked wheel outside, which is turned by a crank. The ends of the wheel-spokes beat against two nearly parallel sticks or wires protruding from the pot. This dual number makes one think that it is a device employed to turn the object inside the pot, which may be a friction wheel. Problematic also is the line curving
on the lower side of the drum, clearly outside it, extending from the frame of the spoked wheel towards a hook on the rim of the pot.

While this attempt at interpreting the drawings themselves remains guesswork, we may find relevant information in contemporary instruments of Leonardo’s time, and recall certain folk instruments that show similarities to Leonardo’s pot drum. One is a scrap pot as we find it illustrated occasionally after 1500 in German literature. It is shown in Virdung (Ill. 8), and evidently copied from there in Praetorius where neither name nor explanation is given except that in Ch. XIII of the «De Organographia» he refers to it by calling it a «Pritschen auf dem Hafen» (beater in the pot). It is also illustrated in a facetious set of «Musicians» by Tobias Stimmer, where the last picture is that of an old woman playing the pot with a spoon ending in a hook (Ill. 9). No treatise
III. 9 – Old woman with pot drum, woodcut by Tobias Stimmer, 16th century.
gives the name or an explanation of how it is played, but from Stimmer we can safely conclude that the playing technique was that of scraping. The first two rhymes of the funny poem which accompanies the drawing say:

« Nimmer zergaht ein Spil ohn Narren.
Drum muss ich auf dem Hafen scharren.»

("Never a play occurs without a fool, therefore I must scrape [scharren] the pot [Hafen].

There was also another folk instrument which combined pot and membrane and is so widely disseminated that it must have a very long history. Its most famous illustration is found in a painting by Frans Hals (Richmond) (Ill. 10). It is the Rommelpot, to use its Dutch name mentioned already in Mersenne’s Harmonie Universelle, Paris 1636. In Provence it was known as the pignato, in Naples — caccarella, in Apulia — cupacupa. Lombard forms are not known to me — neither as existing specimens nor in paintings, not even in Saronno. But the similarity between this and Leonardo’s instruments is so striking that it is not unlikely that Leonardo may have known these folk instruments in one form or another.

* * *

Sketches like these are interesting not only because of the originality of Leonardo’s inventions and the superb economy of his drawing technique; they permit a glimpse at his forma mentis. He begins his series of drums with what was probably a passing idea: an unusual tone colour or rather noise colour for a drum and a mechanical contraption for playing it. But then a whole flood of novel ideas is let loose, all going beyond existing devices. Leonardo endeavors to enrich the traditional function of drums by making them capable of producing chords and scales. For this, he tries
Melodic, chordal, and other drums invented by Leonardo da Vinci 67

two different methods: one is the combination of several drums or skins of different pitch into one single instrument. The other consists of devices to make one skin produce tones of different pitch in rapid succession. This aim is realized by various methods: either through the introduction of side holes; or through the use of scissor-levers or screw-devices to change the tension of the skin while it is beaten; or through slides that open and close a large hole in the resonating body; or, finally, by mechanisms that detach the skin cover from the body of a pot drum. Hardly an opportunity offered by nature is overlooked in this series of quick though methodical sketches, jotted down on a page which began with quite a different subject — theoretical mechanics — and is going to wind up with new ideas for wind instruments.

EMANUEL WINTERNITZ
LEONARDO'S INVENTION OF KEY-MECHANISMS
FOR WIND INSTRUMENTS

The eight sketches on the bottom of fol. 175 r of the Codice Arundel 263 concern one of the crucial problems in the construction of wind instruments with side holes: the control of fingerholes which are spaced wider than the reach of human fingers. The laws of acoustics determine the distance between the fingerholes that are bored in the side walls of the tube of a wind instrument for the purpose of obtaining different pitches from it (1), and the lower the range desired, the longer must be the tube and the larger the distance between the holes. Thus in the building of larger instruments with side holes, a critical point is reached and a device is needed for transferring the action of the fingers to the distant holes, in order to close them. A device for this purpose is the key, or lever, pressed on one end with the finger and closing the fingerhole by means of a pad on the other end. Keys are used today in all so-called woodwind instruments (such as transverse flutes, clarinets, oboes, bassoons, saxophones, etc.).

Keys on woodwind instruments came into use only gradually, however. The first evidence I know of is in Sebastian Virdung's Musica, 1511 (2). There, two of the many wind instruments illustrated in the woodcuts show one key (Ill. 1). These instruments are: a bass shawm (« Schalmei »), there called « Bombardt », and the largest of the recorders, there called « Flöten ». In Virdung's

(1) There are, of course, as any player knows, other means for obtaining a variety of tones, such as overblowing (the special combination of breath and lip pressure to produce harmonics), mechanical devices such as slides and, since the nineteenth century, valves.

(2) But none of the three recorders appearing in the title woodcut of Silvestro Ganassi's Regola Rubertina (Venice, 1542) shows a key.
illustration, only the upper end of the key, or finger plate, is visible (swallow-tailed in shape for use by either the right or left hand), its lower part being covered by a perforated cylinder. The purpose of this key was to control a hole placed out of reach of the little finger. The collection of ancient musical instruments in the Vienna Kunsthistorisches Museum contains several sixteenth cen-

![Illustration showing a keyed shawm and a keyed recorder, from Musica getutscht und ausgezogen durch Sebastianum Virdung Priesters von Amberg... Basel, 1511. Facsimile ed. Robert Eitner, ed., Berlin 1882.](image)

tury Italian shawms with single keys (n. A 191, n. C 192 and n. C 193 in the catalogue by Julius Schlosser, Vieuna, 1920). They seem however, to come from the later part of the sixteenth century.

But at earlier times it was not only woodwind instruments which had side holes. There existed wind instruments which had mouthcups comparable to those of trumpets (and other «brass»
Leonardo's invention of key-mechanisms for wind instruments

instruments) and at the same time had sideholes: these instruments were the cornetti of the Renaissance, straight or curved tubes made of wood and covered with leather or made of ivory (Ill. 2). Many kinds existed of different sizes and shapes — curvi, diritti, muti, — and later their larger relatives, the serpents. Still later, in the second half of the eighteenth century and the beginning of the nineteenth century, a number of brass instruments with sideholes were constructed: the basshorn, the ophicleide, the keyed trumpet, keyed bugle, and keyed horn. They all soon became obsolete through the invention of the valve mechanism, a device consisting of pieces of metal tubing added to the main tube of the instrument to change the pitch.

The family of the cornetto is the only known case of a mouthcup instrument with sideholes at Leonardo's time. And while, of course, we cannot exclude with mathematical certainty the possibility that the principle of the sideholes may have occasionally been trans-

Ill. 2 — Cornetto curvo of ivory, about 1600 with gilded mounting and original mouthpiece.
ferred to the metal trumpet, it is highly unlikely and no picture, sculpture, musical treatise, or any other contemporary record represents or mentions such an instrument.

* * *

The eight sketches concerning wind instruments on our page fall into two groups: four on the left dealing with the trumpet, and three on the right dealing with the pipe (zuolo). Evidently connected with these latter is the schematic drawing lowest on the left side; the reasons for this separation will become clear from the following analysis (Ill. 3, C. A. 263, fol. 175 r).

We begin with the upper left sketch (Ill. 3, n. 1), which shows a straight tube of cylindrical shape terminating in a narrowly flaring bell; six holes are clearly indicated and they seem connected with little circles on a stick, or tube, which runs parallel to the main tube. The whole sketch represents a trumpet with sideholes, equipped with an auxiliary rod beneath it which carries a key mechanism for closing the side holes. Trumpets of this shape but with no side holes abound in Italian paintings, especially of angel concerts — for instance, in Giotto's « Coronation of the Virgin » in S. Croce, Florence (Ill. 4) and in one of the panels of Luca della Robbia’s « Cantoria » (Ill. 5). Thus, if our interpretation of Leonardo's sketch is correct, we have in it the first conception of a brass instrument with sideholes and keys; at least, no trace exists of an instrument of this kind from that early time (3).

The second sketch (Ill. 3, n. 2) is more elaborate, showing a larger trumpet with wider bell and with seven sideholes. On the right, the tube curves upwards under the auxiliary rod and terminates in the clearly drawn mouthcup. On the right of the auxiliary rod, which appears above rather than below the trumpet in this drawing, we see a keyboard of seven keys, which is marked « a b ».

From the auxiliary rod, seven double lines lead to the seven sideholes. The text (between drawings 3 and 4) explains, « Tasti stretti, e

(3) A keyed trumpet was constructed first in Vienna by Weidinger in 1801, and a keyed horn in St. Petersburg as early as 1760, by Kölbel.
III. 4 – Giotto. *Coronation of the Virgin*. Detail showing trumpets. 
S. Croce, Florence.

III. 5 – Luca della Robbia. Detail showing trumpets, from the Cantoria of the Opera del Duomo, Florence.
serrano buchi di gran distanze infra loro, e sono al proposito della tronba prossima di sopra in a b». (Translation: «Straight keys, they close holes separated by wide distances, and belong to the trumpet drawn above and are indicated by a b»).

The auxiliary rod appears to be hollow as we may conclude from its right end; from this opening a faint double line in loop shape appears. I should tentatively venture to guess that these lines indicate wires or threads which run inside the auxiliary rod to connect the touch piece with the closing key. Leonardo has recorded this idea quickly and very sketchily. However, perhaps the same function can be attributed to the two other sets of double lines emanating from the keyboard.

If this conjecture of mine is correct, then one may possibly go one step further and surmise that Leonardo was stimulated in the invention of this keyboard and stopping machinery by his profound knowledge of the anatomy and physiology of the human hand. The threads then, running inside the sheath which I have called the auxiliary tube, would function like tendons conveying an impulse to the furthest point where movement is wanted, that is, the fingertips or, in terms of our wind instrument, the closing pads. Reading Leonardo’s descriptions and looking at the drawings of the play of moving bones, muscles and tendons (Ill. 6, fol. A, 10 r, Fogli d’Anatomia) (Ill. 6), one cannot help being reminded of his technical inventions. An even closer analogy between the stopping machinery and the tendons of the human finger can be found in fol. A 10 v (Ill. 7) of the Fogli d’Anatomia, which is accompanied by the text which I quote only in part: «... The first demonstration of the hand will be made of the bones alone... The fourth demonstration will be of the first set of tendons which rest upon these muscles and go to supply movement to the tips of the fingers... » (trans. by Edward MacCurdy, The Notebooks of Leonardo da Vinci, London 1938, Vol. 1, p. 107). Mechanisms observed by the dissector of the human body would lend themselves to use by the maker of mechanical tools and machines. And, on the other hand, the experience gathered by Leonardo as a builder of machines would help him to understand more readily and profoundly the mechanisms made by nature. How conscious Leonardo was of the connection is evident

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from his plan to introduce his demonstration of the movement and force of man and other animals by a treatise on the elements of mechanics: «Fa che 'l libro delli elementi macchinali colla sua pratica vada inanti a 'a dimostrazione del moto e forza dell'omo e altri animali; e mediante quelli tu potrai provare ogni tua proposizione» (Fogli d’Anatomia, A 10 r, Windsor 19009).

The little schematic sketch beneath the trumpet and immediately above the text (Ill. 3, n. 3) apparently gives a side view of something like a tracker mechanism, connecting the pad that closes a sidehole on the left with a key on the right.

The drawing beneath the text (Ill. 3, n. 4) is a more elaborate version of n. 3: on the left, two of the closing levers are shown; on the right, the keyboard is again drawn with seven keys. Leonardo’s verbal explanation, quoted under n. 2, connects this drawing with the two trumpets drawn above (n. 1 and 2).

* * *

We now turn from the drawings concerned with trumpet keys to the key mechanism for the «zufolo» (Ill. 3, n. 6). On top we find an elaborate keyboard of no less than ten keys whose thin stems are connected with the horizontal rods or wires that presumably lead to the sideholes. Only the lowest of these horizontal rods shows, connected with it, a bent lever which cannot be anything else than the lever with the closing pad. It is marked with a little «a» (4), referring

(4) At first glance, one may perhaps connect the «a» with the drawing beneath it and especially with the upright rod immediately below it; but such an interpretation would make little sense since that rod is evidently a key shaft and far away from the closing pad which alone can be identified with the «loco dell’ordinarie poste dei busi».
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to the text on the bottom of the page which says: «a entri i' loco
dell'ordinarie poste che hanno i pratici ne' lor busi de' zufoli». (Translation: «a marks the place where normally the players
have the holes in their pipes»; or, more literally: «the sketch
a indicates what comes into the place of the ordinary locations
where the players have the holes in their pipes»).

The drawing beneath this (Ill. 3, n. 7) shows the complete
mechanism connecting key with closing pad: a long rod is inserted
in loops which hold it at its left and right ends; the right end bends
forward and then upward, terminating in a broad key with a square
touch surface; the left end bends forward and then down, termi-
nating in what appears to be the closing pad. If the key is depressed,
the long rod rotates and turns the left end down so that the pad
closes the hole.

While the rod in n. 7 is straight, the drawing beneath it (Ill. 3,
n. 8) shows a rod in the form of a crank shaft; it is held by four loops
near its two projecting sections; the projection on the left carries
the stopping lever with the pad and the projection on the right
carries a key; still further to the right five more keys appear, inserted
into what must be an auxiliary rod like that which we saw attached
to the trumpet sketches, nn. 1 and 2.

A schematic sketch of this latter rod, with two projections,
appears on the lower left of the page (Ill. 3, n. 5) and there can
hardly be any doubt that it belongs to the zufolo sketches, parti-
cularly to n. 8.

* * *

Many details of the mechanisms in these sketches are not as
clear as one would wish. However, the drawings are not, after all,
blueprints for the workshops of instrument makers but rather are
rapid records, embodiments of new ideas confided quickly to paper,
to be taken up again and perhaps elaborated on at some later time.
Yet the gist of these drawings is quite clear — it is nothing less
than the invention of a complete keyboard mechanism for wind
instruments for the purpose of overcoming fundamentally, and at
once, the incapacity of the player's fingers to control distant finger
holes on the tube of his instrument.
Only if we consider the fact pointed out above, that at Leonardo's time wind instruments had no keys or perhaps, at the most, one single key, can we estimate the significance and novelty of his idea. A complete keywork for wind instruments, radically replacing, on principle, all finger stopping, was not introduced into instrument building before 1840; it was based largely on the inventions of a flutist in Munich, Theobald Boehm, although Boehm incorporated ideas of some contemporaneous flute makers such as Nolan, Nicholson and Gordon (Ill. 9 Boehm flute). It may not be without interest to mention here that Boehm arrived at his radical invention through an unusual combination of interests, studies and skills: as the son of a goldsmith, he became skilled in this craft; he also learned to play the flute and built his first instrument at the age of sixteen. He became a professional flute player of wide reputation, composed many pieces for this instrument, and combining this practical experience with a thorough knowledge of theoretical acoustics, he embarked on his reform of the flute. His invention spread immediately and, by the middle of the nineteenth century, revolutionized the making of all other woodwind instruments as well. Leonardo da Vinci, in the sketches discussed above, anticipated Boehm's epochal invention by three and one-half centuries.

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Leonardo's invention of key-mechanisms for wind instruments

NOTA DELLA REDAZIONE. — Ci è sembrato opportuno, dato il carattere specialistico dei termini che designano strumenti e parti di strumenti musicali, richiedere all'autore, prof. Winternitz, di stendere un glossario dei termini ricorrenti nei suoi tre articoli:


GLOSSARY OF SOME TECHNICAL TERMS

Arbor: see Axle.
Axle, asse, Achse, essieu.
Bagpipe, zampogna, Dudelsack, musette.
Bell (of wind instruments), padiglione, Schallbecher (Stürze), pavillon.
Bow, arco, Bogen, archet.
Bridge, ponticello, Steg, chevalet.
Cogwheel, ruota dentata, Zahnrad, roue d'engrenage.
Crank, manovella, Kurbel, manivelle.
Crown wheel (a wheel serrated with teeth like that of a saw, placed parallel with its axis; used in the verge escapement of early clockworks), volano a corona, Gangrad (Hemmrad, Bestandteil der Spindelhemmung in alten Uhrwerken), roue de rencontre.
Drone (drone string), bordone, nicht gegriffene Bass-saite, bourdon.
Escapement (the device in a clock by which the motion of the train is checked), scappamento, Spindelhemmung, echappement.
Fingerboard, manico (cordiera), Griffbrett, manche.
Harpsichord, clavicembalo, Kielflügel (Cembalo), clavecin.
Hurdygurdy, ghironda, Drehleier, vielle a roue.
Key (in keyboard instruments), tasto, Taste, touche.
Key (in wind instruments), chiavetta, Klappe, clef.
Keyboard, tastiera, Klaviatur, clavier.
Kielflügel v. Harpsichord
Melody string: a stopped string, see: stopping a string.
Open string, bordone, leere Saite (Bordun), bourdon.
Pallet (in clockworks), paletta, Spindellappen, palette.
Peg, pirolo, pirone, Wirbel, cheville.
Pin, pirolo, Wirbel, cheville.
Pinion, caviglia, perno, Stift, pignon.
Ratchet wheel, ruota a rocchetto, Sperr-rad, roue à rochet.
Recorder, flauto dolce, Blockflöte, flute douce.
Resonating body, cassa risonante, Schallkörper, caisse de resonance.
Shawm, ciaramella, Bomhart (Bombardt, Pommer), chalemie.
Snare (gut string stretched over the membrane of a drum to be vibrated by this membrane), minugia vibrata dalla pelle del tamburo, Schnarrsaite, timbre-corde de boyaux tendue pour entrer en vibration avec la membrane (tambour militaire).
Snare drum (drum with one or two snares), tamburo militare, Trommel mit Schnarrsaiten, petite caisse.
Soundboard, corpo risonante, Resonanzboden, table d'harmonie.
Spindle, fuso, Spindel, fuseau.
Spoked wheel, ruota a raggiera, Speichenrad, roue à rayons.
Stop (in harpsichords and organs), registro, Register, registre.
Stopping (a string), toccare una corda, greifen (eine Saite), presser una corde.
Tuning pin, pirolo, Stimmwirbel, cheville.
Verge (the part of the escapement mechanism in old clock works to which the pallets are attached), verga, die Spindel in der Spindelhemmung, verge.