THE UNKNOWN LEONARDO

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# INTRODUCTION

Leonardo's life, his work, and the most relevant political and cultural occurrences during his time in a synoptical chronology—a biography in pictures and words.

## HIS LIFE · HIS WORK · HIS TIME

A study of the works of the most flourishing period of Leonardo's artistic creation: the *Mona Lisa*, the *Virgin of the Rocks*, the *Last Supper*, the *Sala delle Asse*, the *Cartoon of St. Anne*, the *Battle of Anghiari*.

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## LEONARDO AND MUSIC

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## MACHINES AND WEAPONRY

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## MECHANICS OF WATER AND STONE

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*INTRODUCTION*

"He was like a man who awoke too early in the darkness, while the others were all still asleep," wrote Sigmund Freud. Many of Leonardo's notebooks, folios, writings, and drawings disappeared into that darkness, and it is their rediscovery and reassemblage that is gradually illuminating the enigma of his genius, gradually extending our knowledge of the unknown Leonardo.
He accorded music the highest place among the arts after painting... calling it *figurazione delle cose invisibili* ('the shaping of the invisible').

He was an elegant speaker and an outstanding performer on the lira, and he was the teacher of Atalante Migliorotti, whom he instructed on this instrument.

*ANONIMO GADDIANO*

**Leonardo and Music**

*EMANUEL WINTERNITZ*

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*ANONIMO GADDIANO*
Although Leonardo has always been extolled as "the universal genius," his musical thought and his musical activities have received little serious attention and have never been treated systematically. It is characteristic that the standard works of Leonardo, even in our century, do not mention music at all,1 or content themselves with quoting remarks by Vasari, the author of the famous Lives of Painters.

Leonardo was, in fact, profoundly occupied with music. He was a performer and teacher of music, he was deeply interested in acoustics and made many experiments in this field that had immediate bearing on music, he wrestled with the concept of musical time, and he invented a considerable number of ingenious musical instruments and made improvements on existing ones. He also had some highly original ideas about the philosophy of music that were intimately connected with his philosophy of painting. It is characteristic that in his Paragone, which forms an introduction to his Treatise on Painting, he accorded music the highest place among the arts after painting.2 If we knew nothing of his classification of music other than his remark calling it figurazione delle cose invisibili ("the shaping of the invisible"), we would have a clear indication of the depth and originality of his musical thought.

There are several reasons why the musical merits of Leonardo have never been appropriately examined and evaluated. Art historians have concerned themselves little with the musical situation of Leonardo's time and environment, and have considered neither the properties and intricacies of musical instruments then in vogue nor the level reached by the musical technology of the time. Historians of music, on the other hand, would waste little time on a man who did not leave us any written compositions. Devoted to the collection and interpretation of the innumerable treasures of Renaissance polyphony that have come down to us, the historians of music have had, until recently, little time or love for the study of musical improvisation. Although it was not much discussed in musical treatises of the Renaissance, improvisation was in fact one of the most subtle and popular branches of musical performance, as revealed by countless paintings and other works of art showing the instruments of improvisation in the hands of angels, King David, and the great mythological figures of antiquity, such as Apollo, Orpheus, Amphil, and the Muses.3

The earliest source of biographical information on Leonardo, the Anonimo Gaddiano,4

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The earliest source of biographical information on Leonardo, the Anonimo Gaddiano,6

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Apollo, as the leader of the Muses, is shown playing a nine-stringed lira da braccio in this detail from Raphael’s Parnassus.

STANZA DELLA SEGNATURA, VATICAN

dating from the first half of the 16th century, twice mentions Leonardo’s musical activities: “He was an elegant speaker and an outstanding performer on the lira, and he was the teacher of Atalante Migliorotti, whom he instructed on this instrument.” “From Lorenzo the Magnificent, he was sent to the Duke of Milan to present to him, together with Atalante Migliorotti, a lira, since he was unique in playing this instrument.”

Atalante Migliorotti was a Florentine born in 1466, and therefore still a boy of 16 when he accompanied Leonardo to the court of the Sforzas in 1482 or 1483. He too must have been an excellent performer on the lira, since in 1490 he was called to the court of Mantua by the Marchese Francesco Gonzaga to sing and play the title role in Poliziano’s famous Orfeo.

About 1530 Paolo Giovio, in his short biography of Leonardo, called him a great genius of pleasant appearance, the inventor of many theatrical delights, and mentions his performance on the lira. The great mathematician, Luca Pacioli, who became a good friend of Leonardo in Milan and for whose treatise De divina proportione Leonardo designed geometric figures, refers to him as an outstanding painter, a master of perspective, an architect, and a musician.

Vasari reports that Leonardo “devoted much effort to music; above all, he determined to study playing the lira, since by nature he possessed a lofty and graceful mind; he sang divinely, improvising his own accompaniment on the lira.” Vasari also records that “after Lodovico Sforza became the Duke of Milan, Leonardo, already famous, was brought to the duke to play for him, since the duke had a great liking for the sound of the lira; and Leonardo brought there the instrument which he had built with his own hands, made largely of silver but in the shape of a horse skull — a bizarre, new thing — so that the sound (l’armonia) would have greater sonority; with this, he surpassed all the musicians who met there to play. In addition, he was the best improviser of rhymes of his time.” A number of later historians also extolled his musical ability, notably the Milanese painter Giovanni Paolo Lomazzo, who in his Trattato dell’arte della pittura of 1584, and Idea del tempio della pittura of 1590, names “Leonardo Vinci painter” as one of the outstanding masters of the lira.

The lira mentioned in these sources was the lira da braccio, the most noble and subtle polyphonic bowed instrument of Leonardo’s day — a fiddle with seven strings. Five, as melody strings, could be stopped against the finger board, while two ran outside the finger board, providing a drone effect whenever plucked or touched by the bow. With the possible exception of the lute, it was the foremost improvisation instrument of the time, and it could be used by a singer to accompany himself. One of the few extant specimens, and certainly the most beautiful one, made by Giovanni d’Andrea in Verona in 1511, is today one of the priceless treasures of the Kunsthistorisches Museum in Vienna [111/1 and 2].

Leonardo must have enjoyed musical instruction in his youth in Florence. According to Vasari, Verrocchio, in whose workshop Leonardo worked, was not only a sculptor and painter but also a musician. It is hardly necessary to describe here the intense musical life at the court of the Medicis and in the churches of Florence. In Milan, Leonardo found himself in another active musical center; it was split between two camps — the Italian traditionalist, and the Flemish-German newcomers (Josquin, Compère, Jocatin, and Agricola). The guardian of the Italian tradition, Franchino Gafurio, a friend and exact contemporary of Leonardo, was the director of the cathedral choir in Milan from 1484 to 1522, and it is significant that his writings were characterized by emancipation from ancient philosophical tradition and by empirical analysis of musical phenomena as data of experience; his attitude is similar to Leonardo’s.

In spite of his reputation as a musician, Leonardo probably did not come to Milan for musical purposes. His application for employment at the court of the Sforzas (page 7) did not mention music at all, but stressed his skill in constructing bridges, canals, fortifications, guns, tunnels, and armored cars — in short, all kinds of military engineering — and modestly said at the end that he
Love gives me pleasure

Among the many rebus es invented by Leonardo for amusement, some use musical notation. These are the only examples of musical script found in Leonardo’s notebooks. At his time, it was not customary to commit improvisations to paper. Thus, no scores of his improvisations, nor those of the many other famous improvisers of his time, exist.

Love only makes me remember, it alone makes me alert

One hundred and sixty rebus es made by Leonardo have survived. Of these, 18 include musical notes, which demonstrate his ability to write musical notation. In the rebus illustrated above, he starts with a fishhook, or amo. Next come the musical syllables re, sol, la, mi, fa, re, mi, followed by the word rare. The second group of musical notations, la, sol, mi, fa, sol, is followed by lecita. The sentence reads, Amore sol la mi fa remirare, la sol mi fa sollecita (“Love only makes me remember, it alone makes me alert”). For the seven tones of the scale, Leonardo used the Guidonian syllables, named for Guido d’Arezzo, who invented the system about 1000 A.D.

There is no doubt that he could write music. Musical notation is used in no less than 18 rebus es out of the more than 160 that are preserved in the folios of the Royal Collection at Windsor Castle.

One of the more complex examples is a rebus presenting an aphorism dealing with the nature of love. The expression is for the most part in musical notation. First, after the clef, there appears a fishhook – in Italian, amo – then the notes re, sol, la, mi, fa, re, mi, followed by rare, in normal handwriting. The second group of musical notes is la, sol, mi, fa, sol, and is followed by lecita in normal letters. Thus the whole sentence reads, Amore sol la mi fa remirare, la sol mi fa sollecita. (“Love only makes me remember, it alone makes me alert.”)

Leonardo’s thoughts about music were strewn apparently haphazardly throughout numerous notebooks, some as aperçu or marginal remarks, others explainable from the context if the reader is familiar with the natural sciences and the technology of Leonardo’s time. The systematic study of this substantial material reveals an intense preoccupation with the phenomenon of music. Leonardo was neither a humanist nor a philosopher in the strict sense in which his contem-
poraries understood this word. Among ancient theorists of music, only the thoughts of Pythagoras and Boethius are echoed in his writings. Had Leonardo decided—or had he found the time—to crystallize all his observations into a systematic treatise, it would have been a formidable compendium. Here we can only mention some of the most interesting points.

Leonardo inquired into the origin of sound ("What is sound produced by a blow?") and examined the sonorous impact of bodies upon bodies, expanding age-old Pythagorean notions. He investigated the phenomenon of vibration and sympathetic vibration, of how the percussion of a body makes it oscillate and communicate its oscillation to the surrounding air or to liquid or solid matter. He studied the propagation of sound waves as differentiated from light waves, the reflection and refraction of sound waves and the phenomenon of echo, the speed of sound and the factors that determine degrees of loudness, investigating the laws that govern the fading of sound by varying the distance between its source and the ear. Especially characteristic of his approach in this context is his establishment of what can be called a perspective of sound, parallel to the laws of optical and pictorial perspective that were so important to him as a painter. Also, as a musician he was naturally occupied with the factors that determine musical pitch and experimented with vases of different shapes and varying apertures. Of musical importance, though Leonardo could not foresee its implication, was another of his observations: when he struck a table with a hammer, small heaps of dust formed on its surface; here Leonardo anticipated by three centuries E. F. F. Chladni's discovery of the geometric sand figures produced by setting the edge of a plate in vibration with a fiddle bow. Leonardo's discovery must have had special significance for him, since it constituted an easily observable correspondence between the visual and the auditory realms.

Leonardo's characteristic approach to acoustical problems by analogy to other fields of physical research is exemplified by a neat juxtaposition of nine diagrams...
Leonardo was also deeply interested in the construction of musical instruments. He invented new ones and improved existing ones. His ideas have never been systematically studied and their investigation is not easy, since it requires a thorough knowledge of the contemporary instruments and a familiarity with not only the status of technology in Leonardo’s time (clockworks, the use of coiled springs, etc.) but also his own achievements in technology.

Leonardo deals with instruments in many brief references in several notebooks.
and in a great number of drawings, some elaborate and others only quick embodiments of passing ideas. Some have explanations in words; most have not. And even where explanations are given, they usually appear to be only notes of reminder and accordingly are difficult to understand.

Leonardo's notes and designs dealing with musical instruments are scattered among many pages in the Codex Atlanticus, Manuscript H, Manuscript B, the Codex Arundel, and the Madrid Codices. Cryptic as many of these notes and drawings appear to be if studied in isolation, methodical comparison reveals that they are not merely diverting devices for performing magic tricks, but that they serve systematic efforts by Leonardo to realize some basic aims, of which the most important are the following: automation of certain instruments and facilitation of playing technique through new kinds of keyboards; increasing the speed of playing; extension of tonal range to make it possible, for instance, to play melodies on drums; overcoming the quick fading of the sound of plucked strings, by giving the instruments an endless bow; enriching comparatively simple instruments to make them capable of polyphony or a wide range of successive tones; and even having a polyphony of the sounds of bowed strings at the control of a keyboard.

Leonardo was greatly interested in the construction of drums. He not only tried to make them easier to play but also expanded their musical possibilities, such as tonal range, 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 fortifications.

The Codex Atlanticus contains no less than eight sketches of military drums—some cylindrical, some kettle drums. They show various methods of automation: in some models, the axle of the carriage wheels drives a central cogwheel, and this in turn, through other cogwheels or pinion cages, activates the beaters. As many as five beaters may be used on each side of one cylindrical drum, to perform complicated rhythms automatically while the carriage travels [117/1].
This page from the Codex Arundel reveals Leonardo's ideas for the construction of new types of drums. At the top and upper right he presents some observations on theoretical mechanics and a sketch concerning gravitation and the behavior of weights. The rest of the page deals with drums, which are discussed in detail at right.

The body of the drum is clearly a cylindrical snare drum. The problem begins with the indented vertical line crossing the skin and the concentric cluster of black lines from which a crank protrudes on the left. Leonardo's explanation says, tamburo di tacche fregate da rote di molle ("a drum with notches scraped by a wheel of spring"). 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 rods arranged like the spokes of a wheel. However, it is possible 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. Apparently the flexible rods carried along the notched edge by the turning crank would produce a continuous drumroll, perhaps with an unusual tone color.

This sketch is of incomparably greater importance and novelty than 118/2. Leonardo says that it is a "square drum whose skin is tightened and slackened by means of the lever a b". The body of the drum is not, of course, 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 have this form: . If the player pushes apart the ends at the right, perhaps wedging his fist in between, the opposite ends open, scissor-like, thus tightening the skin, while the other hand is beating it. The result is that of a drum whose pitch can be changed during performance, something which the Occident did not know until the invention of the pedal machine drum, towards the end of the 19th century.

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 (nag'hara, naschere, nacaires, etc.), were commonly employed for rhythm in pair.

Other drums have eight beaters, evidently four for each of the two drum heads, and employ cogwheels and pinion cages in a variety of forms to connect the carriage wheels and the beaters.

In the Codex Atlanticus a kettle drum is shown with three beaters operated by a cogwheel that is turned by a crank. Thus here we have only a simplification of the action of the drummer. Whole sets of small kettle drums, graduated in size and arranged in a row, appear in the Codex Atlanticus and the Codex Arundel. To employ even drums for playing a scale or chord is characteristic of Leonardo's turn of mind.
portion—deals with drums, and to this section belongs also the large choral drum in the right lower section.

The 11 drum sketches represent an astonishing variety in purpose and construction. We should observe, too, that the sequence from top to bottom is not haphazard; the drawings are not isolated flights of fancy, but rather seem to follow a methodical order progressing from group to group, each group dealing with a different problem.

Sketches like these are interesting not only because of the originality of Leonardo's inventions and the superb economy of his drawing technique; they also permit a glimpse at his habits of thinking. He begins his series of drums with what was probably a passing idea: an unusual tone color—or rather, noise color—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 two different methods. One is the combina-

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118/5
This is one of the most original solutions to 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 has several side holes like those of a flute. Before finally convincing myself that the little circles indicate holes, I decided to experiment, and built a small wooden tube with a skin over one opening and with several side holes. The closing of the various holes while beating the skin results in clear pitch differences.

118/6
This sketch 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 the bottom and to the surface of the box, while the free ends are lifted by the teeth of the wheel and allowed to snap back against the surface. The way in which the wheel is attached to the box is not shown—unless one of the curved lines just mentioned indicates such a connection. The unusual feature of this instrument is the flat oblong board on its right side; the board is softly shaded, while the square above it is strongly shaded. In my belief the board is a slide and the square above it a hole that 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 protrusions on the bottom end of the slider, which can hardly be anything other than loops or handles for moving the slide. There is still the question of whether this instrument has a membrane. We must rather assume that its upper surface is of wood, since only this would provide the right basis for the springy tongues of the ratchet mechanism.

118/7
The drum here is evidently based on the same principle as 118/6—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 an ordinary hand beater instead of a mechanical beater.

119/1
The next sketch introduces a group of three drums 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. 119/1 shows a side drum with snare and with several cones inserted into its base. At the right of the cones Leonardo noted, p, 3, 5, signifying the three tones of a triad. 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.

119/2
This is another "consonance" instrument. Leonardo's text says, "A drum for a chord (consonanza), that is, three drums together." The body consists of three shallow boxes with a ratchet mechanism attached at the left. 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.

119/3
Still simpler in construction is this drum sketch. 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 skin tips at the left, which bend around the edge of the whole box and are tied with cords around it. The text says, "Since one and the same drum produces high or low tones according to whether the skin is stretched at various degrees over the same body of a drum produce different tones." The instrument clearly permits playing a scale or the tones of a chord.

119/4 and 5
The last two drawings of drums present greater difficulties in interpretation than all the others. Both are evidently pot drums with detachable drum beads and a mechanism inside the pot to make them sound; no separate beater is visible. In the first, what appears to be a lid or cover at the left (or upper end of the pot) is detached. Whether this lid 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 118/6 and 118/7, we are inclined to interpret the round shape at this end as a board affixed to the drum, in addition to the one which is removed. Akin difficulties in explaining 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 last drum (119/5) has a different and longer shape, and also has a detachable cover and an inner mechanism. The latter, in this case, is activated by a spoke 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 spoke wheel towards a hook on the rim of the pot.
The most complicated musical instrument invented by Leonardo was a mechanism that he called the viola organista. In the Codex Atlanticus, folio 218 recto-c, there are several sketches of different contrivances for bowing a great number of strings at the same time utilizing a keyboard or a set of push buttons. The sketch at the top uses a bow moving back and forth across the strings. The three other sketches use a friction wheel. A technically more elaborate and practical drawing is shown in the illustration at right from Ms. H, folio 45 verso, using a belt of horsehair passing across the strings and functioning as an endless bow, or archetto.

These many ingenious sketches suggest the question of whether or not Leonardo used them for building actual instruments or at least working models. We do not know. Always pressed for time, he may have been satisfied with a brief record of his ideas. I have made models of most of them, and they work well.

Among the many musical instruments contrived by Leonardo, the viola organista is by far the most complicated. No less than six different pages in the notebooks contain sketches for it. None of them are precise drawings intended 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 outcome of our analysis, the drawings 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, a 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 in Leonardo's time but also in our own. It would combine the polyphonic possibilities of the keyboard with the tone color of bowed strings and thus would be something like an organ with string timbre instead of wind timbre, and in addition it would provide the possibility of producing crescendos and decrescendos by finger pressure.

Although it is not known in what order Leonardo made his sketches, it is possible to arrange the drawings in a logical sequence if we assume that Leonardo progressed from less workable solutions to more practical ones. In fact, he proceeds from an instrument with a bow moving back and forth across the strings, to one with a friction wheel, and finally to several versions of a revolving band of hair that sets the many strings into vibration. One page of the Codex Atlanticus shows, on top, a drawing utilizing a bow, and beneath it, three different sketches exploring the possibility of a friction wheel.

The most workable, and apparently ultimate, solution is in Manuscript H, where we find a sketch of a perfectly consistent, workable keyboard instrument with an endless bow (archetto), a belt of hair moved by a motor attached to the side of the sound box and passed across the strings by means of two small rollers. Leonardo also designed a mechanism permitting the player, by pushing the small
projecting buttons, to select the desired strings and draw them against the archetto.

We do not know, however, how near Leonardo came to the actual construction of the viola organista or whether he ever made working models. Today, with an electric motor in place of one using weights or springs, the construction would be greatly facilitated.

We must finally consider two instruments which have special interest because their invention seems directly inspired by Leonardo’s anatomical studies; in fact, they are applications of mechanisms Leonardo found in the human body.

The first is in Codex Atlanticus, where we find, among numerous small sketches for various machinery, drawings of two pipes, evidently one of those countless passing ideas that were crying to Leonardo to be recorded just here and now, so as not to be forgotten in the perpetual flow of images, whims, and new ideas [122/1].

Leonardo’s invention of the viola organista fulfilled the old dream of having a great number of strings under the control of the ten fingers. The other existing keyboard instruments did not fulfill this ideal: the harpsichord, while having many strings operated by a keyboard, produced only rapidly fading sound; the organ, while producing a lasting sound, did not provide crescendos and decrescendos by variation of finger pressure. Independently of Leonardo, Fray Raymundo Truchado in 1625 constructed an instrument (above) which was actually a keyboard instrument with four friction wheels. It was a free imitation of the Nurnbergisch Geigenwerk invented half a century earlier by Hans Hayden in Nuremberg and described in great detail by the famous musical theorist and composer Michael Praetorius in his Syntagma Musicum of 1618.
Every connoisseur of musical instruments will recognize immediately two recorders by their characteristic heads and mouth holes. Their basic structure has not changed substantially since Leonardo's time. Beneath the upper end held by the player's lips is a hole with a sharp edge which is struck by the air-stream emanating from his mouth. Ordinarily recorders have on their sides six finger holes which are closed and opened by the fingertips of the player to produce the distinct tones of the scale. But Leonardo's recorders look strange. The one on the left has two broad slits on the side of the tube, and the other has one long, thin slit. Fortunately we have an explanatory text in Leonardo's most beautiful calligraphy, running from right to left: "These two flutes do not change their tone by leaps as most wind instruments do, but in the manner of the human voice; and one does it by moving the hand up and down just as with the coiled trumpet and more so in the pipe a; and you can obtain one eighth or sixteenth of the tone and just as much as you want." Obtaining an eighth or a sixteenth obviously means — in acoustical language — to reach the upper octaves; and "moving the hand up and down" evidently means not to stop prearranged finger holes, but to move along the slits to change pitch gradually, or as we say today, to produce glissandos, or gliding tones.

Such a glissando instrument would not have fitted into the orchestra of Leonardo's days. Could he have foreseen, in one dreamy corner of his incredible brain, glissando instruments such as the one invented in 1924 by the Russian scientist Lev Theremin and called by the inventor's name and later also by the name Aetherophone? Did Leonardo perhaps want to imitate bird calls? Or did he just think of inventing another of his tricky toys to baffle or amuse the cavaliers and ladies at the court of Lodovico Sforza, an occupation to which he devoted much of his time?

Where could he have found the idea or a model for his glissando pipes? The clue lies in the words "the human voice," though I must confess that I found the solution by chance and then had it confirmed by Leonardo's own words. The model for our glissando pipes is found in the larynx, and it is significant that Leonardo calls the larynx "the human voice," applying this term to the machinery that produces the voice as well.

Leonardo made designs of the larynx and the trachea, now in Windsor Castle, in which we recognize immediately that the upper opening resembles that of a recorder [123/1 and 2]. Furthermore, in accompanying texts in the anatomy manuscripts the trachea is called fistula, which is also the name of a vertical flute such as the recorder.

There is, though, one flaw in our analogy: Leonardo wrongly attributed the change of pitch of the human voice to the narrowing or widening of the cartilage rings of the trachea and failed to observe the function of the vocal cords in the
larynx. This failure was probably caused by the technical difficulty of dissecting the small and fragile larynx. (By the way, Leonardo's drawings are thought to have been based on the anatomy of an ox.)

Still, we have in Leonardo's glissando recorder a new musical instrument which opened, or could have opened, a new musical horizon; which works well (some reconstructions that I have made function perfectly); and which was patterned after an anatomical analogy, that of the larynx, even though Leonardo misunderstood its actual function. Hence we have here a positive result built upon wrong premises.

In the Codex Arundel, on the large page with the 11 drum sketches discussed earlier, we encounter an entirely different kind of analogy — and more than analogy — in the invention of fingerboards for musical wind instruments, fingerboards designed as an imitation of the muscles and tendons of the human hand, especially those of the fingers [124/1]. We notice two straight tubed instruments on the left, the lower with the mouth cup of a trumpet. Both instruments have a second, auxiliary tube. Here we must recall that the wind instruments of Leonardo's time did not possess the many keys that we find in our modern orchestral instruments. It was the fingertips of the players that closed and opened the six or seven finger holes spaced along the tube according to acoustical ratios. Now when lower, and therefore longer, instruments were...
needed, a problem arose. The stern laws of acoustics demanded finger holes spaced at certain mathematically determined intervals, but these holes would have been too far from each other to be controlled by the short 10 fingers of the player. Leonardo found a solution — actually several, though we will deal here only with one.

Leonardo draws the main tube of the lower instrument perforated by seven holes; seven little double lines, evidently levers for closing pads, reach over to the main tube from the auxiliary tube, which also possesses a compact keyboard of seven keys comfortably close to each other. But where is the connection between this central keyboard and the distant closing pads where motion is required? My suggestion is that Leonardo thought of wires; he indicated them at the right of the open end of the auxiliary tube. Leonardo knew that the mechanism of the human hand and fingers contained a solution for a problem of this kind. In Anatomy Manuscript A he draws the tendons of the hand as they transfer motion from a central point to the point where motion is needed, the fingertips [125/1 and 2]. He also illustrates there the similar situation that exists in the fingers themselves. There remains only to say that Leonardo’s idea stayed buried in his notebooks; we do not even know whether he himself ever built an instrument embodying his invention. Still, the significance and novelty of his invention is indisputable. Three hundred and fifty years later the wind instru-

In this detail from his page of sketches shown on page 118, Leonardo develops designs for wind instruments with a keyboard. Again he finds clues in anatomy, this time in the structure and workings of the human hand (opposite page). In the top two drawings at left, the instrument’s main tube has finger holes spaced according to acoustical laws. In the lower of these drawings, seven double lines, probably indicating wires or levers, connect the main tube to an auxiliary tube which has an easily played, compact keyboard.

Leonardo’s philosophy of music is neither consistent nor systematic, at least on the surface. His thoughts are scattered over many notebooks and pages, and most of them occur in little clusters of phrases among different topics. But again, putting them together not only is rewarding but reveals, if not a systematic philosophy of music, at least his perpetual and ever-renewed wrestling with musical problems, which are conceived in a radically original light and

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are notably independent of the traditional philosophy of music of his time.

This remarkable fact has been somewhat blurred by the many interpretations of the Paragone — the introduction to the Treatise on Painting — which is a compilation of parts of Leonardo's manuscripts made after his death under the supervision of his pupil Francesco Melzi and preserved in the Vatican Library as the Codex Urbinas. The choice of the material from Leonardo's manuscripts is incomplete, and the organization of the material is not his. In fact the Paragone, a comparison of the values of painting, sculpture, poetry, and music, in its present form is a mixture of traditional ideas and even common clichés with important
and highly original thoughts of Leonardo. On a superficial reading of the dialogues between the painter, the poet, and the musician, music appears to have regrettable flaws: different from painting, it quickly fades ("it passes away as soon as it is born ... it is afflicted with the disease of mortality"); furthermore, it requires repetition and can become tedious. But these somewhat banal statements must be taken with some reservation, for Leonardo had a strong interest in exalting painting and rating it, at least officially, higher than music. The musician — that is, the learned musician — had enjoyed high social status ever since the time of Boethius, the great philosopher, statesman, and musician, who lived about 500 A.D. For music was a philosophical discipline, one of the sisters in the quadrivium, together with mathematics, geometry, and astronomy, while the painter was still an artigiano, an artisan excluded from the artes liberales. It was the new art of prospettiva, the linear perspective based on mathematical ratios, that in Leonardo’s time helped to bring about a radical change in the official status of the painter. Therefore we must not take too seriously Leonardo’s arguments for the precedence of painting over music; what he had at heart was the elevation of the social status of the painter.

Indeed, if we closely examine the descriptions of the single arts one by one and regroup them into a systematic order, it appears that music ranks higher than poetry and painting. It is regarded as more noble than poetry because "within its harmonious flow it produces the sweet melodies generated by its various voices, while the poet is deprived of their specific harmonic action, and although poetry operates through the sense of hearing, it cannot create musical harmony since it is not able to say different things at the same time, as painting can do by the harmonious proportionality created between the various parts of the whole." And as for the comparison of music with painting, it was music that always had its firm mathematical foundations in its theory of harmony, and it is painting that only now borrowed this theoretical basis for its new theory and technique of linear perspective. Thus, in Leonardo’s estimation, music is not inferior to any other art.20

The Madrid Codices contain only a few pages devoted to musical matters, but they add considerably to our knowledge of Leonardo’s interest in music and musical instruments and to our comprehension of his indefatigable mind, so overwhelmed by new ideas, associations, and technological imagination that he could cope with this onslaught only by jotting down passing thoughts, often so sketchily that important details, which he evidently took for granted, are neither delineated nor explained in his comments.

One of Leonardo’s drawings of musical instruments in the Madrid Codices is of a bell with a wide rim [128/1]. Instead of a clapper inside two hammers strike the rim from opposite sides. To the left of the bell there is a mechanism including what seems to be a set of four keys operating on a tracker action that in its turn controls four levers ending in oval heads. In my opinion, these heads must be dampers. The accompanying text says, "The same bell will appear to be 4 bells. Organ keys with a fixed bell. And when struck by 2 hammers, there will be a change of tones as in an organ."

Acoustically important in this explanation are the indication that the bell is firm, neither swinging nor equipped with a clapper in the manner of a church bell, and the statement that it produces "a change of tones," which is in all probability one of pitch, not of timbre.21 Thus Leonardo must have believed that the upper
Of harmonic instruments

The partition of bellows a shall be secured at the belt and it functions as a bagpipe. b is fixed to the arm, which arm moving afterwards in and out, will open and shut the bellows according to need. That is, when bellows a opens, bellows m doses. And when m opens, n closes, and thus the blast will be continuous.

Organs with flattened pipes, made out of boards or paper.

Or a viola, where the bow is drawn with the elbow, like the bellows.

section of the bell has ring-shaped areas that produce tones of different pitch if they are slightly muted when the rim is set into vibration by the hammers. It is interesting that Leonardo, here as in many other of his musical inventions, tried to obtain from one instrument what could normally be produced only by several instruments or by an entire set of instruments.

The first of the sketches in Illustration 127/1 represents a wind instrument; two pipes point into the air, a third one points downwards. They all emerge from a contraption that is, beyond doubt, a bellows. The three pipes give the instrument a superficial similarity to a bagpipe in that they resemble its chanter (the melody pipe) and its drones. And indeed, Leonardo begins his verbal description with the explanation that the new bellows here is made per piva. The word piva means, or at least can mean, “bagpipe.” Leonardo was, of course, very familiar with the way that the bellows of the viola organista worked, and in this way, it will diminish together with the notes.

Here, when the elbow moves two fingers, the teeth n will also move 2 fingers. And the teeth will turn pinion m one entire revolution. Likewise, the major wheel will also turn one entire revolution, which will be ⅓ braccio. And so it will collect and release one braccio of bow upon the strings of the viola.
The same bell will appear to be 4 bells.

Regarding this bell Leonardo says, “The same bell will appear to be 4 bells. Organ keys with a fixed bell. And when struck by 2 hammers, there will be a change of tones as in an organ.”

Leonardo’s accompanying explanation reads as if his contraption had occurred to him as a new invention; and in fact I do not know of earlier examples of this type of bellows in texts or illustrations. Perhaps it worked best in small sizes, while for industrial purposes the arrangement of two alternating, large, separate bellows proved more practical.

At the end of his explanatory text, Leonardo claims that his new bellows produces continuous wind. This claim, of course, has to be taken with a certain reserve. There is, first, the inevitable dead point when, one of the bellows sections having reached its maximum volume and the other its minimum expansion, the pumping action goes into reverse. This imparts to the pipes a moment of silence which, however short, is just as noticeable as the pause between the upstroke and the downstroke of a fiddle bow, or when the player of a concertina turns from the expanding phase to the compressing phase or vice versa.

And quite apart from this dead moment of silence, we have to bear in mind the fact that the wind stops immediately when the bellows action stops. This is not the case with the bagpipe. The sounding pipes of a bagpipe are supplied with wind by a bag, made of the skin of an animal. This flexible wind reservoir is filled with air either from the player’s mouth by means of a blowpipe or, in later specimens, such as the musette of the 18th century, from a pair of bellows. A bag of this type supplies wind for some time, even after the player has ceased to breathe into the blowpipe or to pump the bellows. In this way, a real continuity of sound is achieved. Such a bag is missing in Leonardo’s contraption.

Furthermore, another essential feature of the bagpipe is missing: the chanter, or melody pipe, which is a reed pipe equipped with finger holes. These are stopped by the fingers of the player to produce the melody, while the larger drone pipes supply the continuous humming bass. Normally, the chanter has a shape different from that of the drones. In Leonardo’s sketch, only the pipe on the left pointing down is approximately in the position of a bagpipe chanter, but it has the same shape as the other two pipes and, more important, does not show the faintest trace of finger holes. Therefore, Leonardo’s contraption is certainly not a bagpipe, and if he calls it pīra, he uses this word not as an equivalent for

with that popular instrument the bagpipe. In one of his drawings he shows a bagpipe squeezed by a vise [128/3].
cornamusa or zampona, both common names for bagpipes, but in its original sense, that is, *pipa*, meaning "pipe" or "pipe instrument."

What then is our instrument? Since there are only three tubes — not enough for a scale or melody — and since there is not even machinery for selecting or alternating single tones, we can only assume that three simultaneous tones of different pitch formed a chord, in all probability a triad. The tubes would then be reed pipes with a trumpet sound, and the whole machine would be not an instrument designed to play actual music, but possibly a gadget created to sound a three-voice signal as a kind of fanfare. One recalls the manifold activities of Leonardo as an organizer of fetes, processions, and stage entertainments. Perhaps our musical gadget served as a hidden machine that produced fanfares easily to accompany the appearance of allegorical figures, such as Fama or Gloria, who, by long iconological tradition, had trumpets or even multiple trumpets. One example is the beautiful quadruple trumpet in the hands of Fama in one of the early-16th-century tapestries at the Metropolitan Museum of Art in New York, representing the Triumph of Fame over Death, one of the numerous illustrations of Petrarch’s *Trionfi* in Leonardo's time [131/1].

Leonardo must have been more impressed with his new bellows than with the
The early-16th-century North French tapestry on the opposite page shows the "Triumph of Fame over Death." The allegorical figure of Fama sounds a fantastic trumpet with four bells. Fantastic instruments such as this may be related to the workable triple-tubed instrument in Illustration 128/2.

The sketch of the portable organ bears two inscriptions: on the left, tasti dell'organo ("organ keys"); and on the upper right, canne schiacciate ("flattened pipes") [132/2]. Leonardo describes the pipes as being made either of wood or of cardboard. Six pipes can be distinguished — a strange number, too many for a chord and too few for a scale, though the sketch may be only a hasty suggestion.

An indispensable element of an organ, the one by which the single keys open up and shut off the access of the wind to the single pipes, is not indicated at all. Here again Leonardo may not have taken the trouble, as so often happened in his quick embodiments of passing ideas, to include technical details that he took for granted.

The combination of organ pipes and bellows recalls immediately the construction of an organetto, an immensely popular and practical instrument used in Leonardo's time and for centuries before. We may therefore cast a quick glance at various types of organetti, concentrating on the question of bellows. If we disregard the larger instruments, which were played on a table and which required the use of both hands on the keyboard and therefore an extra person to operate the alternating bellows at the back, we find the following arrangements used in organetti: in one arrangement, one small bellows beneath the wind-chest was operated by the player's left hand [132/1]. In another, a single large bellows at the back of the wind-chest was operated by the player's left hand, while his right hand pressed the keys with the fingers in a position that would strike a later musician as very awkward [133/1]. In still another, two small alternating bellows at the back of the wind-chest were operated by the player's left hand [134/3].

In all these small instruments, where the single or alternating bellows had to be worked by one hand, there was an inevitable pause in the wind supply, and therefore in the music, between the movements of the bellows. However, as the fingers on the keys could only play melodic lines without substantial chords, the pause caused by the bellows mechanism was not more noticeable than that of an experienced singer breathing in the middle of a phrase; and the wind-chest, essential to every organetto, must have helped somewhat to bridge these pauses, although it did not have the flexibility of the bag in the bagpipe as a wind reservoir.

Leonardo's sketch of the portable organ does not include any visible wind-chest. Thus the wind supply depended exclusively on the action of his special bellows, which, as already pointed out, immediately stops providing air when pumping ceases. One possibility that would justify the new bellows remains. The sketch shows a little curve at the lower left corner of the bellows. If this indicates a handle, it was perhaps worked with the elbow (con gomitо), thus leaving both hands free for the keyboard, an achievement that would indeed have meant notable progress if we assume that this instrument was supposed to have many more pipes than the six delineated.

Even more problematic is the small sketch of a chamber organ [134/1] flanked by two bellows evidently of the same construction as those in Illustrations 128/2 and 132/2. The big box from which the pipes arise contains, of course, the inevitable wind-chest that in every pipe organ guarantees an even wind pressure and continuous sound just as the bag does in the bagpipe. Therefore the application of Leonardo's special bellows to this organ makes little sense. Any simple conventional bellows would do just as well.

Operation con gomitо may have captured Leonardo's mind to such a degree that he proceeded to extend this playing technique to string instruments. In two sketches in Illustration 127/1 he delineated schematically string instruments, of which at least one is operated by an elbow action, again possibly in order to free both hands for the keyboard [134/2]. Enigmatic as these instruments appear at first glance, their interpretation is easy if one recalls Leonardo's profound
interest in the *viola organista* [120/2], described earlier. Anyone looking at Illustration 120/2 will easily realize the link with the sketches in the Madrid manuscript [134/2] if he recognizes that the 16 dots marked in a horizontal line in the upper sketch of Illustration 134/2 are nothing other than cross sections of
This detail of the organ panels from Nijera by Hans Memling (c. 1465) shows an angel playing an organetto with a large single bellows on the back of the instrument.

In this 14th-century Florentine example of an organetto, the angel is operating with the left hand the small bellows beneath the wind-chest.

This detail from Leonardo's sketches on page 127 shows six organ pipes emerging from bellows of the type illustrated in 128/2. Left of the bellows, small dots indicate "keys of the organ," and are so described by Leonardo in the vertically written words.

The strings shown in the prior illustration. Over these strings moves the endless bow supported on the left and right by two rotating wheels. In other words, the upper sketch of Illustration 134/2 is a schematic front view of the instrument shown from the side in Illustration 120/2. Illustration 120/2 also shows clearly a keyboard, or rather a set of frontal push buttons which by means of a tracker action move little circular loops that grasp the strings in order to draw them against the moving archetto, which sets them vibrating; and this illustration shows a motor for driving the archetto.

In the upper sketch of Illustration 134/2 we see two interacting cogwheels moving the right wheel of the two that support the archetto. The cogwheels in turn must receive their impulse from a motor or from the player or an assistant.

The lower sketch differs from the upper one in several respects. It indicates only 11 dots for strings; below the dots is written viola a tasti ("viola with keys"). The left wheel is much smaller, and above all, the device for driving the right wheel is different: instead of two cogwheels, here only a segment of one is visible; it is operated by a lever with a handle inscribed gomito. The use of this wheel segment does not permit a continuous movement of the archetto in one direction, but only facilitates a forward and backward movement comparable to that of the actual bow of a viol or any other bowed instrument. All these features point to a smaller and simpler version of the viola organista, and possibly to a portable version. If gomito here means not a movable part of the mechanism but the human elbow, then both hands would be free to operate the keys or push buttons, and this would constitute a substantial advantage over the hurdy-gurdy, in which the keys — a very small number for that matter — are operated by one hand while the other works the crank to turn the friction wheel.

It remains to comment on the charming little figure jotted down with a few rapid strokes in the center of Illustration 127/1. Unfortunately the instrument played by this youth is not recognizable, but in any case he is a musician in fancy garb; his three-tiered hat, short pleated tunic with square neck, and shepherd buskins characterize him as a participant in a masquerade or stage entertainment.

His exotic appearance may provide the clue for the interpretation of all the instruments shown in Illustration 127/1, except for the chamber organ with the flanking bellows. Evidently these instruments are conceived not for the performance of serious music, but as contraptions for fetes, stage entertainments, or one of the colorful masquerades whose organization and artistic preparation were among the duties of the courtier Leonardo. There are in Leonardo's other...
At right is a mid-15th-century relief by Agostini di Duccio from Rimini Cathedral. One of the angels plays an organetto with two alternating bellows.

In this hasty sketch, Leonardo applies his special bellows (see 128/2 and 132/2) to a chamber organ (detail from page 127). The bellows flank the wind-chest from which the pipes arise.

These sketches, details from page 127, represent two different methods for moving the belt of hair, as an "endless bow," across the strings of a portable viola organista. The wheel moving the archetto (endless bow) is turned by a cogwheel - or section of it - operated by the elbow of the player.

The results of our interpretation, then, are comparatively meager as far as the musical importance of these machines is concerned. However, they are interesting in another way; they show Leonardo’s restless, quick imagination at work, leaping by rapid association from one idea to the next. The triple trumpet begets the idea of a new kind of simplified bellows with automatic synchronization; these bellows are applied to a small set of organ pipes, and even to a massive, positive organ. Then fantasy takes another turn: just as the bellows can be operated by the elbow in wind instruments, an equivalent simple playing method con gomito may be applied to string instruments, and so a smaller, portable version of the viola organista is born. The number and variety of Leonardo’s inventions of instruments permit a clear reconstruction of his leading ideas, which are admirably systematic.